Biological Services Program

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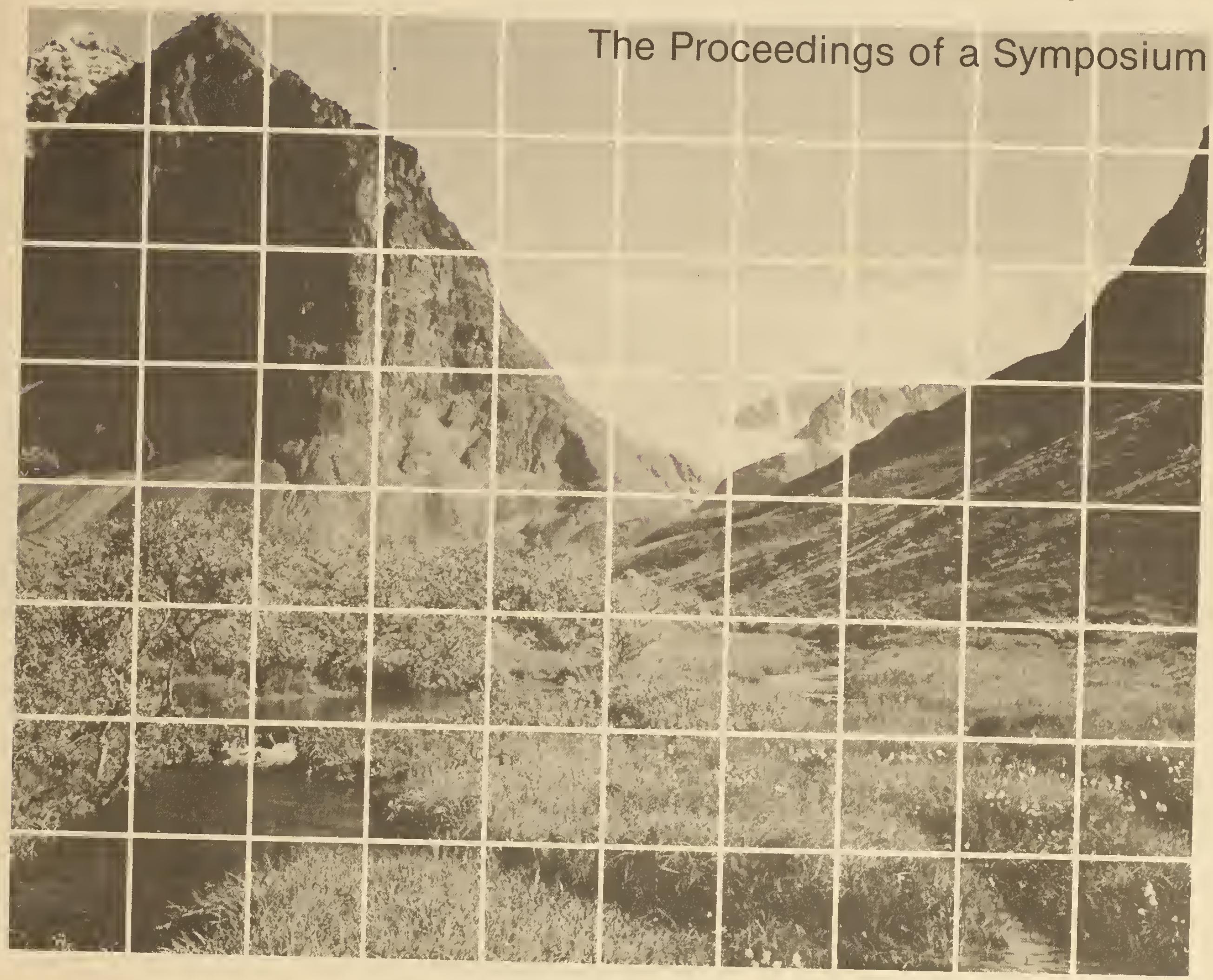
Biological Evaluation of Environmental Impacts

The Proceedings of a Symposium



Council on Environmental Quality
Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; mineral development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; environmental contaminants; National Wetland Inventory; habitat classification and evaluation; inventory and data management systems; and information management.

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FWS/OBS-80/26
June 1980

BIOLOGICAL EVALUATION OF ENVIRONMENTAL IMPACTS

PROCEEDINGS OF A SYMPOSIUM AT THE 1976 MEETING OF

THE ECOLOGICAL SOCIETY OF AMERICA
AMERICAN INSTITUTE OF BIOLOGICAL SCIENCES

COSPONSORED BY

COUNCIL ON ENVIRONMENTAL QUALITY
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PREFACE

In 1976 the Council on Environmental Quality (CEQ) sponsored a symposium with the Ecological Society of America at the annual meeting of the American Institute of Biological Sciences. The symposium dealt with the contributions that the science of ecology was bringing to the field of environmental impact assessment. At that time CEQ was beginning an extensive analysis of the implementation of the National Environmental Policy Act (NEPA). It was our hope that the papers presented at this symposium would help in developing CEQ's new NEPA regulations, and indeed they did prove to be very helpful. The positive reception the regulations have received derives significantly from such contributions obtained from the scientific community.

Although some time has passed since the symposium, the papers, most of which are conceptual in nature, remain pertinent today. I am extremely pleased that the Fish and Wildlife Service has joined CEQ in cosponsoring the symposium through the publication of these Proceedings.

GUS SPETH
CHAIRMAN
COUNCIL ON ENVIRONMENTAL QUALITY

BIOLOGICAL EVALUATION OF ENVIRONMENTAL IMPACT

Summary

INTRODUCTION

The symposium on Biological Evaluation of Environmental Impact, was organized by the President's Council on Environmental Quality (CEQ) and hosted by the Ecological Society of America at the 27th Annual Meeting of the American Institute of Biological Sciences in June 1976 at Tulane University. The Fish and Wildlife Service is publishing the Proceedings. All of these institutions are symposium sponsors.

This symposium focused on how the biological significance of environmental impacts can be both evaluated by ecologists and described to decision-makers in the environmental impact assessment process. The National Environmental Policy Act of 1969 (NEPA) and similar laws and regulations in many states established the process of environmental impact assessment as a significant factor in public decisionmaking. The importance and value of this process, as well as its points of weakness, are well-known to the nation's ecologists -- a sizable number of whom have participated in it. The symposium permitted ecologists to voice their views on improving the process.

Perhaps the two most difficult questions that biologists repeatedly face in assessing environmental impact are also the two most important:

- How can the biological significance of environmental perturbations be evaluated?
- How can these evaluations be meaningfully described in order to enlighten and influence public decisionmakers in the environmental impact assessment process?

The difficulty of these questions (as well as their scope) is intimidating on both conceptual and practical grounds. Yet the development of new concepts and methods for evaluating and describing ecological responses to environmental damage is occurring at a rapid pace.

This summary attempts to bring together some of the main ideas of the various contributors. Given the wide range of topics chosen by the authors, there is no attempt to synthesize the various ideas into a central theme. Also, since the various authors frequently disagreed in their points of view, it seemed unfair to pull together a set of recommendations from the individual papers, since it would not permit contributing authors with differing perspectives to rebut the collective result. This was a symposium, not a workshop.

There were several goals to this symposium. The first was to facilitate the immediate exchange of information concerning the present state of impact assessment. This was accomplished at the 1976 AIBS meeting. Secondly, it aimed to present this state-of-the-art thinking to persons not then present. That is the purpose of these Proceedings. And thirdly, the CEQ staff wished to avail itself of the best current thinking on the topic for the Council's work on environmental assessment and monitoring. The summarized concepts presented below do not constitute an endorsement of the ideas of the individual authors, but rather are offered as a means of stimulating further discussion and improvement in our ability to evaluate environmental impacts.

PHILOSOPHICAL OVERVIEW

The environmental movement is an expression of social consciousness. An outgrowth of this movement has been a variety of environmental laws and regulations as well as a recognition that for long-term planning and policy formulation, long-term tracking of environmental trends is needed. Environmental assessment programs seek to satisfy these needs.

While many of the papers in this symposium address specific methodology questions, present case studies, or discuss individual monitoring problems, this first group of papers sets a perspective for the whole assessment process because the authors place the technical process of data collection in the context of the scientific and societal framework from which the process sprang.

The conceptual basis for assessment is evolving. Several of the papers summarize earlier efforts.

For example Hinckley's contribution growing out of The Institute of Ecology's Environmental Impact Assessment Project is based on the assumptions that the principles and methods of ecological analysis are valuable for the assessment of technological impacts, and that a summary of ecological analysis methods may increase their application under the provisions of NEPA. What he states is needed is impact assessment at the ecosystem and regional level, with biotic diversity treated as a nonrenewable resource, rather than an analysis that consists of little more than a species list. However even though ecological analysis can help predict adverse impacts to human health and welfare, the prediction cannot be complete because of insufficient baseline information, the stochastic nature of ecological change, and the imperfect link between ecological effects and their socioeconomic consequences.

An EPA perspective on environmental assessment is offered by Kibby and Glass who, after reviewing EPA's procedures for evaluating EISs and offering candid observations for several of them, discuss their view for improving EISs. They emphasize the role ecologists ought to play in the process and point to the necessity of solving the data availability problem. They call for the use of contemporary ecological techniques and complex models. Ecologists will have to fill gaps both on the applied and basic research level to meet the needs society has asked them to satisfy. They especially emphasize the relationship of health hazard levels of pollution to ecological damage as a subject demanding more exploration. They also call for a reexamination of the indicator concept, although perhaps at the community levels. In this regard they decry the presence of large species lists in EISs and call for adoption of a format which will be read by decisionmakers so that environmental considerations enter into the planning process.

The State of Michigan in an attempt to perform such an integration has several avenues to resolve environmental conflicts: legislated standards, the Environmental Protection Act, and the Michigan Environmental Review Board. Cooper uses his experience as Chairman of this Review Board in providing his views on environmental assessment. This Board's recommendations, which arise from review of impact statements, directly enter the administrative structure via the Governor's office.

Cooper's point, that to be useful an EIS must integrate engineering, ecology, and economics, is widely shared by this symposium's contributors. He points out that if an EIS clearly stated the assumptions used in the analysis, then the outputs will fall obviously into place. Unfortunately, in his opinion, the typical analysis only obscures the real issues since the data are presented based on their availability, not as a measure of their contribution to solving the social conflict, even though typically societal issues are at the base of decisionmaking. He uses as an example that typically the public is looking for the minimization of risks whereas the typical cost/benefit analysis of an EIS emphasizes the maximization of benefits; furthermore frequently the segment of society accruing the benefits is not that segment exposed to the risks. As a further confounding problem in dealing with societal issues, there are no stated national goals for agricultural lands, natural resources, etc.

Cooper concludes that his experience at the state level shows that general systems theory can integrate a variety of disciplines to accomplish useful environmental assessment.

At the federal level many of the difficulties of the EIS process discussed by the authors of this symposium are a historical outgrowth of the initial implementation of the National Environmental Policy Act. Smythe and Flamm of CEQ review this history, pointing out both past progress and future potential. Several precedents were set in the post-NEPA catch-up phase for projects initiated but not completed prior to passage of the act: (1) the EIS was used to justify a decision already made, (2) alternatives were treated as strawmen, and (3) the process was regarded as something to be overcome rather than as an aid in planning. During the first two years of NEPA, the courts emphasized procedural rather than substantive issues, as a partial result of which the bloated EIS originated as a defensive reaction to these decisions.

Some agencies continued to produce a late-stage full disclosure document at the behest of their attorneys while others moved to an earlier, more concise effort aimed at the planning process. However, a CEQ review of the EIS process indicated that most agencies had taken steps to integrate the EIS process into their decisions.

Buffington et al. report on the synthesis arrived at in a workshop held at Ann Arbor in 1975. The purpose of that workshop was to derive a definition of the term "significant" as used in impact assessment. The definition they propose is: "An impact is significant if it results in a change that is measurable in a well-designed sampling program, and if it persists or is expected to persist more than several years." They distinguish this concept from that of "acceptable" which judges impact on the basis of social norms.

Their paper, drawing from the contribution of a large number of contributors from their workshop, offers a number of recommendations. Some of the more salient are:

(1) The duration and extent of preoperational and operational studies should reflect the variability in the data and expected intensity of response due to impact.

(2) Detailed static descriptions of ecosystems, such as species lists, offer little value in impact assessment; however, they provide a mechanism for crude comparisons of before-and-after situations. The use of indicator species in impact assessment should be encouraged, but additional work should be sponsored to permit their most efficacious use.

(3) Present use of statistics does not take advantage of existing state-of-the-art.

(4) The assimilative capacity of a system should be recognized and accounted for in impact assessment.

(5) Use of simulation models has potential in terms of providing sharp focus on expected impacts and collection of relevant information in analysis of impacts.

They summarize the role to be played by the biologist contributing to the impact assessment process as: (1) predict the level of impact, (2) state whether the impact is significant, and (3) impart to the decisionmakers his views of the acceptability of the damage.

Probably the most fundamental expression of underlying philosophy in the environmental assessment process is provided by Regier and Rapport. They scope out the relation of ecology and related sciences to the societal role erected for (and by) it. Their principal thrust is that broad ecological concepts and methods, within which they state widespread intellectual and practical compatibility are already apparent, and are developing rapidly. The focus of their paper is the effective transmission of ecological information and insight to decisionmakers, and the addressing of the applicability of current ecological concepts and methodologies in practical dealings relating to the valued living resources. They describe environmental assessment as a "transfer science," the generic characteristics of which place it between analysis (basic) type science and action (applied) type science. As such, impact assessment is evolving into a separate interdisciplinary quasi-discipline. Their analysis of the dynamics involved lead the authors to feel that the movement of the ecological transfer sciences into positions of disciplinary power will only be accomplished by struggle with those disciplines already in such a position.

Regier and Rapport evaluate the likely future state of the environmental impact transfer science with related sciences and conclude: "The role of environmental impact assessment is not now well specified. Within the set of ecological transfer sciences it is somewhat anomalous. It aspires to be more than they are. But in the absence of clear higher level policies it is not likely to succeed." On the bright side, however, they conclude that the three groups they identify as methodological innovators, theoreticians, and planners seem to be converging toward mutually compatible viewpoints. In their opinion there will shortly be a reservoir of competent people to lead efforts based on this synthesis.

METHODOLOGICAL CONSIDERATIONS

The papers in this section are grouped together because they speak to the problem of how to make environmental assessment satisfy their presumed goals. On the one hand this grades into philosophy and on the other into specific case studies. Several of the papers deal specifically with biological monitoring, including the rationale for baseline monitoring and the role and rationale of modeling in assessment. Here again we find that the authors in this section have not only addressed the question, but also suggest some approaches that they have found useful. Finally the integration of these methods into an EIS is considered to conclude this section.

Brungs in his paper emphasizes the necessity of using sublethal and chronic toxicity data in making impact assessments. To some degree this is due to technological improvements making acute toxicity problems less of a consideration. Most importantly however is the fact that the science has passed the point where we must rely on acute lethality data in making predictions. These gross effects studies provide only crude evaluations. There is now both field and laboratory data for sublethal and chronic toxicity available for predictive assessment. He points out for example that in a baseline/post-operational comparison of monitoring data, short term adverse impact can be demonstrated on the entrained plankton. This impact may, however, be of no significance at the pollution or community level which is where the assessment emphasis should be placed. He further provides some examples of studies where sublethal effects have had a large impact at the population levels.

Cairns and Dickson indicate how use of the sublethal and chronic approach has been incorporated into their own assessment of potential ecological damage. Their biological in-plant monitoring systems show that these concepts have immediate practical value. These in-plant monitoring stations provide an early warning system to prevent potentially toxic materials from entering aquatic systems. Additional biological monitoring systems in the receiving water help maintain and/or improve environmental quality or at least prevent undetected degradation.

Most active workers in environmental assessment would agree that as necessary as such monitoring programs are after a facility is constructed, it is even more important that to the extent possible the risks are predicted prior to construction, since the level of risk anticipated will influence the amount of monitoring. This risk analysis of the ecosystem should include both its vulnerability to displacement and its likelihood of return to its initial state. Cairns and Dickson provide extensive discussion of the ecosystem characteristics they define as (1) vulnerability to irreversible damage, (2) elasticity or ability to recover from a damaging incident, (3) inertia or ability to resist displacement of ecosystem structural and functional characteristics, and (4) resilience or the number of times a system can snap back after repeated damaging incidents. Some of these characteristics are difficult to deal with precisely. The authors have presented a means of quantifying some of these, however, so that they can be used in impact assessment.

Typically these system characteristics, to the extent that they are dealt with at all, arise in the context of what is commonly identified as "baseline monitoring." Hirsch's discussion of baseline monitoring is more precise and analytical than what is usually meant by the term. He analyzes the definition of the term because he feels that what some perceive as problems are due at least in part to lack of agreement as to its basic purpose. Hirsch distinguishes between ecological characterization on the one hand and baseline and monitoring studies on the other. The ecological characterization takes place early in the assessment process. Its first emphasis should be the bringing together all of the available and relevant data including related elements such as geology and climate. The ecological characterization should describe processes organized about a conceptual model (e.g. the ecosystem). Where gaps are present, follow-on inventories may be needed. He points out that some of the data acquired for the characterization are needed not because of anticipated environmental impacts, but rather because they contribute to the understanding of the system. This characterization comes early in the environmental assessment process and will provide the basis for what he calls reasoned judgments about the impact of the anticipated development. It can further serve to guide the design of baseline and monitoring studies.

The baseline and monitoring studies are needed to supplement predictive capability and provide early warning of impact. "The baseline is usually considered to be a description of conditions existing prior to development, and monitoring to be a program of measurements subsequent to development for the purpose of detecting changes. However, in actuality, the two phases may frequently represent a continuum, with subsequent monitoring strengthening the statistical validity of the initial baseline. Conversely, a program of monitoring may develop trend information without an initial baseline study of the area concerned."

Most of the papers in this section call for greater attention to ecosystem considerations. Odum and Cooley's paper is devoted to this call for a more holistic analysis of environmental information. While the authors state that it is probably premature to use large scale ecosystem models on a regular basis, they suggest that pictorial and graphic models provide a bridge between traditional piecemeal analysis and the ideal holistic assessment. In their view, analyzing a system by profile analysis and performance curves, while more difficult than analyzing components, should not require additional time or expense because selectivity can be employed. In actual practice they claim to combine elements of both kinds of analysis. The authors draw from their own experiences and emphasize the importance of human values assigned to an impacted system as being important in impact assessment.

The role suggested for models by Hilborn et al. is somewhat different from that suggested by Odum and Cooley, although their analysis of predicting impact in a system with complex behavior indicates the compatibility of the two approaches. In light of such complex behavior they call for environmental management systems that can absorb the inevitable "surprises" rather than rely on their prediction.

There are several sources of uncertainty for the analyst. One arises from extrapolating past the available data. A greater problem lies in areas which are in principle unpredictable either because (1) unforeseen future events such as environmental changes may occur, or (2) some levels of detail will always defy prediction.

These authors, as did almost all participating in the symposium, point out the shortcomings in the interdisciplinary environmental assessment process which arise from the failure of the contributors to closely work with one another. They suggest the use of a simulation model to open communication across disciplines (including management) in the impact assessment process. Their communication model is refined in an iterative process and eventually evolves into a tool for the assessment process itself.

There are a variety of potential uses of modeling in the assessment process. Parzyck et al. report on their use of a broad range of modeling capabilities in working at the regional level since any single project usually takes place in an environment already impacted by other actions. The tools they comment on include atmospheric transport models for several levels of resolution, hydrologic models, terrestrial and aquatic ecological models, mapping of endangered species, health impact models, and an interesting cost/benefit approach including non-marketable items. The cost benefit approach is offered as a means to factor considerations of various environmental impacts into a site selection process or into decisions relating to the size of proposed facilities.

THE PERSPECTIVE FROM SPECIFIC STUDIES

Biologists active in environmental assessment have been grappling with these problems of philosophical perspective and methodology since before the passage of NEPA. The requirements for short-term analyses have sprung out of legislation, agency regulations, and the discovery of unexpected environmental degradation.

Two contributors to this symposium dealt with the special problems associated with endangered species. Baysinger provides extensive background information on the Endangered Species Act of 1973. An interesting point he raises is that the Act leans away from quantitatively defining crucial population size for a sensitive species but rather recognizes that the alterations or changes in use patterns caused by man are major considerations. He points out that Federal agencies are to use their authority to conserve "official" species, not to do anything that might jeopardize them, and not to destroy or modify Critical Habitat. (The procedures for determining Critical Habitat are very similar to those for Threatened or Endangered Species. Considerations include space, nutrition, reproduction, cover, and related requirements.) In planning or assessing an activity which may result in adverse action, the action agency may enter into consultation with the Fish and Wildlife Service or the National Marine Fisheries Service which results in a nonbinding Biological Determination. As an additional caution the author urges that an environmental impact assessment process should include an analysis of whether the action sought results in a species not threatened or endangered to become so.

With respect to endangered plant species, Ayensu points out that 10% of the native flora of the continental U.S. are endangered or threatened. Of these 761 taxa are actually listed as endangered. The habitat of these 10% probably accounts only for about 1% of the nation's land surface, two-thirds of which is on Federal lands. The situation in Hawaii is even more severe than on the continent. The Director of the U.S. Fish and Wildlife Service has issued a proposed rulemaking which would officially determine 1700 plant species as endangered.

While all of this does not serve to make the life of one engaged in impact assessment any easier, the author does offer at least some succor. As part of the Endangered Flora Project he has initiated a computer plant-distribution mapping program. While this will be of help, he further calls for a detailed floristic inventory of proposed sites as an aid in considering alternatives. While the author's call for an inventory flies in the face of the ecosystem approach called for by the other authors, the legislative requirements for dealing with endangered species may result in compromise.

Terrestrial ecosystems provide a variety of problems for those engaged in evaluating environmental impact. Two of the contributors look at several of the many possible areas of inquiry. Newton and Norris examine effects associated with herbicide use, while Wagner uses a more ecosystems approach in analyzing assessment in arid and semiarid systems.

Newton and Norris observe that although the EISs published for vegetation management programs have improved, there is an over-emphasis on considering direct toxic impact on nontarget animals rather than the ecosystem considerations of altered vegetation composition. (Because of the public interest in direct toxic questions, they agree that it should be treated amply.) For example, in releasing a potential grasslands community from the existing tree-shrub community, the long-term succession pattern is altered. Thus although the persistence of these herbicides is typically short-term, the impact is long-term, and the associated animal community will be affected accordingly. As the modified system matures the unmodified components of the vegetative community will accelerate their development.

The papers on methodology discussed in an earlier section emphasize the value of analysis of potential impact at the ecosystem level. Wagner's contribution provides a wealth of detail which could well underlie an initial appraisal of potential damage from a proposed action in the western arid and semiarid ecosystems. Much of his discussion is in the context of ecosystem control mediated by moisture. He points out that desert vegetation, since its productivity increases with increased moisture, is under some moisture stress. As a consequence, actions which change moisture stress are likely to result in vegetational changes either to more xeric or mesic form. The implication is that actions which alter moisture, such as grazing, will impact community composition. Furthermore it appears to take more time for a xeric system to recover from damage than it does for a more mesic system. The present degraded state of much of our western range lands dramatizes these dynamics. Not only is species composition shifted by disturbance, but also the nature of the vegetation. Increased annual cover will result in a community more variable over time because of the variation in annual production. However, overall increase in production of annuals is advantageous for many animal species.

Wagner casts his vote along with those who call for modeling in the assessment process. Specifically he believes the physiological and morphological mechanisms involved in community change are amenable to this form of analysis.

Four of our authors draw on their experience of biological monitoring in marine ecosystems. As Boesch points out, there are a variety of current activities on the continental shelf which require impact assessment. These include dumping of chemicals, debris, sludge, and refuse, thermal effluent, offshore oil ports, extraction of minerals including petroleum, and various fisheries. However, because the scientific questions fundamental to assessing impact have not received adequate attention to date (e.g. chronic low-level petroleum pollution), decisions are based on a poor base of information. He reviews past research and shows that even the most exhaustive studies have not resulted in unequivocal conclusions. There are several reasons for this, some of which are within the capability of the scientific community to address better: (1) determine causes of natural variation, (2) use controls effectively, and (3) relate impacts on biota to ecosystem condition. The author offers a conceptual framework for impact evaluation on the continental shelf. The design of baseline, predictive and monitoring studies should draw from the preliminary impact assessment, and the results of these monitoring programs should feed back to the impact assessment.

The initial phase of the baseline studies should be a broad reconnaissance of the system. Susceptible components would be identified from these studies and the long-term studies of the dynamics of these components could begin. Unfortunately, while this might result in a baseline that reflects the dynamics of the system, causality of future impact cannot be fixed unless the causes of natural variation are included. Pollutant fate and effects studies should be closely integrated with the biological studies to make sure that the final analyses have depth. The baseline data contributes to subsequent monitoring both by providing data from comparison as well as helping delimit control habitats. Boesch concludes that unfortunately, although there is a rationale for the management requirements for current research and assessment studies, these procedures may prevent the desired integrated approach from taking place.

Where Boesch used marine systems as a vehicle for a broad appraisal of evaluative methodology, Swartz employs it to take an indepth look at one method, diversity indices. The term diversity as used by ecologists has two components. The first is the number of species present (or some sampled group of these). This is referred to as richness. The other component, equitability, analyzes how the numbers of individuals are distributed in these species. The author reviews the various indices used in analyzing these concepts. After reviewing various marine literature, he points out that the two components do not follow the same pattern along pollution gradients. Typically (although with exception) the richness of macro benthos decreased with increased pollution while equitability and the commonly used information theory indices may be highest in stressed environments. Since the author's analysis of the literature indicates that diversity indices may be inadequate to distinguish the effects of pollution from natural variation, they should be used as part of more comprehensive investigations of population and community dynamics.

One of the examples which Boesch draws upon in his paper was the situation in the New York Bight. O'Connor has expanded that into a full blown case study of its scientific, public communication, and decisionmaking aspects. One of the fundamental lessons to be learned from this experience is that "biological evaluation" is not enough. The results of this evaluation must be quickly and accurately passed on to the public.

O'Connor reviews the scientific findings and their public interpretations, and the consequences emanating from these two sources. The research showed that while the inner New York Bight is extremely polluted, sewage sludge is a small contributor to the total pollution load whose relative significance is unclear. Preliminary observations reported in the press in 1973 and 1974 were of a sensational nature and aroused strong public interest. As a result principal research focus was temporarily placed on the sludge dumping issue at the expense of examining the total pollution situation. The lack of scientific information transmittal to the public and decisionmakers caused a demand to immediately move the site of sludge dumping operations. O'Connor feels that the obligations of satisfying NEPA prevented precipitous action from taking place. What has been done scientifically seems adequate for short-term decisionmaking, but long-term decisions will require more broadly based studies.

O'Connor concludes with the observation that NEPA intended a broad based determination of the significance of an action. Scientists have an obligation to put their findings objectively before the public and decision-makers.

Dice et al. review examples of data acquisition and utilization techniques, using various sources of regional resource expertise that have been shown to influence planning. The data gathering and display techniques described were intentionally not complex and did not rely on models, new concepts or complicated methodologies or checklists.

One example, the Washington Environmental Atlas project, grew out of a concept generated in the Office of the Chief of Engineers as part of a broad environmental information program and was one of four statewide resource inventories. Contributions were solicited from leading academic specialists, local authorities and the public. Information includes discussion of important species, critical habitat, hydrology, archeology, etc. The authors state that the Atlas, in addition to revealing and making accessible to planners a vast pool of non-agency informational contacts, provides a single source of significant environmental information useful to both agencies and the public.

The Willapa Harbor study in the state of Washington utilized a public opinion survey and employed a study of dredge material disposal patterns, past, present, and potential future. The public opinion poll early in the analysis provided valid input concerning the views of the local populace and assisted in acceptance by the locals of the ultimate decision. In this case, a dredging operation was discontinued for environmental as well as economic reasons. In Grays Harbor, several projects and a major permit action were allowed to go forward for a variety of biological, economic, and political reasons. The authors concluded from these studies that successful input of environmental concerns into project planning is possible, but is laced with difficulties associated with the environmentalist's role in the political, bureaucratic, administrative world of agency planning.

Several Fish and Wildlife Service national inventory efforts are discussed by Montanari and Townsend. The National Wetlands Inventory is aimed at providing "a single, universally applicable system of wetland information which will describe all wetlands on an individual and/or cumulative basis in terms of their ecological and physical characteristics, geographic location and natural resource values." The data base will be in both map and computer form. The effect will reduce the field examination requirements for the 35,000 permit applications processed by FWS each year. Secondly, it will aid in the migratory bird wetland acquisition program and it will also provide a data base for the federal-state cooperative bird management program. Outside of FWS the inventory will aid other agencies and private parties in their own resource management objectives.

FWS is also working on an expansion of the wetlands habitat scheme to include terrestrial systems in an all-inclusive habitat classification and analysis. At present there is no such uniform system. The system is intended to provide a sound basis for habitat preservation, conservation and management activities. The authors point to FWS's limited operational involvement in land and water management as providing an opportunity to set up a system independent of constraints not germain solely to living resources.

Despite the large number of environmental monitoring projects currently going on both as part of research efforts and also to comply with a variety of environmental laws and regulations, an investigator trying to tap this pool of information has difficulty because the published information is widely scattered, old, and poorly indexed. To help alleviate some of these difficulties Kemp and Burgess undertook the National Biological Monitoring Inventory in order to collect nationwide data on biological monitoring projects, and to organize the information into an on-line interactive data base. There are 1000 monitoring projects and 2,100 baseline studies in the data base. Projects dealing with human population agriculture, monoculture forestry, domestic animals, economics, remote sensing, and those reporting solely physical data were not included. The authors provide matrix tables for several topics (e.g. Florida marine studies) to show how subject category (baseline, regional, animals, wetlands, etc.) interacts with management focus (air pollution, indicator species, etc.) to provide a capability of analyzing the impact assessment process itself.

CONCLUSION

The contributing authors viewed the topic of Biological Monitoring from a variety of vantage points. What emerges is a technology assessment of a dynamic discipline. Environmental assessment changes and improves not only in response to the continually changing requirements levied against it, but more importantly in response to the evolving concepts of its practitioners.

If there is any single direction to which all of these papers point, it is toward the further integration of biological monitoring with the sciences, resulting in assessments truly at the ecosystem level.

THE NATIONAL ENVIRONMENTAL POLICY ACT AND ITS MANDATE TO APPLIED ECOLOGY

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Concern with environmental impact is not new. In the fourth century B.C., Plato spoke eloquently of the losses of the forests, soils, and waters of the hills of Attica which were then "like the skeleton of a body wasted by disease." Shortly thereafter in India, a system of reserves, in effect, precursors of the national park concept, was established to protect certain areas and their wildlife from human activities, and in the third century B.C., Emperor Ashoka of India promulgated a series of laws to protect certain species of fish and wildlife from overexploitation. Through the centuries, the environmental impacts of man's activities have been recognized by occasional philosophers and scientists, but such people were the exception, certainly not the rule. There was no effective way for them to communicate these concerns to government, much less to see them impact action -- unless of course, like Ashoka, they were the government.

In the decades leading to 1970, particularly in the United States, greatly increased scientific attention was given to the environmental impact of man's activities. However, the scientists concerned still only represented a very small fraction of the scientific community as a whole, and as before they had virtually no means to communicate their concerns effectively to government nor to influence governmental actions.

It is worthwhile to examine these two factors: the paucity of scientists concerned with environmental impact, and the lack of an effective link between them and the government. Scientists who were concerned with the environment represented only a tiny fraction of the total scientific community. If ecologists were taken separately, the percentage of them who were environmentally concerned would be higher, but still an extremely small fraction of the ecological whole. There are reasons for this, among them the ivory tower orientation of academia. In former years students were told that a truly holistic ecology, an ecosystem approach which included man (as opposed to a much more narrow and therefore "more scientific" concern with plant ecology or animal ecology), simply was not scientific and hence there was no future in it. The system of academic rewards and advancement were based on these premises. As a result of these factors, during that period it remained the exceptional scientist who was either very aware of human impact on the environment or who sought to do anything about it.

This problem was aggravated by the real difficulty of communication between government decision-makers and scientists. Decision-makers make decisions. The more quickly they do so, the more expeditiously they see things in black and white, the more successful they may be. Scientific orientation on the other hand is nearly the opposite. Scientific training places a premium on careful consideration of the shades of gray, and consequently, on not making rapid decisions.

The other factor cited involved the scientists' lack of access to the governmental system or vice versa. By the late 1960's, our government had some 80 agencies or major agency activities which significantly impacted the environment. Each agency had its own operational mission which it pursued with bureaucratic zeal, frequently to the detriment of the environment, and occasionally to the detriment of the missions of other agencies. The nation lacked a specific policy for the environment and the government lacked any body with responsibility for coordinating environmental affairs. Where scientific advice was involved -- and, with some outstanding exceptions, not too much was -- it was provided by the agency sources. Federal agencies were considered to have some sort of sovereign immunity. For the most part scientists and other citizens had no access to the agencies' decionmaking process, to the records and data on which decisions were made, nor legal standing to

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challenge or question the agency processes.

The National Environmental Policy Act (NEPA) changed all that. It established a national environmental policy to: "encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man"; and "to enrich the understanding of the ecological systems and natural resources important to the Nation."

It established the Council on Environmental Quality in the President's Executive Office, to act, among other things, as the environmental coordinating body for the federal system.

It also established the environmental impact statement (EIS) process. The process was intended to be an action forcing mechanism, to assure that the federal agencies complied with the Act's main thrust, i.e. that environmental concerns should receive adequate attention at all levels of governmental planning, decisionmaking, and actions.

There has been much misunderstanding about the EIS. To understand the intended role of the EIS process, it is useful to consider the genesis of section 102(2)(c) of NEPA. The Act as originally proposed by Senator Jackson declared an environmental policy but did not provide for preparation of EISs. In testimony before Congress on the proposed Act, Professor Lynton Caldwell pointed out that the Act presented a fine policy goal, but offered no way to assure that the agencies would implement it. "It seems to me" he said, "that a statement of policy by the Congress should at least consider measures to require the federal agencies in submitting proposals to contain within the proposals an evaluation of the effect of these proposals upon the state of the environment." "It would not be enough ... to think that a mere statement of desirable outcomes would be sufficient to give us the foundation of what we need .... We need something that is firm, clear, and operational."

Senator Jackson agreed, noting that, "You see the problem that we are faced with. If we try to go through all of the agencies ... in which there is no environmental policy or standard laid out, we could be engaged in a recodification of the federal statutes for a long, long time." The answer that we developed was the EIS process administered by CEQ. NEPA also provided the legislative basis for public access to and review of the agency environmental decisionmaking process. Court decisions based on NEPA have, among other issues, established that:

- citizens have standing to challenge government action so claims of sovereign immunity are irrelevant;
- consideration of environmental issues must be made part of a reviewable record upon which an agency bases a decision, whether or not an EIS is filed;
- the substantive adequacy of an EIS may be subject to judicial review.

One result of all this was the creation of an instant need for environmental, and more specifically ecological, expertise and information available to the government.

NEPA and the "little NEPAs," similar laws and regulations in the states, have established the process of environmental impact assessment as a significant factor in public decision making. Since enactment of NEPA in 1970, a large percent of the nation's ecologists, and much of the rest of the nation's environmental science community, have participated one way or another in the EIS process. The importance and values of the process as well as its points of weakness are well known to the scientific community. Procedurally, the EIS process has matured rapidly.

Perhaps the two most difficult questions that biologists repeatedly face in assessing environmental impact are also the two most important questions:

1. How can the biological significance of environmental perturbations be evaluated? and
2. How can these valuations be meaningfully described in order to enlighten and influence public decision makers in the environmental impact assessment process?

The difficulty of these questions as well as their scope is intimidating on both conceptual and practical grounds, yet the development of new concepts and methods for evaluating and describing ecological responses to environmental damage is occurring at a rapid pace.

This symposium has focused on concepts and methods by which the biological significance of environmental impacts may be evaluated by ecologists and meaningfully described to decision makers in the environmental impact process. The primary goals of the symposium were to examine such concepts and methods and to stimulate their development and application.

The Council has taken the results of this symposium into consideration in its development of NEPA regulations.

NEPA offers a tremendous opportunity and tremendous challenge to science -- especially to ecological science. In the years prior to NEPA, who would have believed that Congress would unanimously pass an Act which spoke of "ecological systems," "the biosphere," and "utilizing a systematic, interdisciplinary approach to insure the integrated use of natural and social sciences"? NEPA provides an explicit mandate to increase our environmental understanding and use it wisely, and an implicit mandate to the scientific community to provide the necessary knowledge and expertise. It has also provided substantial support for this endeavor. Directly and indirectly, NEPA has generated a very substantial increase in funding of ecological research.

SCIENTIFIC LOGIC AND THE ENVIRONMENTAL REVIEW PROCESS

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ENVIRONMENTAL CONFLICT RESOLUTION

Environmental problems result from man-made insults associated with the design and management of synthetic, engineered systems nested within natural ecosystems. (Fig. 1)

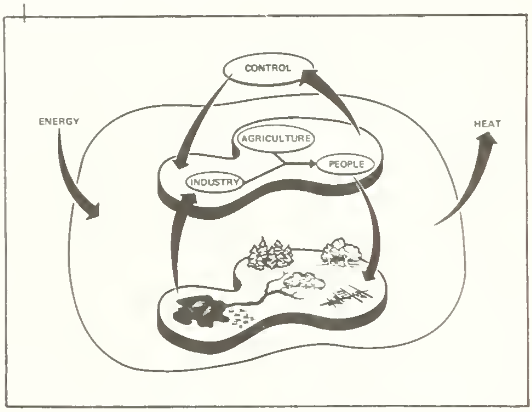

Figure 1. Relation of Engineered Systems to Natural Systems.

Given the distributive nature of both the human system and its environment, the damages resulting from such insults are also distributed widely in both space and time. The process of environmental review is, therefore, part of an elaborate social system designed to resolve individual and institutional conflicts where the participating populations are broadly distributed subsets of society. One must first understand the nature of the decision-making process if one wishes to investigate the roles of scientific logic and data in this process of conflict resolution.

As a "bug picking" zoologist, my understanding has come not from formal academic education, but rather from empirical experience as chairman of the Michigan Environmental Review Board for the State of Michigan. Currently, there exists three alternative mechanisms to resolve environmental conflicts in our state. Each one is designed to emphasize a different set of regulatory processes. (Fig. 2) Very briefly, each is characterized as follows:

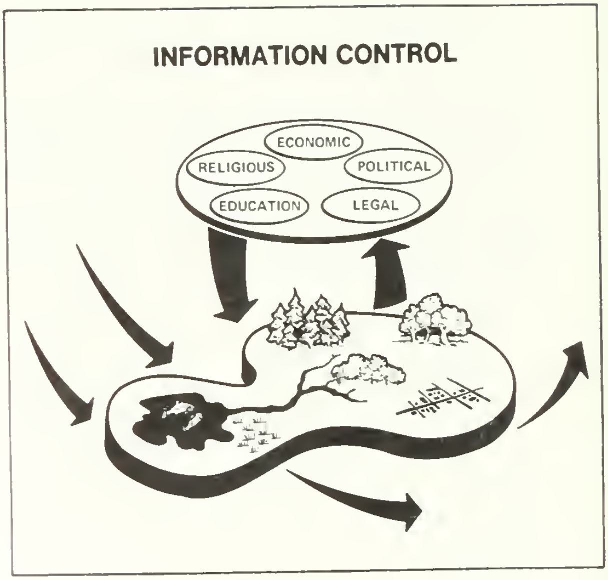

Figure 2. Information Control.

LEGISLATED STANDARDS

For those classes of environmental issues where the mechanisms are known and the stimulus-response curves have been scientifically established, rules and regulations can be embodied in legislation and enforced by traditional bureaucratic activities. In general, the damage functions must be directly observable and easily measured. The most obvious examples include the attempts to insure ambient level of air and water quality that is conducive to a socially acceptable level of human health and welfare. Behavioral standards are established as intensity of discharge at point source measured in ppm, degrees centigrade and decibels. Mechanized monitoring stations can be established and behavioral accommodation can be institutionally enforced. For the vast majority of natural processes, however, the cause and effect mechanisms are not obvious, the observability through empirical monitoring is not available and the material and energy couplings between components are diversified and distributed. In other words, there is no way that man is going to legislate nature.

MICHIGAN ENVIRONMENTAL PROTECTION ACT

Legislation was adopted in 1971 through the efforts of Dr. Joseph Sax, law professor, and Tom Anderson, state legislator, that makes it legal for a citizen to sue any federal, state, industry, municipality or other individual for something called "unreasonable pollution." This is a civil action that does *not* require governmental cooperation. Furthermore, "unreasonable pollution" was purposefully *not* defined. If formal standards do exist, they can be utilized as baseline measurements of reasonable behavior, otherwise the judge may set standards based on social necessity. In a recent article, the 110 cases that have been processed under this act since 1971 were summarized. About two-thirds were settled out of court before trial, took about nine months to resolve, and cost the plaintiff about $2000. The remaining one-third of the cases went to jury trial, took about one year to resolve and cost the plaintiff about $10,000. Roughly two-thirds of these resulted in a determination that unreasonable pollution did exist. Even though the judicial review operates with a paradigm that establishes a bimodal polarity of winners and losers, the judge often maintained the flexibility needed to negotiate mitigating settlements. Effects are still determined through empirical evidence of the magnitude and distribution of damages resulting from environmental insult.

MICHIGAN ENVIRONMENTAL REVIEW BOARD

M.E.R.B. was established by the Governor's executive order, rather than by legislation. The seventeen-member board consists of the agency directors of those seven departments most critical to environmental programs and projects that are initiated, financed or permitted within the state, and ten citizen members selected for social perspective and balance.

Recommendations resulting from environmental impact statement review of specific projects and institutional policy review of state agency programs are put directly into the administrative structure through the Governor's office, and the agency heads themselves. The paradigm utilized in this option is anticipatory, rather than after the fact, and emphasizes negotiated settlement rather than adversary polarization. The rules and procedures are much less formalized than the institutionalized alternatives and provide the flexibility to arrange problem-specific solutions. The public participation is as broad and effective as the communication channels which are individually generated and maintained. The primary purpose is *preventative*, and the mechanism is predominantly *environmental* impact statement review and administrative determination. The objects of review are the programs and policies of line agencies and the method of review emphasis, predictive logic, and qualitative determination of socially acceptable environmental *trade-offs*. The Environmental Impact Statement is a *critical* trigger for this review process since more often than not agency policies are only apparent when they are reflected in specific projects. It is critical that the EIS contain the information and be written in such a fashion that the *irreversible* and *preemptive* characteristics of programs and projects are transparent to the *public*.

THE ENVIRONMENTAL IMPACT STATEMENT

An environmental impact statement is a written document that is supposed to predict the distribution of beneficial and deleterious effects as well as the uncertainties associated with a proposed project or program before its initiation. The same analysis is usually demanded for the small set of obviously logical alternatives that were not selected so that parties that feel aggrieved can challenge the logic of the administrative decision. Since most environmental problems involve distributed effects and involve human perspectives of acceptable trade-offs, the EIS must incorporate an integrated systems orientation that is responsive to human perception. Ecological theories deal with distributive effects on *non-human* organisms and evolved structures such as biological communities and ecosystems. Engineering theories were initially oriented toward discrete physical systems with design and management objectives. Economic theories are based quite specifically on value theory which is strictly human, goal seeking in orientation. To be useful to the decision-maker, an EIS must, as a minimum set, be robust enough to logically integrate the concepts and analytical techniques of these three disciplines, i.e. engineering, ecology, and economics. The General Systems theory that is recently emerging from systems engineering provides the only structure that is logically compatible to the task. Whether or not the problem is mathematically tractable, the logical discipline that emanates from utilizing a formal systems approach of problem definition is absolutely essential to the environmental review process.

The initial steps that are required in this type of analysis involve a careful identification of the boundaries of the object of concern, the characterization of the environment that constrains the set of expected behaviors, and an articulation of the relevant connections or linkage between functional entities within the object and interactions between the object and the environment. (Fig. 3) All this boils down

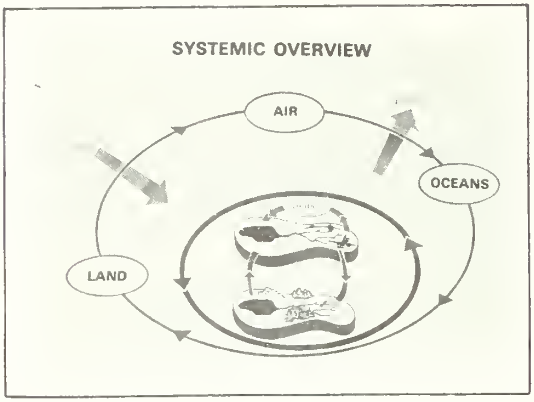

Figure 3. Systemic Overview

to a description of the system in terms of the functional behaviors that are of social concern. This identification process is well understood for ecological problems dealing with individual and population behaviors. Ecological theories based on Darwinian evolution and Mendelian selection provide a logical foundation from which predictions of behaviors can be obtained. Since the predictions are based on fundamental laws of behavior, the process is as respectable as any field of science.

Unfortunately, many of our environmental problems are associated with ecological phenomena at the community and ecosystem level. Ecological theories do not exist that have survived the ultimate test of "failure to reject" over a wide array of repeated challenges. Much of community and experimental ecology is oriented toward statistical massaging of descriptive data in hopes that the fundamental laws of behavior will conveniently press themselves. At best, the state of the science today requires that one utilize the predictive powers at the individual and population level to characterize components within the system and utilize the logic of community and ecosystems to synthesize the anticipated behaviors of large-scale systems. No matter how one approaches the analysis, the ecologist must provide the environmental decision-maker the intuitive insight of big systems. The justification and validation of the analysis will rest on the robustness of the logic, rather than on the completeness of the data.

A good example of the need to know the basic mechanisms affecting the behavior of components in the total system is apparent with the Toxic Substances Act currently being considered by the federal government. Due to the high social costs of discovering the toxicological properties of synthetic compounds by trial and error, considerable pressure is being applied to develop a system of premarket testing and evaluation. Regulation of sale and production of several million species of synthetic compounds is under consideration and yet we still do not know: if thresholds exist for carcinogens; how we extrapolate from non-human to human dose-response curves; how one substitutes intensity of dose for duration of exposure when dealing with chronic effects; if synergisms exist between various classes of substances; or how one determines the transport, storage and transformation of thes substances in natural ecosystems. Current drafts of the proposed legislation state that if no data exists, the substance will be presumed to be dangerous. Multibillion dollar industries and large populations of organisms (including humans) will be affected by these decisions. Most of these administrative tradeoffs will be made by technocrats who will not have the luxury of detailed data and analytical simulations.

MODEL VALIDATION

Since the EIS is really a predictive model, even though it is a funny mixture of quantitative and qualitative relationships, it is important that it be organized and written so that the public can rapidly validate the analysis based on their own, persona reference points. This is probably the most singularly ignored aspect of most EISs currently coming to the Michigan Environmenta Review Board. Frequently the EIS is organized so that the public attention and, therefore, the debate if conflicts exist, is oriented towards the output of the model rath than on the inputs. The three most important determinants of the social acceptability and technical validity are the relevance of the paradigm selected, the validity of the basic assumptions associated with the selected abstraction, and the accuracy of the data utilized to define specific aspects of the model.

The relevance of the model can only be judged by the class of problems that are anticipated. There is no way that any human or any computer can integrate without deletio or distortion the complex and diversified dynamics found in human ecosystems in total.

One must abstract the real world into a simplified form. This synthesis must be based on associations of specific elements based on functional similarities. This intellectual task is possible when dealing with rather gross behaviors like modeling the dynamics of a forest insect population as a function of physiological time in order to predict the general timing of the annual life history. This is far more difficult when attempting to predict the effects of polychlorinated biphenols (PCBs) as chronic carcinogens when each isomer has impact specificity.

The most difficult task is to get the analyst to specifically state early in the statement a list of the ecological, social, physical and mathematical assumptions that he or she was forced to utilize. If these assumptions are scientifically valid and socially acceptable, then the outputs are hardly worth debate. The trade-off between building a limited access freeway over an existing trunkline or starting de novo through productive agricultural land boils down to the assumed long-term value of alternative land forms. Frequently the debate associated with highway EISs focuses on the cost-benefit ratio of alternative outputs (human lives saved per million miles traveled per dollar costs), rather than on the vector of values that the systems analyst is forced to choose.

The data utilized to describe aspects of the analysis are often the focus of much intense scrutiny by critics of the proposed action. Too much importance is given to debating accuracy without knowing the sensitivity of the outcome to measurement errors at specific points. Furthermore, much of the data that we observe in environmental impact statements are there because they are available and easily measured and defended. Much of it has nothing to do with the social conflict nor is it required for the formal analysis. Detailed descriptive data on physical and biological characteristics of the region is usually totally worthless to the decision-maker.

The Michigan Environmental Review Board is currently doing the review of Project Seafarer, which is an underground antenna covering 3500 square miles proposed for the Upper Peninsula of Michigan. The social issues involve exposure to non-ionizing-electromagnetic radiation at 75 Hz; economic impacts anticipated through reduced land values and preemptive land use; and the increased human risk associated with residence in a nuclear bull's-eye. The first installment of the environmental impact statement delivered by the Department of the Navy includes a fifty pound stack of documents which provide a complete description of the region in terms of plants, animals, geology, hydrology, surface water, subsurface water, land ownership, demography, economics, etc. It would have been left predominantly up to the review board to interpret, synthesize and predict significant impacts.

For this reason, the M.E.R.B. prepared a fourteen-page addendum of questions that must be added to the standard federal shopping list that will include the issues of real social concern. There is no way that the decision-maker can or should separate the ecological analysis, the technology assessment, the economic impact and the social acceptability as independent considerations.

INTEGRATION OF SOCIAL WEIGHTS

Given the problem definition in explicit terms of ecological, economic, engineering and social sciences, one must then identify and present the relative weights that are assigned to the various sets of information. Too often these subjective decisions are conveniently hidden within large complicated engineering or economic models and are not offered up for public debate.

The best example in Michigan is our current debate over the need to draft statewide land use legislation. Partly because it is politically safe, the initial activities have concentrated on an inventory of resources and institutional goals. Each interest group has appeared and made their pitch that, although the free market system is essential and private property rights are a sacred trust, there exist extenuating circumstances that dictate that their problems deserve particular consideration.

The following account is an abstracted but accurate representation of the basic problem:

> The Director of the Department of Agriculture states that Michigan must be 70% self-sufficient in food and fiber production. Statistics on world population growth, increasing demands for agricultural outputs, fixed stock of good agricultural lands, balance of payments, etc., are all utilized to defend removing prime agricultural lands from the market place and fixing their future use exclusively for agricultural food and fiber production.

The sand and gravel industry then presents extensive data that the distribution and abundance of those sand and gravel deposits necessary for industrial growth are equally limited with little chance for substitution. Utilizing estimates of the need for more jobs, industrial growth, urban revitalization and economic independence, an appealing argument is made that these unique resources must be protected from alternative uses that only reflect short-term market trade-offs.

The Public Service Commission then makes their presentation on the need for energy parks that require specific locational and environmental characteristics. The sites are restricted to rural shoreline sites along the upper Great Lakes. Quoting data on the energy crisis, the need to shift from hydrocarbons to electricity, the necessary requirements of large amounts of clean water, large tracts of undeveloped land, remote distances from major urban areas but proximity to major user groups, etc., the same need to remove the few unique sites that currently exist from the market system is made very apparent.

Finally, the Director of the Department of Natural Resources presents the problem of the Kirklands Warbler, which is Michigan's addition to the federal endangered species list. Federal legislation mandates that the habitat of such species be preserved for biological preservation. Unfortunately, a considerable portion of the birds' breeding territory lies within the artillery range of the National Guard camp. Big guns and Warbler breeding are incompatible uses and once again the argument is made for exclusive use.

Each of these arguments is logically defensible in the singular. If one includes all of the other special interest groups, a series of unique resource maps can be prepared for the state. When this is completed sometime next year, we most likely will find that the demand for exclusive use will exceed the natural resource endowment of the state. That is when the debate of which weights will be utilized in evaluating the total costs, benefits and risks of alternative trade-offs will become inescapable. How will society decide the trade-off between energy production and shoreline preservation, national security and Kirklands Warbler, agricultural productivity and limited access freeways? These subjective values must be included in any major environmental decision and, therefore, must be included in a visible form in any good environmental impact analysis.

HIERARCHIES AND CONFLICT RESOLUTION

Even when the model utilized is technically validated, the assumptions explicitly stated and the social weights determined, one must recognize that the decision-making structure also has a well-defined structure which is ordered in hierarchical arrangement. This structural configuration is essential for conflict resolution as the constraints always operate from the top down. The ordering of the considerations into a dominance hierarchy is both societal and problem specific. The basic structure of the decision-making system is, however, generic and must be understood by those preparing environmental impact analyses.

The value of natural resources in our society is generally expressed as opportunities to benefit from their utilization either now or in the near future. This predominantly human perspective of the natural world is understandable, given the goal-seeking nature of most individuals and industrialized societies. The fulfillment of these expectations requires a careful matching of the goals with the resource constraints imposed by the nature of the man-environment system envisioned.

Ecological systems have evolved, not as goal-seeking institutions, but rather as systems whose criteria of success is strictly oriented towards survivorship. The constraints are ordered as a hierarchy, with the physical factors dominant over the individual expectations. (Fig. 4) A classic example of this

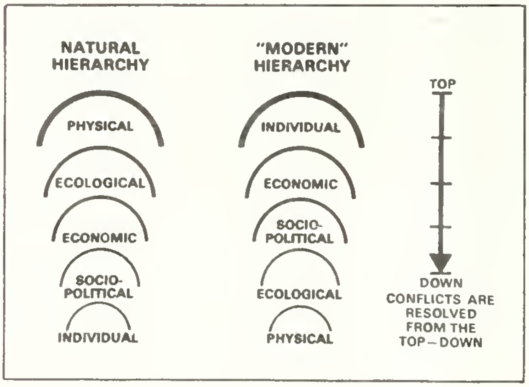

Figure 4. Natural and "Modern" Hierarchies.

dependency is illustrated by Roy Rappaport's accounting of the Tsembaga Maring's cultural evolution to adapt to the ecological constraints associated with existence in the New Guinea central highlands. The cultural arrangements and individual behaviors, evident in the Tsembaga Society, are homeostatic mechanisms to adjust to the physical and ecological constraints imposed upon them by the natural processes of their resident ecosystems.

In order to obtain a system that will allow individuals the opportunity to seek fulfillment of personal goals, one must augment the resources to match the goal constraints. The resource augmentation can only be obtained through the engineered substitution of synthetic materials, synthetic energy or synthetic information in the form of technological development. (Fig. 5) The rapid growth in economic development that

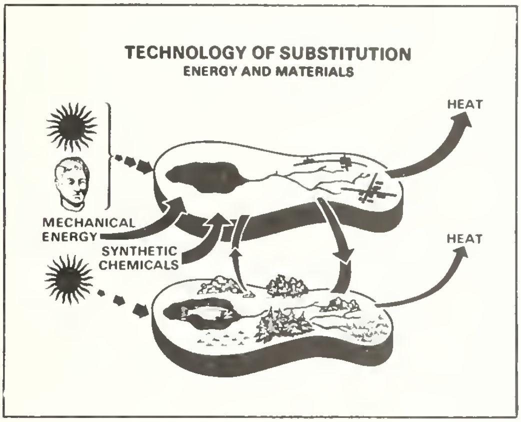

Figure 5. Technology of Substitution Energy and Materials.

many of the industrialized countries have experienced since the 1940s has been associated with the development and expansion of the synthetic chemical industries. The anticipated resource limitations associated with natural, ecological, food and fiber producing, and waste reprocessing capacities have been relaxed through the substitution of man-made alternatives. There are currently some five million species of synthetic compounds being utilized in our economy, with tens of thousands of new ones being considered annually.

A similar pattern of increasing dependency exists with energy other than that accumulated by the daily fixation of solar energy input through photosynthetic processes. Since energy is utilized primarily to maintain the flows of chemicals through our man-made ecosystem, there are inescapable thermodynamic implications to the trend of increasing populations and increasing per capita consumption of material products

PUBLIC DECISION-MAKING

I am now shifting my orientation from the structural characteristics of the environmental review process to the functional process of public review. For a number of reasons, our society has demanded and obtained the opportunity to participate in the environmental review process. The major justifications relate to the fact that many of our environmental resources are in public ownership and the damages experienced through mismanagement are endured by large numbers of people. It is essential that the scientists preparing the documentation to assist the decision-maker understand how and why the information will be utilized.

In designing a scientific experiment and preparing a manuscript for publication, the investigator follows a set of disciplined rules to obtain objectivity and acceptability. The rules of statistical inference and experimental design constrain the experimentation. The rules set by professional journals and enforced by editorial boards constrain the format of the manuscript. This is accepted without fear of academic prostitution. In a similar fashion, the design of the environmental impact statement should be dictated by the decision-making paradigm utilized and the format of presentation oriented towards the specific user group. A very different set of criteria are utilized when preparing the documentation for the legislative (standards), judicial (civil court) or administrative (M.E.R.B.). To attempt to standardize all impact analyses into a single format would be counter-productive.

Another characteristic of public review that is essential, is the subtle, but important, distinction between risk and uncertainty. Risk involves an error in prediction given the fact that the probability distribution of alternative events is known. In statistics the alpha and beta errors are two types of risks. Uncertainty, on the other hand, is related to a lack of understanding of the cause and effect relationships so that the probabilities of errors can not be quantitatively determined.

The environmental impact analysis should articulate a complete set of costs, benefits, risks and uncertainties. This should be included even if the uncertainties and risks cannot be defined and, therefore, must be stated qualitatively. Traditionally, cost/benefit analyses have emphasized the maximization of benefits. This logical orientation is challenged during many environmental debates where the public is concerned with minimizing risks.

M.E.R.B. is currently reviewing the social acceptability of utilizing salt deposits in Michigan for the disposal of nuclear waste. These materials are characterized as biologically active, mutagenic, soluble in water, and having long half-lives. These properties create a psychology in many individuals on M.E.R.B. that dictates the rational goal is risk aversion (this is not a case of uncertainty), rather than maximizing future economic growth and development. To prepare an extensive description of the natural ecosystem in the proximity of the proposed sites would be a total waste of effort given this social definition of the problem. In this case the technical, economic and social considerations predominate over the traditional ecology. This basic concern is human health and welfare.

INEQUITY IN DISTRIBUTION

One of the most difficult dimensions of an environmental impact analysis is the assessment of the spatial and temporal distributions of the costs, benefits and risks. Since the environmental insults, if they exist, are distributed in space and often in time, the human populations that are affected (exposed to the risks) are usually not the same set that benefit from the project under consideration. In short, the private sector benefits from the economics of development, the public sector pays the cost of being wrong.

Two case studies currently being experienced in Michigan amply illustrate the issue. Due to consecutive human errors within the Michigan Chemical Company and the Michigan Farm Bureau, a substantial quantity of a fire retardant containing PBB (polybrominated biphenyl) was introduced into dairy feed in the state. To date, some 31,000 diary cattle have been destroyed due to this contamination by a toxic compound. There are many alternative ways to produce fire retardants, but the product represented profits to the stockholders of the company involved. The dairy farmers involved suffered irreversible losses, both economically and personally. There is no mechanism to assess the total cost of damages reaching into the multimillions of dollars to those who benefited from the economic activity. The two subsets of people were essentially non-overlapping sets. We have what is called in engineering terms an open looped system with little hope for direct accountability, because the rights and responsibilities are not assigned to the same set of individuals.

The second example involves the discharge of 67,000 tons a day of taconite tailings by Reserve Mining into Lake Superior. The industry has maintained that they should be allowed the right to discharge until someone obtains direct evidence that the tailings cause negative effects. These tailings have been shown to contain significant levels of asbestos fibers. Furthermore, it has been demonstrated that asbestos fibers cause lung cancer if inhaled. It has not yet been demonstrated that ingesting these fibers will cause stomach cancer. What happens in the future, however, if someone performs the critical experiments and scientifically demonstrates carcinogenic activity? Again, the population that benefits economically from continued discharge is not the same population that is being exposed to the uncertainty (the residents who obtain their drinking water from the lake).

These problems are even more difficult when estimating damages that cross national boundaries (transnational externalities) or extend through time sufficiently long to impact on future generations. The concern over the impact of fluorocarbon 11 and 12 on the stability of the ozone layer in the outer atmosphere illustrates this class of problems. The time lags in effect dictate that the damages, if they occur, will only be apparent to empirical measurement many decades into the future. How does one affect a trade-off where the benefits of the technology are experienced today and the risks of increasing skin cancer due to increased exposure to ultraviolet radiation are experienced in your grandchildren's generation? Again, we have an open looped control system with no direct accountability.

Any environmental impact statement that hopes to address the problem of the trade-offs associated with distributed benefits and risks must provide a detailed analysis of the spatial and temporal dimensionality. Current analytical techniques either assume spatial homogeneity or completely ignore the spatial dimension.

CONCLUSION

The process of environmental review and conflict resolution has been a rather unique and often frustrating experience for many of us on the Board. We are in fact participating in ecological and social engineering of a complex, distributed system that is non-linear, hierarchical and characterized by a multitude of time lags. Furthermore, we are attempting to implement anticipatory or preventive solutions to design and management problems without any clearly articulated social goals. We have no national goals for population size, agricultural lands, energy utilization, natural resource utilization, organization or integrated land use, to mention a few. As a society, we have spent a considerable amount of our time and energies analyzing what we don't want, rather than planning for desirable alternative futures. Much of the environmental review process is oriented towards negative effects because they are identifiable and their definition does not require closure of social values and expectations.

Given this uncertainty and/or multiplicity of specific goals, the process of anticipating the overall impacts of current projects and policies requires a scientific understanding of the basic mechanisms of change. At the current state of ecological, engineering and economic knowledge, the best we can do is to characterize the total system structure in a disciplined, logical manner, obtain empirical data for those aspects that are measurable and then deduce the future impacts in a logically consistent fashion. The review process really needs the scientist for his logic far more at this time than for his enormous data set or unique social sensitivity. The only common denominator that we have found that allows us to integrate the many different disciplines necessary for a real environmental review is the logic of general systems theory. The task is to perform this integration without significant distortion or deletion of the information and logic available, then to extrapolate alternatives into the future and evaluate the outcomes in terms of the magnitudes and distributions of socially determined costs, benefits and acceptable risks. Finally, all of this must be retranslated to the user group in a form that assists in the ultimate social determination. Our experience with the Michigan Environmental Review Board has indicated to us that this can be done.

THE GREENING OF THE ENVIRONMENTAL DECISIONMAKING PROCESS

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Contrary to what some readers may believe, the title of this paper is not a veiled reference to the fees charged by consulting firms for the preparation of environmental impact statements. It is intended, rather, to suggest that this paper is directed toward the second principal question before the symposium: How have biological evaluations of environmental impacts served to enlighten and influence government decisionmaking, and how can they better do so in the future?

The National Environmental Policy Act of 1969 (NEPA) was intended in part to establish a mechanism for such influence through the preparation of environmental impact statements (EISs) for "major Federal actions significantly affecting the quality of the human environment." (National Environmental Policy Act of 1969.) By December 1975 this initially obscure requirement had generated nearly 7,000 environmental impact statements (see Table I), several hundred federal court decisions, and significant changes in the planning and decisionmaking processes of most federal agencies. While it is important to remember that NEPA involves much more than the production of impact statements, we have chosen here to focus on the evolution of the EIS process as the most tangible indication of the effect of NEPA on federal agencies.

PHASE I: NEPA IN THE COURTS

Prior to the enactment of NEPA there was no clear legal mandate for federal agencies to consider the environmental consequences of their projects and programs. In the planning offices the emphasis was on economic considerations such as benefit-cost analysis and on proper engineering and design. Public participation and review was limited or nonexistent. Soon after NEPA became law, however, environment groups and private citizens discovered the EIS requirement and eagerly seized upon it as a means of obtaining full disclosure and review of federal projects; the federal courts were generally sympathetic. Since NEPA contained no "grandfather clause," a number of projects that had already reached the late planning or construction stage were enjoined while federal officials hastily prepared EISs to satisfy demands originating from persons outside the agency. As can be seen in Table I and Figure 1, the Department of Transportation and the Corps of Engineers had a particularly large number of such projects, which accounted for more than 80 per cent of all draft EISs filed with CEQ during 1971.

Three unfortunate precedents were thus established which continued to restrict the utility of environmental impact statements up to the recent publication by CEQ of its NEPA regulations. First, the EIS was prepared as a disclosure document to justify or rationalize planning decisions made months or years earlier.

Second, alternatives to the proposed action were often presented and dismissed in a few sentences, or were simply variations of the proposed action devised ex post facto, or both.

Third, the EIS was viewed by many of those preparing it as an externally-imposed legal hurdle to be overcome, rather than as an internally-valued planning tool (Curlin 1972). There was much courtroom debate over the proper interpretation of the phrases "major Federal action," "significantly affecting," and "human environment," and little discussion of the analytical content or the potential value of the EIS process.

As Anderson (1973) has pointed out in his analysis of the first two years of NEPA litigation, the courts focused on interpreting the procedural requirements of NEPA and the EIS process, and shied away from reviewing the substance of agency decisions. This was partly because of the generality of the "substantive" language in NEPA (§ 101), but also because federal judges were unwilling to choose between the conflicting testimony of various expert witnesses. Nevertheless, biologists, ecologists and other scientists were

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Table 1

Draft Environmental Impact Statements Filed, by Agency, 1970-1975

Agency	1970	1971	1972	1973	1974	1975
Agriculture	62	79	124	166	179	189
Commerce	0	8	12	15	12	13
Defense	5	27	24	19	26	14
Corps of Engineers	119	316	211	243	303	273
Health, Education, and Welfare	0	1	11	4	0	3
Housing and Urban Development	3	23	26	22	21	78 1/
Interior	18	65	107	119	109	67
Justice	0	0	3	1	1	0
Labor	0	0	0	3	1	4
State	0	0	3	1	3	1
Transportation	61	1,293	674	432	360	229
Treasury	2	2	5	0	2	0
Energy Research and Development Administration	-	-	-	-	-	7
Environmental Protection Agency	0	16	13	26	14	23
Federal Energy Administration	-	-	-	-	-	5
Federal Power Commission	0	0	38	16	12	29
General Services Administration	3	34	6	24	26	23
Nuclear Regulatory Commission	-	-	-	-	-	26
All others	14	64	63	26	37	13
Total	319	1,950	1,385	1,145	1,137	1,010

1/ Total includes 27 EISs prepared by local governments under the Community Development Block Grant Program.

suddenly in demand by federal agencies to assist in the preparation and defense of environmental statements, and by environmental groups to assist in critiquing and discrediting the statements. Lawyers for both sides welcomed their new-found colleagues to the courtroom. The public's attention was focused on legal battles over EISs for projects such as the TransAlaska Oil Pipeline, the Calvert Cliffs nuclear power plant, and the Tennessee-Tombigbee Waterway. This activity prompted at least one environmental lawyer to argue that too much attention was being given to NEPA in the courts, and not enough to NEPA in the agencies (Schoenbaum 1974).

This early emphasis on judicial review of compliance with NEPA produced a defensive response from some federal agencies, resulting in an "empty the file drawer" approach to EIS preparation that is discussed further below.

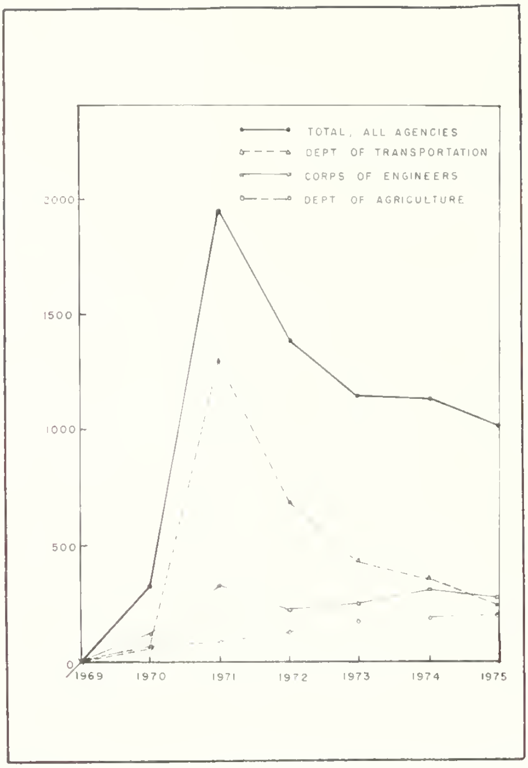

Figure 1. Draft Environmental Impact Statements Filed (selected data from Table 1).

But the lawyers and judges deserve credit for compelling the agencies to take the EIS process seriously. Environmental litigation has stimulated federal agencies to hire or contract with biological and social scientists for hundreds of environmental assessments, to underwrite additional basic ecological research, and to establish several training programs to familiarize key agency officials with ecological principles and methods. Litigation has also helped bring ecological concerns and those who study them to the attention of the public. These were necessary first steps in the implementation of NEPA -- it soon became apparent, however, that the courtroom was not always the best place to obtain substantive scientific guidance on the scope and content of environmental statements.

PHASE II: NEPA IN THE AGENCIES

Between 1971 and 1973, pursuant to Executive Order 11514 and guidelines issued by the Council on Environmental Quality (CEQ), most agencies developed and adopted procedures for implementing NEPA and the EIS process, and established special in-house environmental offices at a fairly high level to oversee the implementation of these procedures. At the request of Congressman John Dingell, the General Accounting Office conducted a critical review of the EIS process and reported that, while progress was being made in the integration of EISs into agency decisionmaking processes, improvements were needed in several areas, such as more timely completion of EISs more emphasis on public participation, and further guidance on the scope, content, and review of impact statements (General Accounting Office 1972). In August 1973, CEQ issued revised and expanded guidelines for the preparation of environmental impact statements which responded to these and other recommendations (Council on Environmental Quality 1973). The new guidelines emphasized the need to restrict the amount of descriptive material in EISs and include the analysis of significant secondary or indirect, as well as primary or direct, consequences of proposed federal actions.

In related articles, Andrews (1973), Flamm (1973) and Jordan (1973) discussed the value of NEPA and the EIS process as a new dimension to the planning process, and stressed the importance of early formulation and evaluation of alternatives.

It soon became apparent that agency personnel responsible for EIS preparation were being pulled in two directions at once: toward a late-stage comprehensive full-disclosure document by their lawyers to satisfy the courts, and toward an earlier more concise working paper by their agency planners and other policy analysts. Scientists involved in environmental impact assessment have taken both sides of this important issue. Some have seemed more concerned about obtaining sufficient time and funds to conduct definitive studies than about having their findings affect the agency's decisionmaking process (Wali 1975). Those who took this position found themselves in the lawyer's camp, supporting the preparation of a comprehensive, but historical, document. Those who tried to be effective found themselves working under severe time constraints, or subject to accusations of unprofessional conduct, or both (Schindler 1976).

In some agencies the lawyers prevailed. In these agencies, decisionmakers and other EIS recipients have been increasingly confronted with massive documents, often in multiple volumes, often prepared by large consulting firms for large fees. Much of the material is either devoted to detailed descriptions of the proposed action and the existing environment or to justification for decisions already made. Other nonanalytical material has included exhaustive species lists of all flora and fauna in the region, tables of raw water and air quality data, legal briefs, etc. Program statements and statements for permit and licensing actions have in particular contained much extraneous description and detail, while continuing to lack sufficient analysis.

CEQ and others have become concerned about the consequences of this development for the future of the EIS process. In 1976, CEQ Chairman Russell Peterson sent a memorandum to federal agency heads which stated in part:

> "[Excessively lengthy EISs ignore the precept that the EIS is not an end in itself but is primarily intended to aid decisionmaking. The statement does not achieve this purpose when it has such prodigious bulk that, while it may serve some academic purpose, no one at the decisionmaking level in any agency will ever read it. Since its purpose is to clarify, not obscure, issues and to forecast and analyze significant impacts of a proposal and its reasonable alternatives, efforts must be made early in the EIS process to weed out unnecessary information. Then, by focusing effort and attention on meaningful analyses, the legal adequacy of an EIS will also be supported and enhanced."

RECENT DEVELOPMENTS

The results of a recently completed CEQ review of the federal EIS process (Council on Environmental Quality 1976) are encouraging, because they indicate that most agencies are taking steps to increase the use of environmental statements in their own decisionmaking process. The Soil Conservation Service now routinely prepares and circulates its draft EISs together with other planning documents, allowing simultaneous review, and making possible the elimination of previously duplicated material. The Park Service and the Forest Service have integrated NEPA into their land use planning process. The Park Service's principal approach is to prepare EISs on park master plans (now called general management plans). The Forest Service has a hierarchical planning system in which EISs have been prepared as part of (1) the national assessment and program required by the Resources Planning Act, (2) some National Forest Plans, (3) all National Forest Unit Plans and (4) many functional plans, i.e., timber, recreation, wilderness, etc.

A noteworthy recent use of an EIS in the decision-making process was Transportation Secretary Coleman's personal involvement in the decision concerning plans for a six-lane Interstate Highway (I-66) extension into Washington, D. C. NEPA was also instrumental in Bureau of Land Management's denial of the 1976 application to continue the annual Thanksgiving Day hare and hound motorcycle race from Barstow, California to Las Vegas. The environmental analysis and subsequent monitoring revealed that the use by up to 3,000 participants had caused major damage to soil, vegetation and archeological sites. This is an example of the "adaptive management" discussed in the paper by Hilborn, Holling, and Walters in this proceedings. The Corps of Engineers, after following their EIS process, recently rejected two permit applications for dredging and filling on Marco Island, Florida that would have destroyed 2,000 acres of valuable mangrove wetlands.

These are only a few of the many examples of federal agency use of the impact statement process to change and improve their decisions. In the last two years, as the backlog of pre-NEPA projects has diminished, EIS preparation has increasingly been integrated into the federal planning and decisionmaking, with encouraging results.

We expect the trend to continue, but there are a number of steps that CEQ and the agencies will need to take to improve the EIS process. One need is to give additional guidance to help agencies prepare EISs for broad federal programs, or groups of projects. Another is to help agencies determine the scope of analysis appropriate to EIS; NEPA, as you know, applies to the "human environment," but does not define it. A third need is to help agencies determine the level of detail appropriate for an EIS. Ecologists and other scientists can assist this effort greatly by working on ways to adapt their field studies and their analytical methods to the particular kinds of choices that federal agencies must make. Decisionmakers need scientific information and analysis to determine the scope of reasonable alternatives when they are formulating broad programs as well as when they are evaluating specific project proposals. But the kind of information and analysis -- its scope, level of detail, and form of presentation -- will necessarily differ, depending on the nature of the planning and decisionmaking process. An understanding of this process, and its practical limits, by scientists who hope to contribute to it is essential.

SUMMARY AND CONCLUSIONS

In summarizing this review and analysis of the EIS process, a few points deserve emphasis.

1. Environmental impact statements have undergone considerable evolution since 1970. They have improved both in the quality of the environmental analysis which they contain and in their utility to decisionmakers. Additional improvement is, however, needed, particularly in the replacement of general descriptive material with a timely, integrated analysis of the projected impacts of specific project or program alternatives.

2. The critical role which many environmental scientists have played should be balanced by a greater willingness to seek out, work with, and advise government officials on a more regular basis. In doing so, scientists must recognize that the decisionmaking process necessarily goes beyond "strict scientific analysis."

3. If they are to serve this process, environmental impact statements cannot be purely scientific research papers prepared by ecologists alone. They should, rather, synthesize the best efforts of a multidisciplinary environmental impact assessment team, which must normally include professionals from several disciplines. EISs should present defensible scientific conclusions where they can be reached, and should set forth as clearly as possible, without "stacking the deck," the consequences of pursuing reasonable project alternatives or policy options.

4. CEQ and other federal agency officials must seek continuing advice and assistance from the scientific community as we pursue constructive implementation of the National Environmental Policy Act.

Hopefully the papers that have been presented at this symposium will lead to further improvements in environmental impact assessment and agency decisionmaking. We should continue to work together toward that end.

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ASSESSMENT OF ECOLOGICAL DAMAGE: CONSENSUS

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THE ROLE OF THE ANN ARBOR WORKSHOP

The co-authors of this paper organized the Workshop on Biological Significance of Environmental Impacts at Ann Arbor in June 1975. This paper will restate the central theme of that workshop and summarize the workshop contributors' views, with the goal of trying to capture areas of broad agreement or disagreement, unifying principles, and identified research needs which can provide a stepping stone for this expanded symposium effort by the Council on Environmental Quality.

Most of the ideas of the first two sections of this paper draw deeply from the contributors to the 1975 Workshop. Because many of these concepts were approached by a variety of those authors, each from his own perspective, we will present these concepts as workshop consensus or synthesis with a minimum of specific citation lest this paper become unwieldy. The success of the 1975 Workshop rests principally with the wealth of ideas presented by the contributing authors. Several of the Ann Arbor authors appear to have transcended the need for the 1975 Workshop since they started last year at a plane of understanding which hopefully can soon become state-of-the-art for us all. We view our role as proselytizing their work which is available in published form (Sharma, Buffington, and McFadden 1976).

We and the sponsors of our Workshop, Argonne National Laboratory in collaboration with the U.S. Nuclear Regulatory Commission and the University of Michigan, viewed the central theme of that workshop as investigating whether or not there existed a consensus among professionals engaged in impact assessment as to what constituted "significant" impact. The background for the problem may easily be perceived by examining a random selection of Environmental Impact Statements and seeing how frequently an expected environmental modification is labeled significant or non-significant (or other similar adjective) without definition of term. If, for example, a judgement is made that a given number of organisms will be killed because of the project under consideration, a biologist writing the EIS may decide the number is so small that the loss is easily insignificant by any definition. While this seems straightforward he may find himself at a hearing trying to defend the insignificance of the expected loss while struggling under cross-examination to indicate at what level he would have found the damage significant. While such questions may seem philosophical, current legal processes may cause projects of many millions of dollars to be modified, cancelled, or delayed by the likes of such a distinction. We were seeking to find a common ground to permit the scientific professional engaged in impact assessment to comfortably operate in this legal environment.

There is a distinct but related concept which we label as "acceptability," by which we mean a change or impact which is in agreement with societal norms. Which is to say that an unacceptable impact in some way violates society's (or portion thereof) system of values. We raise the issue here to more precisely distinguish significance as a separate issue. An example of the difference between the two ideas might be derived from an example such as the alewives of Lake Michigan. The biologist would view major changes in the alewife population as a significant impact, in this case since he recognizes that the alewife is an important element in the food chain. The authors have elicited responses from their colleagues in other disciplines which indicate that the alewives are a public nuisance, and therefore impacts resulting in lessening of their numbers may be viewed as acceptable. At the start of the Ann Arbor Workshop the organizers had a broad view that in some way significance related to ecological factors while acceptability related to value systems and similar social factors. We wished to address principally the significance issue in the 1975 Workshop. However we did invite

*Present address: Council on Environmental Quality several social scientists to the Workshop to help relate their perspectives to the significance and acceptability issues.

PERSPECTIVES FROM THE ANN ARBOR WORKSHOP

OBJECTIVES AND QUALITY OF INFORMATION

One of the most important messages from the Ann Arbor Workshop was that much sampling design is poor because there is no preconceived purpose to monitoring programs. No questions are posed nor hypotheses tested. Data are gathered because they can be gathered. To some extent this is the fault of regulatory agencies since applicants frequently are bombarded by agency staff with requests for more data. Compliance with such requests by the applicants is cheaper than the delays which may be incurred in defending noncompliance even when the requested data will fill no discernible need. Undirected data gathering is the shotgun approach for which the contributors to the Workshop had little use. The blame for past abuses probably lies equally among the persons performing the program, the persons sponsoring it, and those requiring it. Existing state-of-the-art permits the technical specialist to do a better job than the constraints of a contract typically allow him to do. It comes down to whether a monitoring program follows the scientific method or not. If impact assessment is to become truly predictive, then we should be willing to erect falsifiable hypotheses. The essence of these ideas as presented by several of the Ann Arbor Workshop authors is that first it is necessary to have a reason for doing something, then one should do it (and nothing else), but it should be done well. Well-informed technical input is necessary for the manager to realize what is at stake and what is necessary for a properly designed program.

The consensus of the 1975 Workshop appears to be:

> *Ask meaningful questions, then answer them well, but only them. The substance of far too many programs is only marginally related to the evaluation of expected impacts. More raw data do not necessarily mean better assessment.*

TIME FRAME AND SPATIAL CONSTRAINTS

Many of the Workshop speakers pointed out that artificial constraints imposed by sponsoring organizations do not recognize the realities of natural systems. These systems change by time of day and season of the year as well as from one year to the next. To be able to detect a signal emanating from an impacted system, correction must be made for the background noise. Likewise the spatial variability of most measured variables even over very small distances makes detection of changes resulting from impact difficult. While in many systems the professional biologist can design monitoring systems to at least partially overcome these problems, the sponsoring organization frequently constrains the programs to unrealistically modest time and space limitations, resulting in a program sufficiently compromised as to suffer serious loss of its ability to deal with meaningful hypotheses concerning possible impact. The most frequent constraint is a requirement to sample the system for a short period, usually only part of a year or even of a season.

There was general agreement among the participants that whatever monitoring program is decided upon should provide at least one year's data before the EIS is written. The annual cycle will not be denied. However, even a year's worth of data provides nothing more than a starting point. Many of the Ann Arbor authors, from their own perspectives, point out the tremendous temporal variability in the natural environment. Every measurable environmental variable is dynamic; even adequately sampled information over a given year will only capture that year's dynamics. Furthermore, the effect of seasonal changes and year to year fluctuations can be compounded if changes in sampling design take place through change in contractors, etc.

Similar statements were made by the contributors regarding the spatial problems of sampling. Once again arbitrary constraints without adequate technical consideration are frequently put on a sampling program by the sponsors. The distribution of many variables in the environment is patchy, furthermore spatial organizational problems such as perimeter-area ratios have to be recognized. Consequently a monitoring program must be designed to measure the non-uniform, non-random distribution of phenomena. For such reasons, a spatial (e.g., upstream) control is not always useful. To begin to do a good job, a monitoring program must cover enough space and time to reflect ambient dynamics. Given the problems associated with the proper design of a sampling program, placing unrealistic temporal and spatial constraints on monitoring programs only weakens the probability of a definitive assessment. This is not a call for bigger more expensive monitoring programs; rather it is a call for wise use of fiscal and personnel resources by use of adequately designed sampling programs which fall within current state-of-the-art.

There seems to be consensus on the following points:

The duration and extent of preoperational and operational studies should reflect the variability in the data and expected intensity of response due to impact. More time is needed to get a better pulse of the system where variability in the data is high. Similarly, more observations are needed to detect low level chronic impacts as opposed to catastrophic changes. The time frame as well as spatial limitations should be decided on a site-by-site basis to meet the needs of the program and the uniqueness of the site.

SPECIES LISTS AND DIVERSITY INDICES

The role of species lists, the use of indicator species, and the use of diversity indices were addressed by many of the authors at the Ann Arbor Workshop. There seems to be broad support among the participants for informed use of indicator species greater than exists at present. Most of the speakers couch their views with cautions concerning the sensitivity of chosen species, and their relationship to the overall biotic system. This interestingly offers a remedy for the ills of shotgun sampling especially as exemplified in multi-paged species lists. Howmiller, however, rather eloquently argues for analysis based on the total system. Nevertheless, given the shortage of decent taxonomic aid available for most studies, we suspect that if eventual consensus occurs, it will be for the use of indicator species rather than for extensive species lists. What appears to be needed is an agreed-upon approach to the use of indicator species which satisfies both the pragmatic requirements of clients as well as the data analysis requirement of ecologists. A modestly funded research program should be able to produce at least an interim working position. Here is an area where modest improvement of the state-of-the-art would result in substantive improvement of assessment capabilities.

Another means of simplifying data analysis has been the widespread use of various indices. Probably there would be less dispute if people did not try to use these indices as a final synthesis of the data collected for a biotic community, but rather used them as another element in such a synthesis. The use of indices independent of at least some knowledge of biotic composition is derided by Workshop contributors as being not responsible. A surprising number of the speakers appear to be opposed to any use of indices.

Consensus (not unanimous) for the Ann Arbor Workshop appears to be:

Detailed static descriptions of ecosystems, such as species lists, offer little value in impact assessment, however, they provide a mechanism for crude comparisons of before-and-after situations. The use of indicator species in impact assessment should be encouraged, but additional work should be sponsored to permit their most efficacious use. Diversity and other indices should be used with one eye on the original data, and another on the ecological literature. They are not equivalent to an ultimate synthesis of information on the state of a system.

ROLE OF STATISTICS

Statistics has become a universal tool. Many of the Workshop contributors felt that it is a tool that has been abused in impact assessment because it is used in an attempt to bail-out ill-conceived programs without consideration of the differences between biological significance and statistical significance. The problems of poor sample size (time constraints), poor replication (space constraints), lack of ecologically meaningful hypotheses, and shotgun sampling create a situation which a statistician cannot salvage. When statistically significant differences may be detected, they are rarely of any use in decision-making concerning ecologically significant phenomena. Here again improvement in monitoring programs need not wait for the state-of-the-art; we need only to utilize current knowledge. Statistical considerations should be a basic part of experimental design. They should not merely intrude for data analysis. But as Zar pointed out at the Workshop, we have a nasty habit of ignoring fundamental principles even when we are aware of their existence.

A reasonable consensus therefore is:

Present use of statistics does not take advantage of existing state-of-the-art. If programs are designed around suitable hypotheses with adequate consideration for problems of environmental variability, need for replication and adequate sample size, our capabilities for making predictive impact assessment will be improved.

METHODOLOGY STANDARDIZATION

A related problem was raised by several speakers, namely that they consider uniformity in sampling methodology to be desirable. For direct comparisons of data from one study to another the necessity of the same methodology seems obvious. Several authors suggested an even broader standardization for approach across all methodologies which seems to argue for a cook-book approach to data gathering. The counter argument is that such an approach caves into shotgun sampling. The peculiarities associated with each site mandate a specific sampling design for each site. Certainly, however, if direct comparison of two sets of data are to be made, as many extraneous variables, including differences in sampling gear, should be removed as possible. We also should profit by experience and abandon those techniques we agree are unproductive. However, premature standardization would chill progress on methodology improvement and retard state-of-the-art advancement.

There is no consensus but we feel that a reasonable synthesis at the present time is:

> *As techniques mature to the point of widespread applicability associated with reasonable cost, precision, and accuracy, their widespread adoption seems reasonable. However, undue emphasis on standardization can stagnate state-of-the-art.*

SIMULATION MODELS

The role of modeling received quite a bit of discussion. Lucas says that both mathematical modeling and ecosystem simulation are heading in the right direction but our present capabilities still need further development. Several authors pointed out that a modeling effort gives you a feel for where additional data shall be gathered and a variety of the 1975 Workshop participants [such as Christensen, et al., Risser, McFadden, and Botkin and Sobel] argue for models. The role of models in impact assessment and decision-making is undergoing change as the state-of-the-art advances. The broad range of informed opinion among the Workshop authors and others seemed to admit that modeling is a useful tool that can be integrated into the decision-making process, but given currently available data bases, and the developing state of biological models, to base a major decision on a postulated outcome derived from a model without independent back-up or validation should be done with caution. A decision based upon predictions derived from a model in addition to informed professional opinion, is more likely to be correct than the same decision based upon professional opinion alone.

There is no consensus but we feel that a reasonable synthesis at the present time is:

> *Use of simulation models has potential in terms of providing sharp focus on expected impacts and collection of relevant information in analysis of impacts. Predictive models can help evaluate assumptions and point to data needs. Informed use of models should be encouraged, their output interpreted carefully, and decisions based upon them should seek independent confirmation of the decided upon course of action.*

ASSIMILATIVE CAPACITY AND COMPENSATORY RESPONSES

The ideas of irreversibility and resiliency appeared in a variety of papers. There appears to be consensus that for an impact to be considered significant, some aspect of irreversibility must be present. Various authors used different terms for different aspects of irreversibility. Cairns segregated inertia, elasticity, and resiliency. If the capability of a system to resist change, and its ability to recover after change, could be determined prior to impacting a system, ideally many significant impacts could be avoided. A fundamental problem seems to be that of predicting system response so that irreversibility could be determined *a priori*. Assimilative capacity, at least as considered at the Ann Arbor Workshop, is a response at the community level to insult. It is a function of inertia, resiliency, and elasticity of impacted communities, and should be considered and factored into the impact analysis.

Functional integrity of the communities, as, for example, discussed by Cummins, is an important constituent of system response. Insults to functional integrity of communities are likely to result in changes that cannot be accommodated by natural processes. It is not certain how many species can be lost, nor how their role can be replaced by species already in the community picking up the function, without risking collapse of a community. Replacement of one fish species by another with similar functional values may be important in a social context because of the perceived socio-economic utility. Experience on the Great Lakes seems to bear this out.

Several of the Ann Arbor authors dealt with compensatory responses from a perspective similar to that of the fishery biologist. Compensatory responses may be limited to the single impacted population as, for example, shifts in breeding age, or may be spread over the community impacted, as, for example, by another species assuming an additional functional role. Some generalizations can be factored into analysis e.g., for a given cohort, impacts at early stages of life history are less significant compared to impacts at a later life-history stage. Compensatory responses are difficult to document on large systems such as the Great Lakes, and as such are difficult to factor into impact analysis.

Viewing things from the point of view of a resource manager permits us to talk in terms of resource allocation. If we assume that cropping a resource insignificantly (i.e., the final state of the system is similar to the initial state) impacts the resource, then the amount cropped becomes a utilizable resource which can be allocated among potential users. In this way a fishery may be allocated among sport and commercial users. It may be then argued that part of the crop may be allocated to industrial users as an appropriate cost effective way of using our total resources including not only the impacted biotic resources, but also the economic resource which must be used for ameliorative action.

A philosophical debate by society at large would appear to be inevitable if any attempt to implement such a view were made. There was a lack of agreement among the Workshop's participants on the biological mechanisms which would serve to regulate such use of resources. Given the sophistication of fisheries science, where we are concerned with the significance of response of a single sport or commercial fish species where an adequate data base exists, then allocating the species to power plants might not result in significant impact, although whether or not it would be acceptable as discussed elsewhere in the paper is clearly open to question. Where the insult to the system is primarily borne by a single species whose population dynamics is known, this approach may prove viable. However, several of the Workshop contributors had reservations about applying it to whole systems because we have poor understanding of compensatory response at the ecosystem level.

The broad range of opinions on these subjects permits only narrow consensus.

> *The assimilative capacity of a system should be recognized and accounted for in impact assessment. The use of resource management tools and philosophy warrant close consideration especially where a single species with an adequate data base is impacted.*

CONCLUSIONS FROM THE PERSPECTIVES

Much of what is contained in this section of the paper appears blatantly obvious to the technical individual working in impact assessment. Unfortunately, it is not so obvious to the decision-makers who are not biologists. Until these perspectives are built into the system of environmental impact assessment, the potential for improvement will not be realized. Consequently this section will be of greatest use if the middle managers of industry and regulatory agencies realize that implementation of these perspectives will result in major improvements in the quality of impact assessment, with only minor costs in terms of dollars and schedule.

THE DEFINITION OF SIGNIFICANCE

BIOLOGISTS AND ACCEPTABILITY

In the beginning of this paper we indicated our distinction between the concepts of significance and acceptability. Several of the authors suggest that the acceptability question be settled first in an impact assessment. Curry, for example, would have the acceptability threshold drawn and then the biologist would sit down to make his prediction as to whether the line would be crossed. This point, made in a variety of manifestations by several of the contributors, is vital. If significance is a label applied by the biologist to a damage function objectively determined on a solid technical basis, e.g., taking more than the maximum sustained yield, an irreversible impact, loss of 10% of the breeding population, or some other objective definition, then it makes no difference what the biologist emotes about the impact. The converse is the intrusion of his own values. The loss of a small relict population, clear cutting on a grand scale of forests, or reduction or loss of species diversity in a community are happenings likely to be *unacceptable* to many ecologists independent of how they define significance or apply it to such occurrences. There is a broad range of shared values among resource biologists (albeit in a morass of diversified opinion). As individual biologists we opine that widespread adoption of our value systems could only improve the universe. A moment's reflection will suggest that there must be at least an equal number of factory production managers with a similar bias toward their own profession. A decision about a project will hopefully be made in consideration of the conflicting views provided the decision-maker. The regulatory decision-maker will usually attempt to satisfy the public interest, as he sees it. He should consequently consider the values not only of the biologist, but also his mother-in-law, the economist, and the bishop. It is important that the values of the biologist are incorporated into the decision-making process, but it is arrogance to expect them to dominate.

The biologist then has three jobs:

1. Predict the level of impact.

2. State whether the impact is significant.

3. Impart to the decision-makers his views of the acceptability of the damage.

The first issue represents the basis of our professional training and exercise. The preceeding part of this paper dealt with that issue. Assuming that we all have a value system imparted in our genotype and phenotype, performing number three ought to be possible. But still we are left with good old number two: When is an impact significant?

A PROPOSED DEFINITION OF SIGNIFICANCE

It was a major goal of the 1975 Workshop to seek a definition of significance. This section will attempt to synthesize a definition from the perspectives offered by the participants at that workshop.

There is a surprising diversity of opinion among the 1975 Workshop authors. A sampling of some of their definitions and semi-definitions of significance is included as an appendix. Some of them confound the ideas of significance and acceptability so we will not deal further with those.

The texts of many of the contributions to the Ann Arbor Workshop indicate that some aspect of irreversibility is probably an important part of any definition likely to be broadly agreed upon. This element appears to have sufficient support to warrant its inclusion in this synthesis.

> *To be defined as significant an impact should not be temporary.*

While the definition of temporary could lead us down another garden path, let us assume it to be within several years of the stressing event. The definition is then slightly refined:

> *To be defined as significant an impact should persist or be expected to persist more than several years.*

An impact represents a change, and it is the magnitude of that change to which the expert witness must testify as to its significance. A fair amount of discussion dealt with the problem of whether there is a baseline and the detectability of it. Superimposed on this are the well discussed problems of sampling design and methodology. Eberhardt sums it up rather well by stating that it is unlikely that anything but quite sizable changes would be detected, even with a large sample size. If one is willing to state that "quite sizable changes" is an attribute that usually denotes significance, then the limitations of our methodology lead us to the next stage of the definition. We might construct an argument which states that if an impact is measurable, then the change in the real world that our crude schemes detect must be very large, and consequently significant.

The synthesis then further becomes:

> *An impact is significant if it results in a change that is measurable in a well designed sampling program, and if it persists or is expected to persist more than several years.*

For example, if a phytoplankton expert is asked if entrainment losses at a proposed power plant are significant, he could respond yes if he expected a competent program to be able to detect changes in primary production ascribable to the plant (i.e., free of upstream and background noise). This does not make the proposed action unacceptable. The fisheries expert may then be asked if the predicted loss of phytoplankton would result in a detectable loss in fish populations. An affirmative response means that a significant impact is expected. If the bottom line results in a detectable loss of N% of the standing crop of a commercial or sport fish, the acceptability of that impact must be judged by the decision-maker based not only on the technical advice of his experts, but also in consideration of their values. For the individual or group designated to make the decision, a process of weighting must ensue to determine the acceptability of this significant impact. Will society gain more from 2000 MWe power production than it will lose from a detected loss of N% of a fishery? Our society will continue to judge some impacts acceptable where biologically significant damage is wrought.

The proposed definition is operational. It offers several advantages:

1. It is useful. It provides an objective standard where one is needed;

2. It has some basis in ecological phenomena. The heart of the definition is the capability of the system to respond reversibly to an impact; and

3. It reflects the point of view of at least some of the Workshop participants. For example it overlaps several of the definitions given in the Appendix.

The material that Bibko presents in his Ann Arbor Workshop paper suggests that the proposed definition might be common ground for the legal specialist as well as the biologist. To us that seems sufficient ground to offer it to the CEQ symposium for further discussion.

ACKNOWLEDGEMENT

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APPENDIX

DEFINITIONS OF SIGNIFICANCE

Anderson: "To identify significant environmental and ecological damage requires a concurrent determination of who benefits and who loses."

Bibko: "The significance of a thermal or any other impact upon the function of an aquatic ecosystem is highly dependent on the <u>resiliency</u> of the system to absorb the stress to which an ecosystem may be placed."

"...a Section 316(a) demonstration will represent an attempt ...to prove levels of power plant impact harmless or insignificant with respect to the protection and propagation of a balanced indigenous community."

"The opinion [United States vs. Baker] leads one to believe that <u>any</u> disturbance or interference with these wetlands would lead to a significant ecological impact that would represent an irreparable loss."

"...the AEC staff concluded...these data alone do not necessarily indicate a significant impact when losses are placed in proper perspective with natural mortality rates."

Christensen <u>et al</u>.: "The concept of a 'significant' adverse impact on a biological system is operationally defined in terms of an adverse impact which, according to a proposed 'decision-tree,' justifies rejection of a project or a change in its site, design, or mode of operation."

"Significance must be determined from the viewpoint of the entity making the decision. Humans must, therefore, exercise judgment as to what constitutes a significant impact."

Cooper: "The definition of a significant biological impact assumes that a commonly accepted standard exists from which the importance of some deviation can be evaluated."

Cummins: "...in the long view, all damage is probably significant."

Eberhardt: "Significant ecological damage ensues when there is a reduction in the productivity of an ecosystem in terms of qualities perceived to be 'desirable' by mankind."

Lucas: "Assessment of the significance of the effects on ecosystems of proposed changes in human activities requires evaluation of the effects in some cost-benefit framework."

McFadden: "...it should be possible at the extremes to dismiss as insignificant very low percentage mortalities, and admit as obviously significant those situations in which a high percentage of the population is killed."

"If some measure of biological productivity is taken as the criterion of ecological significance, an environmental impact may result in a range of responses which, scaled from 'good' to 'bad,' include (a) increases in productivity; (b) changes in ecological processes but no net change in productivity; (c) declines in productivity of moderate proportions; (d) depletion of some part of the ecosystem and significant decline in productivity; (e) extinction."

Risser: "A certain measure of biological significance is the amount of a particular community which is committed by a project as a percent of the total amount available."

SYNTHESIS: "An impact is significant if it results in a change that is measurable in a well designed sampling program, and if it persists or is expected to persist more than several years."

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GUIDELINES FOR ECOLOGICAL EVALUATION*

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INTRODUCTION

The Environmental Impact Assessment Project (EIAP) of The Institute of Ecology (TIE) had two distinct phases. The first phase was devoted primarily to scientific and policy reviews of environmental impact statements. Malcolm F. Baldwin and Robert B. Smythe, both now with CEQ, served as Director and Assistant Director, respectively, of EIAP from June 1973 to July 1974. Thomas C. Jorling was chairman of the EIAP Policy Board during that period. The second phase was directed toward the development of guidelines for the improvement of NEPA applications, especially EIS preparation. During this phase, Gordon A. Enk served as Chairman of the Policy Board with John S. Winder, Jr., as Project Director from November 1974 through October 1975, and Ruth H. Allen as Assistant Director from February through October 1975. EIAP's second phase attempted to derive draft guidelines from the first phase reviews, a questionnaire sent to review team members, an interdisciplinary workshop (June 1-4, 1975 in Billings, Montana), and a study directed by Richard N.L. Andrews (1977), focusing on ecological aspects.

A separate project (UrbSec), under the direction of David L. Jameson sought to provide EPA with guidance on ecological consequences of urbanization induced by such projects as highways and waste water treatment facilities (Jameson 1976). Both EIAP and the UrbSec project were designed to show how ecological knowledge can be used to fulfill the letter and spirit of NEPA.

The National Environmental Policy Act of 1969 (Public Law 91-190) has three high purposes:

"To declare a national policy which will encourage production and enjoyable harmony between man and his environment;

"To promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man;

"To enrich the understanding of the ecological systems and natural resources important to the Nation." (Council on Environmental Quality 1970.)

Several sections in the Act endorse scientific methods as means towards achievement of the stated goals. All agencies of the federal government are required to "utilize a sytematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences" (102,A) (Council on Environmental Quality 1970) and to "initiate and utilize ecological information in the planning and development of resource-oriented projects" (102, G) (Council on Environmental Quality 1970). The specifications for the Annual Report of the Council on Environmental Quality can be interpreted as requiring a comprehensive and thoroughly scientific analysis of major ecosystems in the United States, each year describing their current status and most probable future condition (Council on Environmental Quality 1970). However, the first reports of the Council on Environmental Quality and many Environmental Impact Statements (prepared to comply with one subsection of NEPA-102,C) (Council on Environmental Quality 1970) and surveys of impact assessment methodologies (Warner and Preston 1974) indicate that methods of science in general and ecology in particular have not been well or widely used.

This paper is based on two assumptions:

1. That the principles and methods of ecological analysis are valuable for the assessment of technological impacts;
2. That a summary of ecological analysis methods may increase their application under the provisions of NEPA.

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Both assumptions are open to question. Some argue that ecology is of little value in predicting the economic or social consequences of an action. Others admit the possible utility of ecological inventories, monitoring or other procedures but claim that the expense is far too great, even in projects or programs where the possibility of economic loss is high. However, government agencies or environmental consulting firms may avoid the expense, ignore the potential, and settle for a "passing grade," fulfilling the letter of the law as required by the courts but losing the essential spirit of NEPA. The diverse presentations of this symposium will show them just how much they are missing.

This paper on ecological analysis of technological impacts, will focus first on the description of environmental components, then natural changes, and finally changes attributable to technological impacts. The approach is quite similar to that commonly used by a scientist in designing field experiments. Baseline conditions are described; changes expected without intervention are delineated; and the consequences of the experimental manipulation predicted. From this viewpoint, every environmental impact statement is a hypothesis, to be tested by careful monitoring of subsequent events. The big difference is in the reaction to predicted events. In a field experiment, the ecologist simply measures and records the effects of his manipulation. In an impacted environment, corrective measures (mitigations) must be applied to prevent health hazards, resource loss, or other forms of degradation.

DESCRIBING THE ENVIRONMENT

Ecological analysis begins with a description of systems subject to impact using the hierarchy of abstractions which ecologists have developed to explicate the scope and level of their concerns. The hierarchy can be viewed as a set of boxes within boxes. Species populations considered together are a community, the community and its immediate physical-chemical environment are an ecosystem, interconnected ecosystems occupying a similar climatic zone across a continent form a biome, and the layer of life on land and in the sea is the biosphere (Hinckley 1976). Only the biosphere is specifically mentioned in NEPA and then somewhat misleadingly in the phrase "environment and biosphere" (Council on Environmental Quality 1970). We easily forget the interdependence and essential parity of atmosphere, hydrosphere, lithosphere and biosphere as equally vital components of our global environment. The ecosystem occupies a central place in the hierarchy and provides the conceptual framework for much modern ecological research. Every ecosystem contains autotrophs (usually green plants) which capture solar energy, and heterotrophs (herbivores, carnivores, and detritivores) which consume the green plants, animals and organic debris. An ecosystem is open to gas exchange with the atmosphere as well as water-dissolved nutrient exchanges with the hydrosphere and the lithosphere. Measurements of caloric content and nutrient concentration for each major component of an ecosystem are quite possible and provide a baseline for subsequent measurements of nutrient cycling or biotic productivity. In short, both structure and function of ecosystems are being studied in many areas, yielding data of great potential value in impact assessment.

Unfortunately, the typical EIS is more apt to have lists of common or conspicuous plants and animals. These give some feel for the "nature of the place" but they do not provide a good starting point for the monitoring of change. Review of such a list permits only the conclusion that names have been added or removed. Furthermore, a list does not recognize the importance of many small, hard-to-identify organisms that contribute to the maintenance of a normal ecosystem. However, lists of economically important or rare and endangered species can be of value, especially when accompanied by density measurements, since subsequent changes in numbers per unit area or volume may indicate profound changes in the total ecosystem.

There is one measure, the diversity index, that may represent a compromise between a list of representative species and a comprehensive description of ecosystem structure and function. The concept of diversity as applied in the environmental sciences can be stretched to include several inter-related characteristics of ecosystems. "Habitat diversity" implies a wide array or an elaborate mosaic of habitats and micro-habitats. "Process diversity" is, however, a more dynamic concept alluding to variety in cycles and fluxes. For the purposes of this discussion, habitat diversity will be called "heterogeneity" and process diversity, "complexity," both being distinguished from "biotic diversity" -- a measure of species in an ecosystem.

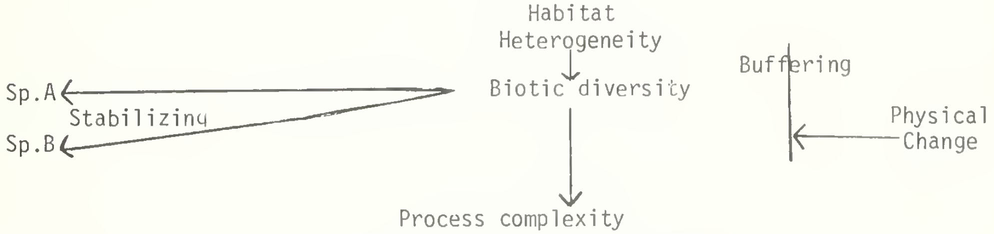
Although the discussion will focus on biotic diversity, it is recognized that heterogeneity contributes to biotic diversity by making possible the co-existence of species with different adaptations and requirements.

Furthermore, a complex web of processes is a logical certainty when many species share an ecosystem. Therefore, biotic diversity is a concept with both static-spatial and dynamic-temporal elements. It cannot be divorced from either heterogenous structure or complex function (Woodwell and Smith 1969).

Biotic diversity can be regarded as a non-renewable resource, although it is not usually included in that category (Hinckley 1976). To be sure, evolution will insure the eventual replacement of species driven to extinction but this process is measured in the same leisurely time-scale as the deposition of organic material creating fossil fuels. Biotic diversity is a heritage of evolution over eons and we should certainly try to understand its significance in ecosystems, and its possible value to us, before trifling with it.

It has been generally assumed that a species population is less apt to fluctuate widely in a diverse community, amplitude being dampened when the population "runs out of a requisite or runs into an enemy build-up." This diversity-stability link seems quite logical but it has been very hard to demonstrate in highly diverse communities. Furthermore, as E. Odum points out, "the extent to which an increase in community diversity -- can, in itself increase the stability of the ecosystem" under stress from weather changes and other physical fluctuations "has not yet been measured" (Odum 1971). In other words, diversity may contribute to "checks and balances" and it may provide buffering or redundancy, leading to greater stability at the population, community and ecosystem levels but the contribution of diversity to homeostasis at any level is not easily measured.

The concepts associated with diversity can be summarized in diagram form:



This will be discussed later in the context of impact assessment.

NATURAL CHANGES IN ECOSYSTEMS

In ecology, there have been no unifying theories on the scale of Darwinian evolution. However, many empirical principles have been developed through painstaking observations. One, almost a truism, is that ecosystems develop in a predictable sequence called succession. On land and in water, this is a natural sequence generally characterized by increasing biomass, species diversity and vegetation stature. In terrestrial environments, an open area is colonized by weeds, then grasses. Precipitation permitting, the sequence proceeds through shrub and shade-intolerant tree stages to a dynamic climax of shade tolerant vegetation. Characteristic animals are associated with each of these stages but the vascular plants are the primary producers and it is logical to use them in designating stages (Odum 1971).

In aquatic ecosystems, especially impounded waters, the sequence is similar. A new lake has little life but it is usually enriched by an influx of nutrients, colonization of plant and animals, and the eventual development of shore to shore vegetation. Pond -- marsh -- meadow is one example. In its early stages, at least, this form of succession is known as eutrophication.

Over decades of succession or during one annual cycle, an ecosystem may go through dramatic changes in its biological productivity. "Productivity" is a word with a common usage somewhat different from its application in ecology. A businessman may use it to describe a factory's output; an artist may use it in discussion of a painter's creations; but an ecologist is referring to the rate at which organic matter is produced. Although all biological productivity ultimately depends on some form of photosynthesis, it is often necessary to measure processes other than photosynthesis in order to delineate the productivity of an ecosystem. Green plants grow by storing part of the energy fixed photosynthetically; but much of the rest is used in the cellular respiration which keeps the plant's metabolic machinery going.

Plants also lose energy to heterotrophs through the process of death and decay.

It is useful to specify exactly the types of biological productivity being discussed.

gross primary production = the amount of solar energy fixed by photosynthesis in green plants.

net primary production = gross production minus that used in respiration of green plants.

net ecosystem production = net primary production minus that consumed by herbivores, and organisms of decay.

Characteristically, a late succession ecosystem (at or near "climax") no longer shows perceptible increases in weight over time, as it did during earlier successional stages. The amount of energy entering the system through photosynthesis is equal to that lost from the system through respiration, decomposition and consumption.

Since productivity measurements focus on the movement of energy through an ecosystem, they may miss important chemical changes. These are usually treated under the heading of nutrient exchange or, more broadly, biogeochemical cycling.

Two main groups, atmospheric and sedimentary, may be compared in order to discern similarities and differences. Key elements in cycles drawing primarily on atmospheric pools are carbon, oxygen and nitrogen. CO_2 is assimilated by green plants and fixed in carbohydrates through photosynthesis. It is released by respiration of plants, animals, and soil microorganisms, and by combustion of fossil fuels. Oxygen is involved in this cycle as a component of CO_2 and as a by-product of photosynthesis. Of course, oxygen is also entrained in the great hydrologic (H_2O) cycle of evaporation, atmospheric transport, precipitation and run-off. The nitrogen cycle can be said to begin when atmospheric nitrogen is fixed as nitrates through biological or industrial processes. The nitrate serves as a precursor of amino acids which, in turn, form the building blocks of all proteins. Through excretion, death and decay, nitrogen is released, passing through ammonium and nitrite stages to be reformed as nitrate or denitrified back to N_2. These movements of elements through atmosphere, biosphere and hydrosphere are well illustrated in the 1970 "Biosphere" issue of the Scientific American (also published during 1970 in book form by Freeman and Co.).

Sedimentary cycles include all those elements which do not form volatile compounds easily transported in the atmosphere. Sulfur has often been placed in this category but evidence is mounting that SO_2 from burning sulfur-containing fossil fuels provides, in the possibly undesirable form of "acid-rain," a large portion of the sulfur entering fresh-water and terrestrial ecosystems. Phosphorus is, perhaps, a better example of an element with a long-term sedimentary cycle. Phosphates are dissolved from rocks, taken up and used by organisms, eventually escaping from terrestrial ecosystems, being carried by run-off into the ocean. There phosphorus is not readily available to man unless reconcentrated by fish-eating birds in the form of guano. We also short-circuit the sedimentary cycle by mining phosphate rocks formed beneath ancient seas. Other elements such as calcium, magnesium, sodium and chlorine which follow the sedimentary pattern are more abundant than phosphorus, so we have not felt it necessary to accelerate their cycles.

All these patterns of change in ecosystems -- succession, productivity, and biogeochemical cycling -- antedate man and his technology. Our impacts may retard, accelerate or otherwise modify their roles and patterns (Detwyler 1971). This fact of modern life will be the main subject of the next section.

EFFECTS OF TECHNOLOGICAL IMPACTS

To build an impact analysis on the successional concept it is first necessary to include some reference to successional status of ecosystems described in the introductory section of an EIS. Then in the actual impact analysis it is possible to show how succession will be changed. A strip mine, for example, will take an ecosystem back to the earliest stages of succession. However, reclamation efforts in the same environment can be viewed as an acceleration of succession -- a combined strategy of reseeding, fertilizer application and, in some cases, irrigation being used to restore a facsimile of the original ecosystem. An EIS dealing with any management of living resources will also have strong successional components. Agriculture typically involves holding ecosystems in early successional stages characterized by quick growing vegetation with high net primary productivity. Forestry usually focuses on a longer time frame, mid-succession, with its conifers ready to harvest after 15 to 25 years.

One of the most important impacts in aquatic ecosystems can also be analyzed in successional terms. Fertilizer in run-off from farm lands or nutrients in the effluent of a sewage treatment plant are common causes of accelerated or cultural eutrophication. Algal blooms may be the immediate consequence with subsequent algal die-off, oxygen depletion and fish kills, but the process is no more than a variation on the natural pattern of nitrates and phosphate leaching from soil into water.

Many impacts can be viewed as causing reduced diversity, overloaded cycles and misplaced productivity in what otherwise might have been a normal successional sequence. Think of a hypothetical gradient from a highly impacted urban area through its suburbs into the surrounding farmlands and ending in a forest. Ecological measurements can be applied in impact assessment at different points along the gradient. The underlying assumption is that both a city and its surroundings should be analyzed at the same level -- as ecosystems (Hinckley 1976). Raw materials, food and water are inputs essential for the sustenance of the urban ecosystem; waste products are dumped by the city into surrounding ecosystems. This view lends itself to the quantification and mathematical modeling of impacts.

Although an ecological analysis of impacts can be based on a better understanding of ecosystems, succession, biological productivity, biogeochemical cycling and biotic diversity, it is wise to recognize the limits of these and other ecological concepts. We are trying to predict effects which will be detrimental to "the health and welfare of man." Ecological analysis can help us achieve this, but only in part, primarily because of three limitations:

1. insufficient baseline data for most ecosystems;

2. the stochastic (probabilistic) nature of many ecological changes;

3. imperfect linkage between ecological effects and their socio-economic consequences.

The gaps in baseline data can be filled by investing more time, money and expertise in pre-impact surveys. It is possible to make density estimates for many species of fish and wildlife, and some EISs already include these statistics. Additional effort could yield maps showing the successional status of nearby ecosystems very much as land use patterns are now displayed in master plans. It is also possible to gather and display data on biomass, nutrient concentrations and other aspects of ecosystems.

However, even a "perfect" data set would not guarantee infallible predictions of impact effects. This is a very basic limitation of all science. Still, some general predictions can be made with a high degree of certainty. In the Eastern Deciduous Biome, an abandoned farm will eventually become a hardwood forest. In a pond, a sudden input of dissolved nutrients will induce an algal bloom. For many different ecosystems, great stress or extreme simplification will be followed by outbreaks of tough, opportunistic pest and weed species.

If the prediction is to be more precise, the young science of ecology may be put to a severe test. Just as the meteorologist can predict snow in winter, and the seismologist earthquakes in California, it is easier for the ecologist to state sweeping generalities rather than saying "what will happen when." This is a great challenge to those developing mathematical models of ecological phenomena. As their models begin to capture the true heterogeneity, diversity and complexity of ecosystems, and to utilize real-time data, they will be able to detect and project many important trends associated with impacts. An ideal EIS would be based on such models and would specify the monitoring procedures to be used in validating predictions. A related element in the EIS would be a specification of techniques to be used in mitigating impact effects as they occur. This is a far cry from stating "if problems develop, they will be dealt with."

The final limitation, imperfect linkage between ecological effects and socio-economic consequences, may be the most important. The language of NEPA is clearly anthropocentric. We are protecting the environment for our own good. Unless it can be shown that an impact will increase hazards to human health through physical or chemical pollution, or reduce the resources available for future consumption, we must look to laws other than NEPA for protection of environmental quality. An administrator or a judge will ask ecologists why diversity reduction in an ecosystem is of any importance to the human species. The answers to this question, and others like it, are so important that they deserve a separate section.

EFFECTS OF ECOLOGICAL CHANGES ON HUMAN HEALTH AND WELFARE

The human species must be considered as part of nature. Any man-nature dichotomy is false and misleading. We have, through civilization, increased our control over certain aspects of our environment, by fighting pests and pathogens, extracting renewable and non-renewable resources, and building our urban ecosystems. However, "increased control does not equal reduced dependence." We remain thoroughly enmeshed in the web of life and completely dependent on it.

With that world view (Elder 1970), ecological changes should be taken quite seriously. A reduction in diversity may mean the loss (local or global) of a unique species of great potential interest and value. Carried further, the reduction in diversity can be a prelude to outbreaks of the very organisms we consider hardest to control with chemical warfare. A simplified ecosystem is a precarious one.

Accelerated succession or "galloping eutrophication" remains a major problem in freshwater ecosystems. Green water is but a warning of worse things to come. When the algae die off, the water becomes unsuitable for drinking and unpleasant for recreation. As nitrate concentrations increase, there is the threat of methemoglobinemia affecting babies and livestock nitrate converted to nitrite in their digestive system enters their blood stream and combines with hemoglobin impairing oxygen transport (Novick and Cottrell 1971).

Many toxic chemicals can be entrained in biogeochemical cycles with varying degrees of hazard to the human species and to other species valued by mankind (Woodwell 1967 and 1969). The transport of radioactive isotopes and chlorinated hydrocarbon (DDT, PCB, etc.) from atmosphere to hydrosphere and biosphere are one group of "horrible examples" to be kept in mind when discussing the waste disposal aspects of a project or program. The continuing tragedies of heavy metal poisoning in Japan, first mercury, then cadmium, now chromium, must also be remembered. Toxic chemicals caught up in natural processes and cycles have a way of coming back to haunt us.

Finally, impact assessment must consider the continued reduction in biological productivity. Erosion of fertile top soil remains the most important environmental problem throughout much of the world (Eckholm 1976). This breaks the link between the nutrient storehouse of the lithosphere and the ecosystems of the biosphere upon which we depend for food, fiber and wood. Near cities, productivity is reduced by paving over some of the most fertile lowland soils. If NEPA-like legislation on the protection of productivity is ever enacted, this is one area where ecologists, agronomists, and economists would all agree that a resource has been lost.

CONCLUSIONS

Any one project may make apparently inconsequential contributions to diversity reduction, succession acceleration, pollution increase or productivity curtailment. This is a good reason for moving away from project by project impact assessment and into the realm of regional planning. Only then can incremental and synergistic problems be anticipated and prevented. This would require national legislation on land use or a great expansion of NEPA to cover federal, state and private projects.

Even within the NEPA framework, policy and procedures can be greatly improved by taking advantage of existing ecological concepts, data and mathematical models. Ironically, pre-project environmental research has produced a wealth of information which is used inefficiently. Impact assessments should use, whenever possible, information from earlier studies in the same or similar ecosystems, rather than having each one "start from scratch." There should also be much greater cross-transfer between impact assessments and basic studies, especially those done under the International Biological Program in various biomes (National Academy of Sciences 1974). A handbook containing representative data sets on ecosystems would help accomplish this, although the statistical and geographical limits of the data sets should be made clear.

There is also a great need for continued efforts to improve the predictive capability of ecology. This requires both empirical and theoretical advances. We need more data on natural processes and trends, and their interactions with stresses imposed by urban or agricultural technologies. We also need better understanding of the relationships between ecosystem heterogeneity-diversity-complexity and the homestatic mechanisms regulating the population dynamics of each species in an ecosystem. It will be some time before we can state "there is a 70% chance of an impact-induced outbreak of pest x during the next 5 years." Still, early warnings of problems are worth the effort.

An extension of this approach can help clarify relationships between impacts in ecosystems and adverse (or beneficial) effects in social and economic systems. To be sure, this will bring us into an area of conflicting value judgements. Ecologists still mourn the extinction of the passenger pigeon yet many farmers were glad to see the last of what they considered a grain-eating pest. Right now, however, we are guessing about many effects and this uncertainty clouds our judgments. As we see more clearly what we are doing to our environment, and how much we depend on it, we may finally achieve the "productive and enjoyable harmony" we so desire.

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EVALUATING THE EVALUATIONS: A REVIEW PERSPECTIVE ON ENVIRONMENTAL IMPACT ASSESSMENT[1]

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INTRODUCTION

It has now been almost seven years since the beginning of environmental awareness in the late 1960s and the consequent passage of the National Environmental Policy Act in 1970. In the intervening years since the passage of NEPA, there has been a proliferation of Environmental Impact Statements (EIS) of varying quality from a variety of federal agencies. Early in 1970, many federal agencies chose to either ignore NEPA or prepared Environmental Impact Statements which were of rather low quality.

Two events occurred within one year which basically altered the course of the Environmental Impact Statement. The first event was the decision in April of 1970, when the trans Alaska pipeline case was taken to federal court and the determination was made that the Secretary of the Interior must meet the legal requirements of NEPA. The second major event which occurred, the Calvert Cliffs decision, was related to the operation of a nuclear power plant in Maryland. This decision was important because it elevated the preparation of Environmental Impact Statements from their former status of pro forma reports to required technical documents which must be produced before federal permits for major projects could be issued. In short, the Calvert Cliffs decision converted the Environmental Impact Statement process from one which was primarily preoccupied with form and format into a process concerned primarily with the substantive issues of the nature and extent of environmental effects. This paper will deal only with ecological assessments which are but a part of an EIS. We will not discuss EISs or environmental reports in their entirety, but rather only one aspect of them --ecological assessments.

[1]Text of oral paper presented at the AIBS symposium "Biological Evaluation of Environmental Impact." New Orleans, Louisiana, June 2, 1976.

While the Council on Environmental Quality has developed guidelines to provide procedural guidance for the preparation of environmental impact statements (c.f. The Fifth Annual Report of the Council on Environmental Quality, 1974 (1)), the technical approaches for meeting EIS objectives are not always available or universally accepted. As a result, there have been a number of methodologies developed in a variety of attempts to meet this need. Despite the proliferation of ad hoc methodologies for the preparation of EISs, there is no single methodology which adequately assesses the effect of major projects on the interrelationships between man and his environment nor, for that matter, adequately assesses the impact of a project on lower organisms or the physical environment. The reasons for this deficiency in EIS preparation and analysis are numerous and varied, ranging from the fact that ecosystems are extremely complicated to the observation that institutional problems have arisen which unnecessarily create obstacles to rational environmental impact assessment. Further, the sheer number of environmental impact statements which have been produced prevent adequate EIS preparation since there probably are not enough trained personnel in the environmental sciences to carry out the work. Our estimate today is that some 7,000 to 8,000 EISs have been prepared since 1970 (CEQ 1974).

This paper will explore some of these problems by first examining the role of the U.S. Environmental Protection Agency in reviewing Environmental Impact Statements and discussing the adequacy of ecological assessment methods, then drawing some conclusions and offering some suggestions on ways to improve the quality of ecological assessments.

While all federal agencies have the opportunity to review and comment on EISs, EPA, by virtue of Section 309 of the Clean Air Act, has been placed in a special review role. This section of the Clean Air Act requires that EPA comment in writing on the environmental impact of newly authorized federal actions or legislation posed by other federal agencies. In the event that the Administrator of EPA determines that any such action is environmentally unsatisfactory or of concern, he will publish his determination and refer the action to the Council on Environmental Quality. As a consequence, EPA reviews essentially all EISs prepared by other federal agencies. The job of principal reviewer of an EIS within EPA is a task which is generally assigned to the EPA Regional Offices. This job consists of reviewing the EIS, verifying input from associated EPA reviewers, assessing the importance of the potential environmental effects of the project, preparing the Agency's formal comments, and finally providing assistance to other agencies to minimize the impact of the project. If, however, the project involves a high degree of national controversy, or if the comments are setting new agency policy, then EPA's comments are coordinated through its Office of Federal Activities in Washington, D. C. Research personnel are seldom asked to serve as the principal reviewer, but do provide required technical assistance to the principal reviewer and the Office of Federal Activities.

To simplify and improve EPA's comments on EISs, EPA recently developed a rating scheme (EPA 1976) for reviewing both draft and final EISs. This rating process essentially forces the principal reviewer to comment not only upon the environmental acceptability of the project, but also in the draft EIS upon the adequacy of the EIS itself. This will hopefully assist the originating agency in its preparation of a final EIS. The nature of this rating procedure provides that comments on the draft EIS be designated in one of three categories. These categories are LO, ER, or EU, which signify EPA's assessment of the potential environmental effect of the project. In addition, a number (1, 2, or 3) is also added which signifies EPA's evaluation of the adequacy of the draft EIS. The following description of each of the evaluating symbols has been taken from the EPA manual (EPA 1976).

a. LO (Lack of Objections)

EPA has no objections to the proposed action as described in the draft EIS or suggests only minor changes in the proposed action.

b. ER (Environmental Reservations)

EPA has reservations concerning the environmental effects of certain aspects of the proposed action as described in the draft EIS. EPA believes that further study of suggested alternatives or modifications is required and has asked the originating Agency to reassess these aspects.

c. EU (Environmentally Unsatisfactory)

EPA believes that the proposed action is unsatisfactory because of its potentially harmful effect on the environment. Furthermore EPA believes that the potential safeguards that might be utilized may not adequately protect the environment from hazards arising from this action. EPA recommends that alternatives to the action be analyzed further (including the possibility of no action at all).

An EU rating is based on the following criteria:

1. It is highly probable that a federal, state, or local standard will be violated either directly by the project or indirectly if it can be demonstrated that the project will likely create future development which will itself cause a violation of existing standards.

2. Where the federal agency violates its own substantive environmental requirements which relate to EPA's areas of jurisdiction or expertise. For example, the project will violate federal highway administration guidelines or specifications on noise or air quality.

3. There is a violation of an EPA policy declaration. For example, it may be that the EPA policy regulating stream flow prepared pursuant to Section 102(b) (3) of the Federal Water Pollution Control Act amendments of 1972, may be violated.

4. Where there are no applicable standards or where applicable standards will not be violated but there is potential for significant environmental degradation which could be mitigated by other feasible alternatives (not including the no project alternative).

5. Where there are no applicable standards or where applicable standards will not be violated but there is potential for severe environmental degradation relating

to EPA's area of jurisdiction or expertise.

In addition to the ratings described above, the adequacy of the draft EIS is also rated as follows:

1. (Adequate). The draft EIS adequately sets forth the environmental impact of the proposed action as well as alternatives reasonably available to the project or action.

2. (Insufficient Information). EPA believes that the draft EIS does not contain sufficient information to assess fully the environmental impact of the proposed action. However, from the information submitted, EPA is able to make a preliminary determination of the impact on the environment. EPA has requested that the originator provide the information that was not included in the draft EIS.

3. (Inadequate). EPA believes that the draft EIS does not adequately assess the environmental impact of the proposed project or action or that the statement inadequately analyzes reasonably available alternatives. EPA has requested more information and analyses concerning potential environmental hazards and has asked that substantial revision be made to the draft EIS.

Unlike comments on the draft EIS, comments on the final EIS do not use categorical notations. Instead, principal reviewers rely on narrative explanations to describe the responsiveness of the EIS to EPA's comments or to describe the agency's assessment of environmental impact of the proposed action. In spite of the fact that EPA does not use notations on the review of final EISs, comments generally fall into one of four major categories. First, the originating agency has responded satisfactorily to EPA's comments on the draft EIS and EPA expresses no objections to the action as proposed. However, it should be emphasized that this is not an approval or endorsement of the agency's action by EPA. Second, the environmental impact of the proposed action is of sufficient magnitude that EPA has environmental reservations concerning the project. EPA believes that further study of suggested alternatives or modification is required and has asked the originating agency to reassess these aspects. Third, the reviewer determines that the proposed project or action is unsatisfactory from the standpoint of public health, welfare, or environmental quality, necessitating a referral of the project to CEQ. Fourth, EPA has determined that it is difficult or impossible to assess the environmental impact of the proposed action because the final EIS has not responded to comments made by EPA on the draft EIS or due to an inadequately prepared final EIS. Such comments may also be offered if new environmental concerns have been brought to EPA's attention since the review of the draft EIS and the originating agency does not adequately evaluate these factors in the final EIS.

With this introductory material as background, we will now review the adequacy of some specific examples of ecological assessments so that we can evaluate whether or not there may be further ways of improving EISs. This discussion will, as mentioned above, be devoted solely to the ecological assessment aspect of the EIS and not to a total environmental assessment.

REVIEW OF SELECTED ENVIRONMENTAL IMPACT STATEMENTS

THE LAKE TAHOE EIS

The final Environmental Impact Statement on the Wastewater Treatment and Conveyance System in the North Lake Tahoe-Truckee River Basin provides a classic example of a problem encountered in numerous EISs. Briefly stated, the problem is that either too much data which are not relevant are collected or data are collected but are not used in the evaluation of environmental impact. This may lead to the generation of data for its own sake. Let us look at a specific example. In Chapter 1 of the Tahoe EIS entitled, "The Environment", we find data on vegetation types, rare and endangered species, hydrological balances, flow rate of the Truckee River, air temperature, precipitation, water quality and a number of other environmental factors. In the impact analysis section of the EIS, the unavoidable impacts on the Truckee River of the major interceptor system and the regional wastewater treatment plant at Martis Creek are discussed separately. The following is a direct quote from the analysis of the treatment plant at Martis Creek (EPA 1974):

Impacts of a Regional Wastewater Treatment Plant at Martis Creek

A tertiary treatment plant is proposed to be constructed at the confluence of Martis Creek and the Truckee River. An emergency storage pond will also be constructed to store raw or partially treated sewage in the event of process failure.

The construction of this plant will involve the conversion of 30 acres of sage brush habitat to use as the locale of sewage treatment facilities. This land presently serves as the range of summer deer and other wildlife, and some individuals will be lost due to the conversion of uses. The land in question is by no means unique within the Martis Valley.

During construction of the facility, as well as during its normal operation, the noise level in the area will increase, causing a disturbance to the wildlife occupying the surrounding lands. The generation of odors may also disturb animals in the area, and possibly cause a human nuisance as well.

The construction of a treatment facility at the proposed location will result in a long-term adverse aesthetic impact.

That is the entire analysis of the direct impact associated with the treatment plant. Each of the alternatives to the proposal plan are also treated in a similar superficial manner, as is the analysis of the interceptor line and the secondary impacts of the project. Why then are 81 pages of environmental data of various sorts collected and never used in the impact analysis? This is a common trap that many professional ecologists fall into as well. In fact, even The Institute of Ecology (TIE) in its review of this particular EIS asked for data that would be very difficult to use even if they were available. For example, TIE states "standard water quality indicators such as coliform counts must be supplemented with additional assays. This is necessary because of the extremely oligotrophic conditions at Lake Tahoe.... We realize that direct counts are not considered standard procedure in water quality analysis. However, given the unusual clarity and low nutrient levels in Lake Tahoe, special standards need to be established." Is the purpose of collecting these data for long-term water quality monitoring of Lake Tahoe or is it for analyzing the effect of this specific project? If the purpose is the latter, how will the information be used to make the necessary predictions? What models or other techniques are available to make these predictions? Asking for more data is a common fault in the scientific community which each of us would have difficulty denying. However, the obligation is on the scientific community to know how the data will be analyzed and to what use the analysis will be put.

The Atchafalaya Basin

Let us examine another ecological assessment that will provide additional examples of problems that are presented to reviewers of EISs. These comments are based on information contained in a preliminary draft EIS of a project in the Atchafalaya River Basin (COE 1974). Let me repeat that the comments are based on a preliminary draft which was circulated for comments about one year ago and not upon the current draft EIS of this project. This example is being used for illustrative purposes only.

The Atchafalaya Project is an extremely complex development that involves many features, including the deepening and widening of the main channel of the Atchafalaya River. The habitats to be affected are also wide ranging, varying from Cyprus-Tupelo swamps to bottom land hardwoods, and from large open lakes to small bayous. While there are several deficiencies in the ecological assessment itself, there are two particular examples in this EIS which are common to many similar project statements. Emphasis in the assessment is placed on loss, gain, or alteration of acres of land or water rather than on change in habitats, biota, or ecosystem processes. For example, the ecological assessment section states "channel enlargement right-of-way will require 5,400 acres of land. Completion of these features will require modification of about 44,290 acres of forest land." To the reviewer of the EIS such statements do not convey much information and actually raise more questions than they answer. What kind of habitats are on the land? What kind of forest land? Obviously, modifying 44,290 acres of Cyprus-Tupelo swamp is considerably different from modifying 44,290 acres of Willow. Since there is an enormous amount of aerial photography already available, it should be relatively easy to determine the habitat types that are being impacted.

Another problem with ecological assessments in general which the above statement typifies is that circuitous arguments are presented which evade the point or in some cases apparently convey misleading information. Here are two examples from the Atchafalaya preliminary draft EIS:

"The loss of wildlife resources resulting from elimination of habitat cannot be quantified with the presently existing information. It is believed that the adverse impacts to the terrestrial wildlife will be moderated by the availability of backup habitat adjacent to the area influenced. It will act to absorb animals displaced by elimination of land area. Relocation of wildlife will increase the competition in the remaining areas by increasing the population densities. Deterioration of the remaining habitat may occur until the animal population is stabilized."

It can be seen that this statement simply evades the point that lost habitat is irreplaceably gone which reduces the carrying capacity of the area.

A second example is that the EIS stated that habitat was not limiting bald eagles in the basin. Why is it believed that lack of habitat is not a constraint to the eagle population? If it is reasonably assumed that habitat is not the factor which is limiting populations in the area, we need to know what is the limiting factor. Habitat destruction is beyond doubt one of the principal reasons for decline of the bald eagle. The Atchafalaya Basin is a reasonably large area of diverse habitats, but it is not sufficiently large nor sufficiently undisturbed that it can continue to suffer further habitat loss or modification without affecting wildlife significantly. A discussion of the ecology of the bald eagle and its environmental requirements would be necessary to confirm the statement that lack of habitat is not a constraint to the eagle population.

The Colony Development Operation

In addition to the federal government which is required by law to file Environmental Impact Statements, the private sector has also been involved in the assessment of environmental effects of major private development projects. An example of this style of environmental impact assessment is contained in the report "An Environmental Impact Analysis for a Shale Oil Complex at Parachute Creek, Colorado", which was written by the Atlantic Richfield Company (ARCO). In this assessment, ARCO has examined the proposed Colony Development Operation which includes the construction of a commercial shale oil mine, plant, and related on-site facilities near Parachute Creek, Colorado. This analysis was prepared as a comprehensive project document and includes a description and evaluation of the plant complex, the underground mine, a product pipeline from the plant to a connecting pipeline at Aneth, Utah, plant related off-site facilities, utility and water supplies, and required socioeconomic features. As a part of the overall report, further technical documentation was also included as Appendices to the report and substantial documentation from the open literature was made available. The assessment was conducted in four parts including the description of the construction and operation of the plant and mine, a detailed examination of the environment of the Parachute Creek Basin, identification of the sources of environmental impacts related to this portion of the proposed activity, and accumulative analysis of the effects of these impacts on the local environment. In addition, a pipeline which will be used to transport a slurry is also examined including the effect of this pipeline on blocking of animal migration routes. There is a general socioeconomic analysis which evaluates the areas of the Colorado River corridor from Grand Junction to Glenwood Springs.

The analysis itself is an example of an improvement over most EISs in many respects. Rather than simply enumerating endangered species, or making species lists of organisms there was an actual assessment of probable impact. To summarize the assessment of impact, the Colony report presented a matrix of potential environmental impacts which denoted the effects as being negligible, minor or major. In addition, different aspects of the operation were evaluated with respect to a number of environmental components. For example, the processing complex, mine, mine vents, conveyors, processed shale disposal embankment, etc., were all evaluated with regard to effect on climate, geology, soils, air quality, vegetation, fauna, aquatic organisms, etc. The evaluation of ecological effects included such things as an assessment of the likelihood and extent of destruction of plant communities, their associated animal communities, and the length of time over which the impact would be felt. In addition to direct effects on plant communities, there were also studies on the probable impact on aquatic invertebrates as well as other faunal types including species of major importance to man such as mountain lions, elk, golden eagles, mule deer, bobcats, and a variety of other large, relatively important species. In those instances where environmental impact was considered to be major, the matrix was so noted and a more detailed discussion of that impact was presented. This process enables the reviewer to look at a condensed version of most probable impacts of the proposed action and then, where warranted, ask for more indepth and detailed information. In this way, data which are available can be optimally used and redundant or irrelevant data are not collected.

WAYS OF IMPROVING EISS

Ways of improving Environmental Impact Statements might be broken into two categories: (1) institutional and (2) technical. These categories, as we shall see, are interrelated and affect each other. Both are equally important and ecologists can and should play a role in both areas. First, let us discuss the institutional problems. Wali (1975) very correctly states two major problems of writing good ecological assessments. "One, that we had very little information at the micro scale essential for these impact statements, and two, that we had to race against time. The time available to the ecologist evaluating an impact is usually ridiculously short relative to ecosystem development." The solutions he proposes in his final paragraph are that "We must educate our friends in need of environmental impact statements, whether in government or private enterprise, about the time element involved in assessing a biologically oriented ecological problem." And secondly, "Every impact statement writer will have to be an ecologist, and a good one." Let us analyze what Wali has said. First, that every impact statement writer has to be an ecologist, is simply untrue. A good Environmental Impact Statement contains far more information than a biologically oriented ecological assessment. A good EIS contains an analysis of the project on man's total environment including effects on socio-economic factors, such as displacement of families, employment requirements, building materials (resource requirements), community cohesion, effect on supply or cost of energy, and a variety of others. Consequently, the statement could be made that every EIS writer must be an ecologist. What is true is that EISs must be written by a multidisciplinary team, and that one member of that team should be a good ecologist.

Two other problems mentioned by Wali are really closely related, that is the lack of information at the micro scale, and the need for time. If indeed there was an enormous amount of data at the micro scale, then the time to assess the effects of a project could be greatly reduced. If we lived in an ideal world we would get the necessary time to collect data at the microscale and undertake a thorough analysis of the ecological effects of a project. Unfortunately, in most cases our society has not seen fit to give us the necessary time, nor do we anticipate that in the near future we will be given time or money to undertake the ideal assessment. Ecologists must learn to play the game by the rules that are presently in force and do the best job that they can within those constraints. At the same time ecologists should continue to try to change the rules, not by breaking them or refusing to play the game, but by educating our friends in need of ecological assessments of the problems involved, by running for public office, by helping people who understand the problems become elected, by accepting appointments to key positions within the government. If ecologists are not willing to become politicians and lawyers are, then ecologists will continue to play the same position as in the past.

Part of this role is to accept the fact that ecology will not be funded for research and assessment at the same level as will health effects work or energy development research. This is because federal agencies, and the elected officials that the agencies report to, are swayed by public opinion. When the general public sees high unemployment and rapid inflation they may tolerate environmental controls for health reasons, but not for ecological reasons, which they view as saving the bunnies and the bees. The reasons for these attitudes are:

1. Ecologists have not convinced politicians or the general public of the importance of the functioning of ecosystems or genetic diversity.

2. Ecologists don't have the credibility with the general public that they deserve because of the multi-meanings for the word ecology, and the fact that there are many poorly qualified individuals working as consultants on ecological matters. Professional certification of ecologists might alleviate some aspects of this problem.

In spite of institutional constraints there are ways of improving ecological assessments within the present system and within present funding levels. These improvements may be slow in coming, and EISs are going to continue to be written before changes can be implemented.

First, an environmental monitoring program should be established. The environments surrounding projects which have been constructed need to be monitored over time to determine the accuracy of the effects projected by the EIS.

A second problem that needs to be solved is to improve access to the literature. When reviewing Darnell (1975) two points are particularly striking. It is well recognized that there is a large gap in ecological knowledge about the functioning of wetland ecosystems and the effects of specific perturbations. However, the knowledge which we do have about wetlands is rarely used. Darnell reported significant work in widely scattered places and in hard-to-find reports. Somehow, we need to find a way to better utilize existing information. Just the use of this existing information in assessments would improve most EISs considerably.

We must use up-to-date modern methodology and techniques, rather than those taught in undergraduate ecological courses ten years ago. There is a need to adapt existing models to ecological assessment functions. This is really a two part task, one step is to develop simplified instructions and manuals for using possibly complex systems models. The second step is to develop simple models such as the one developed by Vollenweider for predicting levels of eutrophication. These simple models are far from perfect, and they may only give a gross prediction of what is going to happen, but considering the political, time, and financial constraints that ecologists are working within today, they become very necessary. Whatever models are developed and used, ecologists must temper the results with common sense and with knowledge of local conditions and life history information of critical species.

In addition, ecologists need to fill gaps in knowledge with both basic and applied research on specific perturbations. A change in the approach for identifying these gaps, particularly on functioning of ecosystems, needs to occur. In the past individual investigators looked for gaps and submitted grants proposals for their studies. While this type of mechanism needs to continue, another system has to evolve. That is for the Ecological Society, The Institute of Ecology, or National Academy of Sciences to appoint a committee that critically examines the literature available on different ecosystems and identifies which systems or functions within the system have the biggest gaps, and where research is most urgently needed. The report from such a committee could be used by granting agencies in program development and proposal review.

Next, standards that are being developed now and in the near future are going to be based largely on human health considerations. Research is needed to determine what effect this level of contamination will have on ecosystems. Are ecosystems sufficiently resilient to withstand pollutant loadings up to the level that protection of human health would allow? Such low level pollution loads can and do affect organisms, but the systems may remain viable with minimal loss of genetic diversity. Such a group of studies would prove invaluable in improving the quality of EISs, and the quality of reviews that EPA could provide.

While the idea of indicator species has lost much of its appeal, we need to reexamine this concept and try to develop either indicator species, key species concepts, or community impact measurements. In this connection it is recognized that insults to the environment from rather diverse sources (toxic substances, pesticides, radiation, disease, and adverse climate) produce a similar array of effects at the community level in spite of very different effects on individual organisms studied under experimental conditions. The response mechanisms may vary, but overall results are often similar: (1) a reversal of succession or simplification of ecosystem structure (Whittaker 1953, 1969, 1970); (Woodwell 1962, 1967, 1968a, 1970, 1973); (2) a reduction in the ratio of photosynthesis to respiration; and (3) a reduction in species diversity at more than one trophic level, which may include the elimination of certain species (Woodwell 1962, 1967, 1968a, 1973). Effects may be temporary and reversible (i.e., the system adapts) or chronic and cumulative. In any case, we recognize that large environmental impacts will be registered as a diminution of alteration of community structure, complexity, and function (Woodwell 1968a, 1973).

Further, we recognize that both plant and animal diversity and energy transfer between and within trophic levels are measures of community structure. These functions may be regarded as important ecosystem resources. We hypothesize that the immediate population-level effects from environmental stress may result from differential impairment of competitive ability. At relatively low pollution or environmental impact levels we may expect to find predisposing chronic or subclinical effects that would be difficult or impossible to detect or predict in the absence of appropriate population dynamics, biochemical, and physiological information (Glass 1975).

Adverse impact need not necessarily be caused by alterations in food chains or energy flow. Certainly food chains and mass energy flow patterns will be affected. For example, a pollutant may alter the physiology or behavior of the individuals that comprise a population. These alterations are ultimately reflected in altered survival, reproduction and/or emigration rates. Such effects may be subtle and difficult to relate to the specific stressor. In the real world numerous stressors are operating in complex ways with various lag times; these tend to confound the results of any of the field evaluation of a single stressor. The end result of the response of the community to a continued environmental stress is a readjustment of the component populations (plant and animal) at a new state of dynamic equilibrium. It is not possible to predict with any confidence, either the adjustments and mechanisms most importantly involved or the final population levels that will be reached. Such studies are generally very time consuming and expensive. It is for this reason that we search for key taxa or species which can serve as integrators "of environmental impact", and perhaps simplify the process of ecological impact assessment.

In the State of Oregon for example -- as long as water quality of the Willamette River is sufficient to protect chinook salmon and steelhead, we believe the system is going to remain as a viable, functioning ecosystem, with diverse resources utilizable by man. In addition to protecting sensitive ecological species we would have to identify and protect rare and endangered species. While it is true that in the world of ecology everything is somehow related to everything else, it is necessary to identify those key species for man and concentrate on them. Again, as with the previous suggestion, the ecologist must use caution and common sense in which communities and which species he picks.

Next, many ecological assessments contain massive species lists, which by themselves generally don't contribute to the reviewer's understanding of potential effects. It is recognized that this subject is highly controversial, but from a reviewer's point of view there have been only a very few EISs where species lists have proved to be valuable in and by themselves. They are generally included because they happen to be readily available. Ecological assessments would be greatly improved if they contained short concise descriptions of major communities and briefly discussed the most dominant species. The assessment should contain information on the "successional stage" of the system; are we dealing with a eutrophic situation or an oligotrophic one? What is likely to be the ecological succession of the area if the project is not built?

The next suggestion deals with EISs in general as well as ecological assessments specifically. The purpose of NEPA was to give decision-makers information on the environmental effects of their actions. The sheer volume of many EISs precludes any high ranking official from having the time to read the statement. Environmental assessments should become part of the project planning process and short, concise documents must be prepared for decision-makers, backup data and analyses can be contained in separate appendices for those desiring to delve into the conclusions and recommendations of the shorter document. Further, the implementation of NEPA has to change from a bureaucratic paper exercise to one in which environmental concerns and ecological effects are considered in the planning of projects.

Finally, decisions have to be made. EISs are going to be improved by ecologists facing the reality of having to predict effects based on their knowledge and information that may not be complete or be site specific. This is not to say that ecologists should never ask for additional field data. By all means do so when necessary but be sure you know why you want the data and how you are going to use it in the impact analysis. Also, this means you should temper your request for information by size of project and potential for harm.

This paper has presented EPA's role in reviewing EISs, discussed the adequacy of some ecological assessments and from this review perspective offered some suggestions for improving EISs. The authors believe that after six years experience with NEPA, and having been staunch supporters of NEPA, the time has come for CEQ and EPA to review the implementation of the Act, and consider significant changes. We should not do away with the requirements of doing environmental assessment work, but we should do away with preparing massive project justification documents. An environmental impact assessment should properly go into some detail on effects of proposed activities without spending too much time enumerating species lists. The environmental impact analysis must become part of the planning process, and EISs should become a public information document which will serve to monitor federal agencies, and provide for public dialogue on projects of major importance. The data requirements must be sufficient to provide for public dialogue and for intelligent decision-making.

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ECOLOGY'S FAMILY COMING OF AGE IN A CHANGING WORLD

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INTRODUCTION

"This symposium will focus on concepts and methods by which the biological significance of environmental impacts may be evaluated by ecologists and meaningfully described to decision-makers in the environmental impact assessment process." So reads the opening statement of the announcement prepared by its sponsors, the Council on Environmental Quality.

Consistent with what others have stated, the leading sentence can be analyzed into three aspects:

a) What are the biological aspects of an environment that are valuable? This invites the question: what are the relevant, socially recognized values and norms that determine the values of various biological aspects?

b) Which of the many ecological concepts and methodologies now available are directly applicable in practical dealings relating to the valued biological aspects?

c) How can relevant ecological insights and information be transmitted effectively to decision-makers?

We will not here address explicitly the first of these (see Regier 1978 for some suggestions). Instead we will focus on the last two and in the reverse order. Communication occurs largely within institutionalized settings in which the perspectives and methodologies of various groups may be very different though not necessarily discordant nor incongruent. If there is any single emphasis in this paper, it is that broad concepts and methods - within which widespread intellectual and practical congruency or compatability are already apparent - are developing rapidly.

The political process may be perceived as fathering such offspring as "environmental impact assessment." The mother by analogy may be identified as applied ecology, as a scientific-technical process. Earlier issues that resulted from this liaison include renewable resource management (fisheries, forestry, wildlife), public health programs (sewage treatment, malarial mosquito control, control of contaminants), programs to mitigate the externalized disbenefits of technological developments (multiple use, environmental design, land-use practices), and programs to preserve threatened species and ecosystems (parks, preserves, protection). A more recent issue is environmental accounting on regional, natural and global bases (monitoring, material flows, state of the environment).

The point to be made at the outset is that the environmental impact assessment process is only one of a family of some six or more major programs that have to do with the man-environment interaction. Neither the political process nor the ecological scientific process will likely expect it to deal with more than 15% of all that is of interest in that broader interaction.

We may extend the metaphor of the family (father, mother, offspring) by considering whether the grandparents continue to exercise authority. Of course they do. Here the grandparents on the mother's side, natural history and conventional biology, are of interest. In seeking to maintain rather old-fashion scientific norms and mores, conventional biology is making life difficult for two generations of offspring, i.e. ecology and the ecological transfer sciences. We address these issues next.

LIFE IN THE BIOLOGICAL HOME

Ecologists all through the western world, and derivative quasidisciplines working on environmental and renewable resource issues, are drifting further and further away from the automatic presuppositions and the dominant methodologies of their biological origins. Within the strongly hierarchic framework of conventional biology, ecology appears as a member at one end of the organizational sequence. Though free to move in one dimension, it is in other ways closely constrained. Perhaps the feature of conventional biology that is most constraining toward ecology is the traditional overemphasis in biology on a reductionist mode of inquiry.

To achieve full standing, a theoretical innovation should be analyzed at the very least to the organismal level of organization, preferably to the cellular level, and desirably to the molecular level. Or so it seems. Of all the sciences, conventional biology appears to be most strongly dominated by hierarchic reductionism.

The recent emergence of various applied ecologies may be recognized as a case of high fecundity and adaptive radiation following a great jump in perceived scientific opportunity and a great increase in socio-economic resources devoted to develop the opportunity. Whatever stimuli may have been responsible for their emergence, there now exist quite a number of incipient or protodisciplines being reared in part by a somewhat immature ecology.

The developmental process within ecology itself is far from stabilized. Meanwhile, the emerging challenges directed to its off-spring are not well specified. The institutions and instrumentalities that have recently emerged as political responses to socio-environmental concerns are quite immature or poorly formed; thus the nature of their demands is still changing quite rapidly.

GREATER CHALLENGES

From the perspective of *ecology as a component of conventional biology* the contents of this section may be interpreted as identifying some of the reasons why difficulties occur when adherents of different disciplines seek to collaborate on man-environment problems. For example, different presuppositions and inquiry systems as sketched in the first two subsections below make it difficult for well-meaning collaborators to communicate.

From the perspective of *ecology as trans-disciplinary way-of-seeing,* the contents of this section may serve to frame the larger context into which environmental science may now be moving.

A BASIC PRESUPPOSITION

A philosophical and scientific assumption of far-reaching influence holds that events now are a consequence of linear causal mechanisms, however complex, operating through the proceeding time interval. In itself that assumption may seem so obviously correct as to be quite uninteresting. Yet it is usually associated with other aspects of a mindset that is characteristically "Western," and some of these various aspects have been identified as predisposing us to the kind of man-nature interactions that have contributed to current difficulties.

Quite obviously, if an international working party that included experts from widely different cultures was convened to address a difficult, deep issue, one might expect some dissonance at the very basic level of presuppositions as to the nature of causal processes. The easy way out might appear to be to ignore such philosophical aspects, agree on "scientific methods" and get on with the task. If this degenerates into a poorly organized, ineffectual confrontation, then part of the reason may be attributable to neglect of initial steps of concept clarification. Alternatively, with recognition of deep differences at the outset, it may be possible then to pursue alternative proposals scientifically and eventually compare the outcomes of these studies as an aid to negotiation.

Deep differences of this nature are not only encountered internationally -- they also occur within nations as between, say, native peoples and those of European extraction. Little is to be gained in the long run on such matters by an overemphasis on methodology to the virtual exclusion of a consideration of concepts.

Ecologists' biases can also be separated into three types corresponding to a classification developed by Maruyama (1974). Ecologists who are content to work within the context of classical biological hierarchies and reductionist methologies may be characterized as "unidirectional causal". Other ecologists prefer probabilistic or stochastic models because they lean to the presupposition that certain mathematical or statistical formulations of randomness adequately mirror important properties of reality. Thirdly, there have long been ecologists who perceive homeostasis, as well as occasional creative or catastrophic surprises, consistent with "mutual causal" presuppositions. Ecologists find it difficult to agree on a clear definition of ecology, perhaps because there are important discords at the level of basic scientific presuppositions.

ALTERNATIVE INQUIRY SYSTEMS

Within broad philosphical-scientific approaches that are endemic to the West, a wide spectrum of alternatives exist. The names Leibniz, Locke, Hegel, Kant and Singer may stir recollections of philosophical subject matter of no great interest to most active scientific workers. Yet their various inquiry systems are immediately relevant to a consideration of interdisciplinarity of any appreciable scope (Mitroff and Turoff 1973), say with respect to a major impact assessment project.

Some social scientists have striven mightily to apply the inquiry systems characteristic of the natural sciences to their problems, to the general unhappiness of others who work within Hegelian or Kantian modes. Some of the much deplored relative disarray within the ranks of social scientists may be due to the existence of a wider range of inquiry systems employed by them. Within a social system that is relatively stable within broad limits, such diversity could be very useful in the long run. But in crisis situations their conflicting methods may well contribute to the general confusion. In particular natural scientists are often embarrassed and scandalized by the confrontational mode of some social scientists working contentedly within a Hegelian mode. By comparison they would feel less threatened by Kantians, though doubting that the latter are in any real sense "scientific."

Neither the more conventional natural nor social scientists are likely to be comfortable with political scientists or "broad generalists" working with a Singerian inquiry system. How can "discipline" be assured within such a flexible, relatively unspecified manner of study? In essence we address that question in the next section.

Consider ecology, broadly defined, from the philosophical perspectives. Many of the current ecological theoreticians and small-scale modellers use a Leibnizian inquiry system. Ecologists with a natural history outlook tend to be Lockean in approach. Workers in what we have called ecological transfer sciences may search for syntheses in a simplified version of a Kantian inquiry system. Other workers, expecially activists involved in confrontational legal or political proceedings, may in essence be playing roles in some broad though poorly specified dialectical process. Finally, ecologists working at high levels of government, or in the "planning system" of J.K. Galbraith, may have mastered the elements of the Singerian approach.

It is often the case that those scientists who have little understanding or experience with inquiry systems other than their own will dismiss the others as irrelevant at best. This weakness seems to be particularly common among Leibnizians, or Lockeans, which are the two dominant camps within biological ecology.

THE NATURE OF TRANSFER SCIENCE

Complex problems, for the solution of which new processes of technology assessments and regional planning seem to be emerging (see discussion of the Role of Environmental Impact Assessment), cannot be addressed adequately simply by applying "rote learning" -- no matter how prestigious or avant garde the university at which the learning occurred. Almost always there is an implicit need for creativity as well as for the more routine application of standard methods. Whereas the latter can be organized hierarchically to be cost-effective, the former -- creativity -- is not readily delivered on demand and thrives in less coercive lateral networks. This is one of the more frustrating aspects in seeking to make the new instrumentalities more effective: the old and often disruptive confrontation between pure and applied research must be transformed into something more productive.

Gregory (1975) has described an approach that deserves consideration (Table 1). The term "transfer science" appears to relate generically to a hybrid between analysis-based science (largely "basic," or "pure") and action-based science (largely "applied"). These three may also be termed mission-oriented, curiosity-motivated and program-dictated work (see Regier 1974 and Regier and McCracken 1975).

Table 1. The relationship of an interdisciplinary perspective on science to the conventional basic - applied dichotomy. The size of the crosses corresponds to the relative amount of the effort that current scientists (left column) devoted to basic and applied research (from Gregory 1975).

	Basic research	Elaborated applied research
Analysis-based sciences	X	x
Transfer sciences	X	X
Action-based sciences	x	X

Gregory also uses "transfer science" in a more specific sense when he states:

"A transfer science is always upstream of an important sector of activity. It is, in fact, owing to the pressure of this sector that each of these sciences is born, develops and continues to exist.

If their evolution is examined, it is seen that their importance and vitality are closely linked to the prosperity of the downstream sector from which they emanate and the rapidity of its evolution."

If we understand this correctly, then the environmental impact assessment instrumentality, say, is now likely evolving into a "transfer science", a quasi-discipline of an interdisciplinary sort and similarly with other instrumentalities or major programs as regional geographic planning, national environmental monitoring, establishing sovereignty and new regulatory procedures over economic-zone fisheries, etc.

Transfer sciences that address major issues spanning a decade or more of changing reality may inevitably take on the practical characteristics of disciplines. Practitioners may see no need for transcending conceptual frameworks in which to rationalize their methods -- conventional medicine and engineering have shown relatively little interest in such frameworks (and some would argue that they resemble art forms in this respect). The intensifying social demands for accountability of technology (Hetman 1973), whether based in science or art, may well entrain a deeper attention to conceptual matters.

The emergence of a full-fledged transfer science directed toward some major long-term ecological problem or opportunity may signal the graduation of the broader field of expertise, i.e. ecology, into a relationship of power within the hierarchy of disciplines associated with political authority. Benington and Skelton (1973) have used a concept by Arnstein (1969) related to citizen participation within the political process that might be adapted here for our purposes. For "citizen" we may substitute the protagonists for a particular transfer science or, for the sake of brevity, "discipline" in the sense of an incipient, proto- or quasi-discipline. Table 2 is our adaptation of the Arnstein concept.

If one examines in detail the actual modus operandi of the impact assessment process mandated under NEPA in the U.S. and under analogous political actions in Canada and elsewhere (Leopold *et al.* 1971; Jenkins *et al.* 1974; Munn 1975; Yorque 1975; etc.), then it seems that ecologists may not yet have reached stage six. But clearly the development of the impact assessment process, together with a variety of other initiatives such as pollution controls, land-use planning, environmental monitoring, etc.,

Degrees of power	8. "Discipline" achieves full scientific-technical recognition.
	7. Experts have scientific-technical power delegated to them.
	6. Leaders are invited as junior partners in the decision process.
Degrees of tokenism	5. Protagonist are placated when their views are ignored.
	4. Practitioners are consulted briefly in emergencies.
	3. Some workers are informed of new developments that may affect their interests.
Non-participation	2. Patrons arrange minor opportunity for growth.
	1. If recognized at all, workers are simply manipulated by members of disciplines higher in the power hierarchy.

Table 2. Stages in the evolution of the power status of a group associated with a paradigm destined to achieve greatness. (Adapted from a concept by Arnstein 1969.)

has coincided with some improvement in environment-related practices. Still it is fair to say that no major re-directions have yet been firmly institutionalized and this could all be reversed politically -- though not without some unpleasantness. Many practitioners of the dominant disciplines -- those that have achieved stage eight, such as economists, lawyers, engineers, physicians, educators, architects, militarists, etc. -- would be relieved to see the advance of ecology halted. Yet other workers in each of these disciplines are themselves committed to concepts concordant with those of ecology -- though in no case are these workers dominant within those disciplines.

It all seems to lead to the point that a large scale movement of the new ecology with its brood of six or more ecological transfer sciences into the echelons of disciplinary power will not be achieved without an additional major struggle. In some important ways, as already indicated, it will be viewed as subversive of that scientific -- technical power structure, and quite correctly so. Else it will cease to be ecology.

Other speakers at this symposium have called for a more comprehensive phased, step-wise approach to planning and decision-making concerning big projects. Expert ecologists should from the outset be brought in as collaborators on an equal basis with other scientific and technical experts. To us this would imply a move on the part of ecology from a status of "tokenism" to that of "power," i.e. from level four and five of Table 2 to level six, seven or eight.

ALTERNATIVE X's IN X-DISCIPLINARITY

Perhaps more than any other, the Organization for Economic Cooperation and Development (OECD) has been instrumental in clarifying both the concepts and methodology useful for interdisciplinary planning, research and decision processes (see e.g. Jantsch 1972 and Hetman 1973). Figure 1 depicts concise definitions of "disciplinarity" with various prefixes -- definitions that may well become standard in time. Additional prefixes may be encountered in the literature, but this appears to be a sufficiently comprehensive set for present purposes.

The minimum sufficient level of sophistication, for the various man-nature transfer sciences that appear to be evolving, is "interdisciplinarity" -- according to growing consensus. The "higher-level concept" (Figure 1) may be a transcending concept held in common by a number of conventional disciplines (as discussed below) or a more recently created concept to serve as the frame or focus of the transfer science.

The term "transdisciplinarity" as defined by Jantsch appears to relate to a more comprehensive social process than, say, the evolutionary development of a transfer science related to impact assessment.
The various emerging transfer sciences relating to man-nature problems, together with relevant conventional disciplines, could perhaps be addressed using Jantsch's model of transdiciplinarity as augmented by his extended discussion of the "science/education/innovation system."

Problem-solving capability may be perceived as a function of technical competence deriving from training and experience, available theory from earlier creative discoveries and critical tests, and accessible data in files or from the field. Regier et al. (1974) used this model to develop a concept of interdisciplinarity similar to that of Jantsch (see above). For present purposes we may note that competence, tested theory, and data stores may evolve through time into a mutually congruent and dynamically-reinforcing transfer science. Thus an attempt to achieve a new interdisciplinarity almost inevitably interacts negatively in some way with existing approaches. As the overall process with alternative higher level concepts matures it may be that the scientific

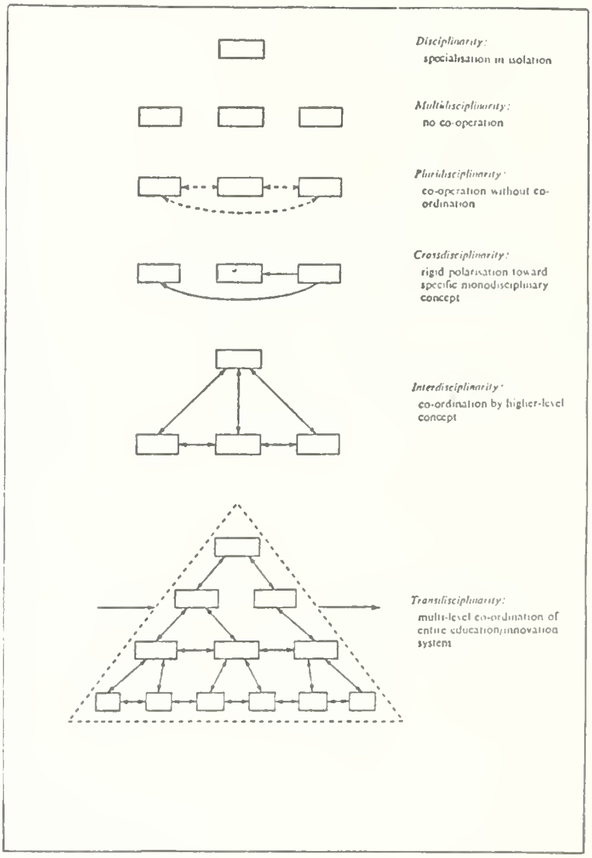

Figure 1. Some definitions of terms involving the root concept "disciplinarity". A strong trend from disciplinary reductionism to transdisciplinary holism has developed recently (from Jantsch 1972).

entrepreneurs and custodians of particular systems will increasingly compare their own current paradigm commitments with what might be implied in various interdisciplinary alternatives, and opt into one of the latter on a well-informed basis.

AVAILABLE THEORY

Some years ago we began investigating whether ecologically-based concepts used in the management of fisheries resources, water quality, forests, wildlife, range lands and farms were congruent within some appropriate classificatory framework. This led first to a search for such frameworks. Geographic and temporal scope and scale have long been used in this manner but did not in themselves seem sufficient. More or less static, structured models are about as common as dynamic, process models and this dichotomy was worth considering further. It happened that scope and scale considerations, the static vs. dynamic alternatives, together with some concepts such as level of ecological organization, could all be accommodated within a generalized two-dimensional framework. The dimensions selected were (1) size of individual species resources or stocks and (2) temporal and/or spatial fluctuations in the same resources or stocks (Figure 2).

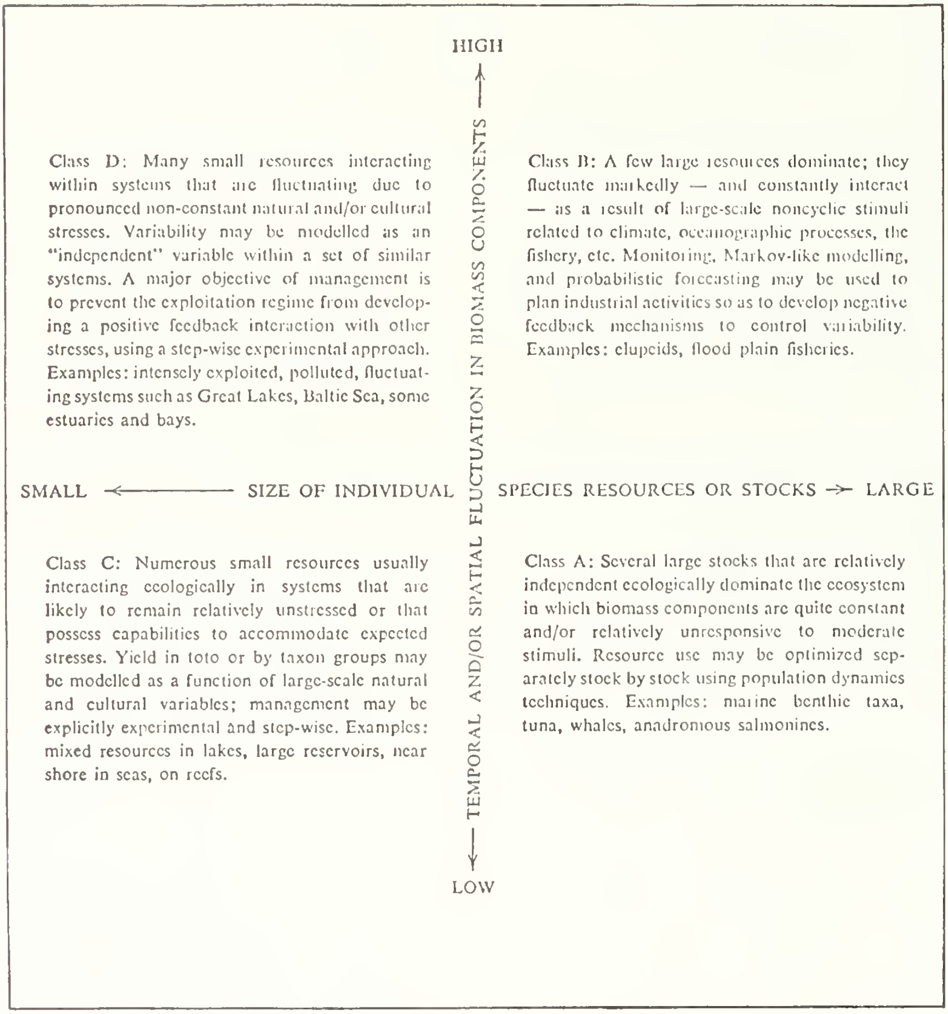

Figure 2. A conceptual model of four major cluster of problems related to fisheries exploitation. An analogous model may be used to classify pollution problems where pollutant loading takes the place of stock size or biomass. (Regier et al. 1974.)

The theoretical and practical significance of this framework has been developed further by Regier et al. (1974), Regier and McCracken (1975) and Regier (1976a, b). The point to be made here is that the ecological models that have been found to be useful by managers of different kinds of resources (fisheries, wildlife, forestry, etc.) tend to resemble each other within particular cells of the framework. Thus the ecological models used in fisheries for large well-behaved stocks are roughly congruent with those applied to wildlife stocks that are large and well-behaved, etc.

Further, to the extent that large fluctuations in unit resources may be due to large exogenous factors such as a varying climate, oceanic regimes, or major human processes, the ecological models for the affected terrestrial and aquatic ecosystems may be similar in essence. In this way, knowing where and how to search for them, it may seldom be difficult to identify appropriate candidate models to serve as higher level or transcending concepts in interdisciplinary ecological transfer science.

As depicted in Figure 2, the framework is a very rough one. Though it has been refined somewhat further in the references cited, it is not proposed as necessarily the best guide to finding common concepts within which to orient interdisciplinary transfer sciences. The important point is that frameworks useful for such purposes now exist and more can be discovered.

Consistent with the above but not necessarily implied by it, some elements of General Systems Theory (Bertalanffy 1962) may be exploited. In particular we note the emergence of resource allocation models in economics and ecology. As shown in Table 3, numerous commonalities among principles and concepts have recently been recognized between microeconomic and "microecologic" theory (Rapport and Turner 1977). These examples suggest that man's economic activities serve similar functions as the resource partitioning activities among species and that a set of higher order resource allocation principles may be sufficient to describe man-nature interactions in terms of an inter-species economics.

The similarities between economics and ecology have not yet been exploited to deal with practical resource management problems. The principles of comparative advantage as elaborated in international trade theory might be appropriate to discover the most beneficial trading patterns between man and nature. Such models of course should consider not only

Table 3. Some Commonalities Between Microeconomic and Ecological Theory (See Rapport and Turner 1975a, b, 1977; and Rapport 1971, 1980.)

Topic	Economics	Ecology
Consumer choice . . .	Theory of consumer equilibrium . . .	Optimal foraging theory (Rapport, Schoener, Charnov, Covich, Tullock).
Production . . .	Investment theory . . .	Life history strategies (Schaffer) Parental investment (Trivers)
	Production theory . . .	Foraging and population growth (Rapport and Turner)
	Contract theory . . .	Energetics of bumblebees (Oster)
	Optimal input mix . . .	Social caste system (Wilson)
	Location theory . . .	Central place foraging (Hamilton and Watt)
Consumer-producer interactions . . .	Theory of markets . . .	Community interaction (Rapport and Turner) Predator-prey interactions (Holling)
Competition . . .	Oligopoly theory . . .	Interspecies competition (McArthur, Rapport and Turner)

man's optimal harvesting of renewable resources but also a long-term balance in terms of a healthy natural ecology-economy. Or consider the propagation of booms and busts originating in man's economy into natural systems and vice versa. In the regulation of these "business cycles" what are the appropriate monetary and fiscal policies to apply to the economy of nature? Might not nutrient loading be equivalent to monetary inflation, and the selective harvesting of certain taxa be equivalent to classical fiscal policies?

This approach of commonalities is not here proposed to serve as the standard path to be taken by those economists who are interested in ecological engineering. Rather we are interested in developing insightful models of energy -- material -- balance flows between man and nature which will serve as a basis for developing viable long-term strategies for continued man-nature interactions in a viable interspecies economy.

In the foregoing paragraphs, *concepts* were stressed but appropriate corresponding *methodology* is not difficult to specify. But no matter what the broader concepts might be, three broad methodologies should always be used to complement each other: spatial mapping, temporal monitoring and relational or explicative modelling (Regier and McCracken 1975). Overemphasis or underemphasis on one or two of these will involve inefficiencies, both from a theoretical and practical viewpoint.

HOLISM AND REDUCTIONISM

Vickers (1973) has referred to ecology as follows:

> "The ecologist has a characteristic viewpoint. He looks at the total pattern of life in some defined habitat, in the belief that it constitutes one system. When he sees populations, of one species or another, growing or dwindling, oscillating or remaining strangely constant, he assumes that the regularities which make the pattern recognizable are due to the mutual influence which each population exercises, directly or indirectly on all the others and all of them on their common physical environment. This net of relations is what he needs to understand; and the only assumption he can safely make is that it is a net -- no mere tangle of causal chains but a field in which multiple, mutual influences are constantly at work ..."

The quoted excerpt is laced with the jargon of a "holistic" or "system" paradigm. Contrasting such an approach to an "atomistic" or "reductionist" alternative, Laszlo (1972) argues ... "characteristics of complex wholes remain irreducible to the characteristics of the parts" (p. 8); ... "The new scientists ... discern relationships and situations, not atomistic facts and events" (p. 13). ..."The systems view always treats systems as integrated wholes of their subsidiary components and never as the mechanistic aggregate of parts in isolable causal relations" (p. 15).

An implication of all of this appears to be that a serious mismatch now exists between (1) ecology as it has been perceived by holistic intellects during the past half century and (2) a currently dominant scientific methodology, borrowed from the physical sciences, which reinforces reductionism. This is not a dialectical dichotomy but rather simple dissonance, incongruence or mismatch. Clearly some concern is in order.

As implied earlier, western nations have during the past decade developed or strengthened a series of instrumentalities to correct the worsening man-nature interaction. It need not surprise us that virtually all of these admittedly ad hoc initiatives have so far fallen far short of full effectiveness. Part of the reason may be related to the fact that the ecological input has seldom escaped a slide into the reductionist mode. Thus Leopold matrices, emission standards, agglomerated air or water quality indices, simple concepts of carrying capacity, maximum sustainable yield, etc. (see Regier 1978), singly and jointly fail to address and safeguard the essence of ecological systems as perceived by holistic ecologists or holists of any disciplinary persuasion (e.g. Galbraith 1964).

What would be appropriate environmental methodology to marry with holistic concepts has occasionally been addressed explicitly (e.g., Regier and Rapport 1978; Rapport and Regier 1979). In order to be applied in practice, a holistic science of ecology -- as may also be the case with holistic social sciences -- may imply important changes in decision processes (see e.g. Bella and Overton 1972 and Emery and Trist 1973). The slowly emerging planning process may pave the way for more holistic approaches, particularly if it involves some public participation. Planning itself may gradually be turning from reductionist methods such as benefit-cost analyses or program planning and budgeting (PPB) into more explicitly dialectical methods (Benington and Skelton 1973). Or it may emphasize "creative learning" (Fox 1975), etc.

Taylor (1976) may have had something like the above in mind when he stated:

> "...planning in a society like ours ... involves more than just a coherent synthesis of many orders of consideration. It requires also the creation of a political consensus, or perhaps better, a resolution of widely felt ambivalences, broad enough and firm enough to sustain a plan over time. Planning is a very *political* activity: and yet we haven't so far succeeded in Western societies in making it other than an administrative-technical operation. This is one dilemma or challenge we face."

A move to more process-oriented, systemic and comprehensive methodologies is consistent with the emergence of "transfer sciences" (see above) but goes beyond it. At the present stage of development of the various transfer sciences related to man-nature problems many if not all are badly mired in reductionist concepts and methodology. Perhaps some rapid evolution will occur soon -- a prospect that is addressed next.

TRANSFORMING INSTITUTIONS

Jantsch (1972) has attempted to characterize a "system of science, education and innovation" (SEI System) that seems to be emerging in the West under broad social institutions and agencies. (Again recall the works of Michel Chevalier, Irving Fox, and numerous others.) Figure 3 is a sketch of the conventional paradigm of the SEI system as it has evolved during the past century. If widely judged to be inadequate, it may be complemented in such a way as to make the new combined system more nearly adequate. If obsolete it will presumably be replaced by a more useful alternative. Almost every major scientific, educational and governmental agency has come against one or both hypotheses -- inadequacy and/or obsolescence -- during the past decade. The inadequacy hypothesis has usually been taken up, perhaps because it is easier to add something to what already exists than to achieve a radical transformation. Here and there new educational institutions have been modelled on an alternative concept than that of Figure 3 and some experience papers are now becoming available (Jantsch 1972; Francis 1976).

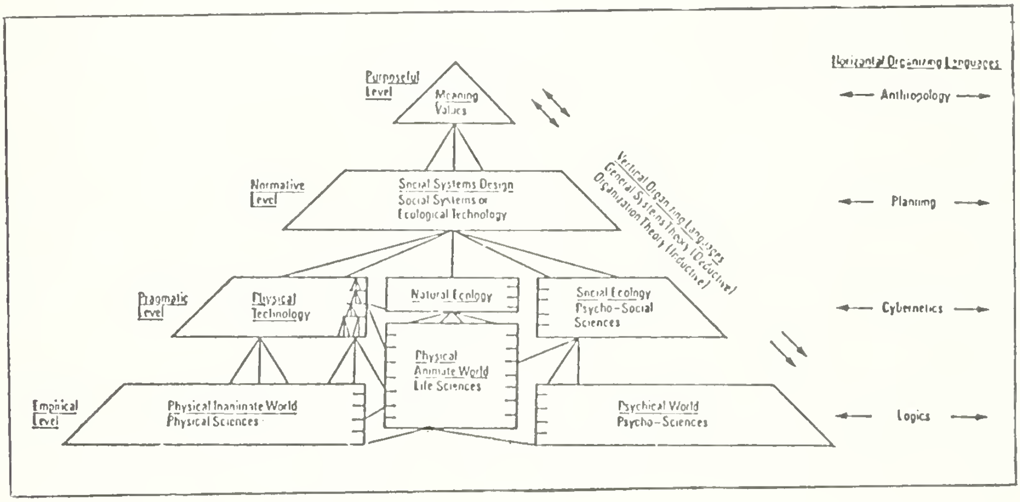

Figure 3. The Science/Education/Innovation System, viewed as a multi-echelon hierarchical system. Branching lines between levels and sublevels indicate possible forms of interdisciplinary coordination (Jantsch 1972).

In Figure 1 above, the bottom sketch refers to "transdisciplinarity." Its configuration resembles that of Figure 4 in an approximate way. But the hierarchic structure has in large measure been abstracted or disengaged from it. The strong arrows imply process orientation -- a kind of compounded interdisciplinarity. This may be altogether too fluid for our present tastes, habituated as we are to focus on structure and authority rather than on process and creativity.

"The basic structure ... may be conceived as being built essentially on the feedback interaction between three types of units, all three of which incorporate their appropriate version of the unified education/research/service function."

Jantsch's suggestions may have been prophetic (i.e. seeing into the contemporaneous, existential present) in that a broad trend along these lines may be noted, even where few people have become aware of Jantsch or the numerous other planners working in a paradigm generally congruent with his. Thus

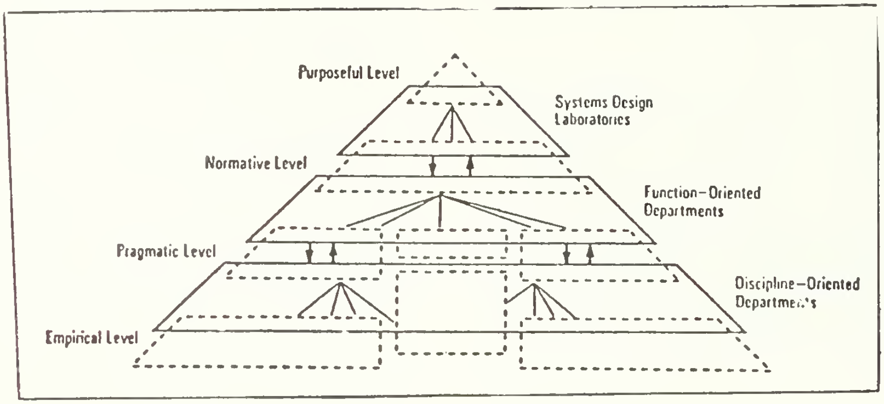

Figure 4. Transdisciplinary University Structure. The three types of structural units (full lines) focus on the interdisciplinary links between the four levels of the education/innovation system (dotted lines) (Jantsch 1972).

Particularly intriguing is the central location in the pyramid allotted to "natural ecology." Though not himself an ecologist, Jantsch apparently recognized that the perspectives of ecology transcended those of the natural sciences, that ecology employed a somewhat different "organizing language," and that ecological systems required pragmatic modes of intervention in normal practice. Clearly Jantsch was more influenced by the holistic concepts of ecology than the dominant reductionists methodologies -- a focus on the latter would have implied that ecology should be assigned to the empirical level in Figure 3.

Figure 4 depicts a kind of half-way step from the conventional wisdom (Figure 3) and a radical alternative (Jantsch's transdisciplinarity). It derives from an attempt by Jantsch in the late 1960s to sketch an alternative strategy for the Massachusetts Institute of Technology (see Jantsch 1972, p. 235 ff.) in which:

many of the "interdisciplinary" centers, institutes and programs of large universities and research institutions now may be assembled into the framework of Figure 4 with some gain in understanding. Parenthetically, the descriptive terms associated with these bands on the right slope of Jantsch's pyramid are not very informative, we find.

The new instrumentalities created by governments to deal with man-nature problems have often been more closely associated with these new bridging ventures in universities, and similar institutions in the private sector, than with the conventional disciplines as organized in Figure 3.

Note again the niche of natural ecology. It is shown as relating largely to a different bridging category than the rest of the "natural sciences." Thus ecology has been associated primarily with the pragmatic-normative bridge rather than the empirical-pragmatic. This makes a lot of sense to us.

THE ROLE OF ENVIRONMENTAL IMPACT ASSESSMENT

In an earlier section we identified a number of offspring mothered by ecology in recent decades. These might be viewed as transfer sciences at the level of what Jantsch calls "function-oriented departments" in Figure 4. (The term may not be apropos in our context, but the concept is.) Consider initially five of these offspring.

a) Renewable resource management: During the past century, schools or traditions have developed in forestry, fisheries and wildlife. As with the other transfer sciences to be mentioned below, renewable resource science was nurtured predominantly by biological ecology though challenged continually by practically-oriented agencies of government. The concepts and methods of study were developed by scientists in close interaction with the felt needs of practical people. Forestry, fisheries and wildlife were always strongly dominated by a production viewpoint -- these resources were expected to contribute to human economic well-being in a very direct way.

b) Human health in the sense of "public health": Many measures have come to be applied in reducing the risk of infection by pathogens and parasites. Also, poisonous chemical contaminants have long been of concern. There has always been a strong ecological component in this, either indirectly through more adequate control of chemical emissions and treatment of sewage or directly through intervention in the ecosystem to control natural vectors.

c) Conservation and preservation: The origin of policies to protect and preserve species such as migratory birds, to set aside wilderness and parks in perpetuity, and to emphasize the long-run benefits of resource husbandry may have arisen in connection with early nineteenth century romanticism. It has since been buttressed by more hard-nosed realists concerned about "outer limits" on the resiliency of the biosphere.

d) Technological fixers: Agencies that in the past have single-mindedly intervened in ecosystems on a grand scale (e.g. to build dams, stripmine coal, drain wetlands, build airports) have come to accept a type of ecological expertise that assists them in minimizing local ecological externalities but that doesn't insist on raising questions of larger scope. Usually the ecologists of this school have been kept at a comfortable distance from the center of the practical action and decision-making by the interposition of modellers, who possessed little ecological insight, between the ecologists and the decision-makers. The early modellers, such as benefit-cost accountants, were very inadequate from the ecological viewpoint -- though perhaps not from the viewpoint of the decision-makers in that they effectively screened out the more important ecological considerations. Some of the current modellers, expert as they may have been in helping to put a man on the moon, have as yet learned little about ecology.

e) Environmental quality: Attempts to measure and monitor the status of environmental quality, in some comprehensive and broad sense, are fairly recent in origin. The environmental accounts are coming to be viewed as complementary to national and regional systems of accounts on the economy (standard of living, rate of unemployment, GNP, etc.) and on social aspects (longevity, crime, educational achievement, etc.). This transfer science hasn't yet lost all its baby teeth -- one of which might be identified as the set of agglomerated environmental quality indices produced during the 1960s.

If those five ecological transfer sciences bridge the traditional gap between pragmatic and normative (Figure 4), what is the role of "impact assessment"? In its more comprehensive form it must clearly take account of all the major concerns addressed in the first instance by the five transfer sciences sketched above. Perhaps "impact assessment" is intended to act as an interfacing process between these five transfer sciences and what is happening at higher levels of the decision-making process.

Consider again Figure 4. Have higher level complements been developed between the normative and purposeful levels to which impact assessment could relate quite directly? It seems that there are two possibilities, i.e. national policies tending toward (a) comprehensive technology assessment in the sense of Hetman (1973), and (b) regional "land-use" planning. Neither of these possibilities are now well developed in North America, but the trend has been in that direction. Both kinds of policy innovations would likely encourage further development of generalized procedures of environmental impact assessment.

In the absence of clearly formulated broader programs like technology assessment and/or regional planning, environmental impact assessment may remain very much an ad hoc kind of transfer science. If its role were to be restricted simply to advise the public in general as to what might happen to the environment following completion of a particular technological development, then it will likely collapse for lack of effective practical feedback.

The role of environmental impact assessment is not now well specified. Within the set of ecological transfer sciences it is somewhat anomalous. It aspires to be more than they are. But in the absence of clear higher level policies it is not likely to succeed.

We have addressed the objective of this section from an ecological perspective. We suspect that there are schools of thought within the contemporary sciences of economics, geography and sociology that would have produced statements generally concordant with ours. Further to the point, all of our so-called ecological transfer sciences, including environmental impact assessment, may be developing toward full interdisciplinary status (see Figure 1).

For these reasons Figure 4 may be a pragmatically useful sketch of the science-education-innovation system as it is currently evolving. Of course it should not become a blueprint -- rather a rationalization of some recent trends that may serve for discussion and consensus building and may provide a basis for short-term forecasts.

ECOLOGY MATURING

In the preceding sections we have referred to ecology as a parent generation falling between conventional biology and natural history as grandparents and a number of ecological transfer sciences as children. In this section we focus more specifically on ecology as it is developing further, partly under conflicting pressures from its parents and offspring, partly in response to challenges of the outside scientific-technical world, and partly in heeding its own creative inclinations.

ENVIRONMENTAL CLASSIFICATION

A priori there appears to be no simple set of criteria by which to classify ecological environments. This may well apply for all the sciences that fall in bands other than the empirical band of Figure 3. Ecologists most strongly attracted or bound by empirical methodologies tend to get upset by the "softness" of much of ecology in this respect.

Empiricists prefer to work with sets of systems each of which is isolated spatially in space. Some small lakes and small islands may approximate such presuppositions but that still leaves out a great majority of ecological reality.

Pragmatists may be content to work with systems that are not sharply delimited spatially but may contain within them recognizable sites that serve as centres or zones of organizational dominance. Large geographic provinces or major oceanographic and atmospheric current systems may be addressed in this way. Process-oriented, holistic methods may serve adequately in such cases.

LEVELS OF ORGANIZATION

As in biology generally, the hierarchic levels-of-organization model has been greatly overemphasized in ecology. Seasoned ecologists have generally treated it as an elementary model which was only very occasionally realistic enough to be useful in practice. Nevertheless the simple idea has taken on a life of its own to the point where it may now be counter-productive, on occasion.

In human social systems persons at the pinnacles of hierarchies -- kings, field marshals, caesars and popes -- are greatly respected, sometimes feared, and occasionally admired. Perhaps through some kind of reasoning by analogy, some scientists who become expert at so-called "higher levels-of-organization" may look down their noses at those of lower levels. More frequently those working at lower levels may gratuitously ascribe this kind of attitude to their "over-reaching" colleagues, convinced all the while that ultimate reality rests in the smallest entities that sub-sub-...-sub-nuclear physicists can discover or invent. This is all quite silly, at least from the viewpoint that "truth" in some form is discoverable at any level or from any reasonably informed perspective. The holist expects to discover some truth at any "level" by methods that may in part be specific to that "level -- though he may not have a useful purpose in his context for "level" in a hierarchic sense. The reductionist tends to rely heavily on analyses of what he perceives to be lower levels-organization to help explain events at the primary levels of interest.

The pragmatic ecologist uses well-defined natural boundaries if they happen to be convenient. He uses a linear hierarchic model of levels-of-organization if he is fortunate enough to encounter such an ecosystem. But for him the term "ecosystem" is a flexible, systemic concept with a primary focus on the nature of processes involved and not on a fortuitous occurrence of a variety of artificial preconceptions.

Conventionally, ecosystem characteristics and properties -- perhaps dichotomized artificially as "structures and functions" or "components and processes" -- are first related to space and time dimensions, then to major exogenous influences including man, then to the major activities of internal features. Each of the exogenous and endogenous factors could be characterized with a model or paradigm that focuses on it, rather than the ecosystem that might interest us. *A priori,* from a very broad scientific or social viewpoint, neither the factor nor the system approach is necessarily the better approach.

METHODOLOGIES

The *sine qua non* of the more tolerant -- perhaps also of the more holistic -- scientists is that ecological observations be related to a "circle of affinity" in sufficient detail, depth and scope that they may be repeatable. Others, perhaps especially the theoretical "hard scientists", might demand that ecological hypotheses be first deduced from pre-existing theory and then be tested exhaustively or definitively before a contribution to "science" be recognized. The difference is in part that between systemic pragmatism and reductionist empiricism.

In recent decades reductionist methodologies have been a driving force in ecology, -- perhaps it is more nearly fair to term them quasi-reductionist since these methodologies seldom began with a deduced hypothesis. At worst a few might be dismissed as opportunistic *ad hoc* simulations that didn't start with theory and didn't end with any. Though the great majority did relate to theory at least implicitly, an overemphasis on mechanistic aspects of analytical methodology was common.

Analysis -- take things apart in the attempt to discover how they work -- has always been a favourite approach of scientists, especially of natural scientists. Ecologists have tended to neglect three other classical methodologies:

a) in a short-term study, to seek out analogues that have already been studied fruitfully, or to examine (compare and contrast) members in a set that are similar at a first order of approximation but differ in detail, thus to seek to discover reasons for those differences;

b) in a long-term study, to observe a number of systems through time to discover how and why they respond to nature's and history's vicissitudes operating on each of them in somewhat different ways;

c) where the opportunity for effective intervention in the system exists, to perform experiments to test hypotheses derived from consideration of analogues or from extended observation.

Of course, all three methods can be seen as complementary, nevertheless most ecologists tend to overemphasize one to the neglect of all the others.

ECOLOGICAL COMPONENTS

The ancient taxonomies of living and non-living, of air, water, soil (land) and fire (energy) are still at the basis of most scientists' approach to ecological matters. The systemic ecologist should not and sometimes does not automatically follow this or any other primary disaggregative compartmentalization. Analytic disaggregation is too often the first step in an ecological study, although it will often be desirable to compartmentalize at some stage of an ecological study.

Identification and measurement of whole-system properties and mapping them in the form of isolines, clines and gradients, as first steps are rather more consistent with systemic presuppositions than breaking the system into box-like conceptual units.

The current overemphasis on matrix frames for ecological work could be dismissed as a harmless fad if it weren't for the fact that it reinforces analytical reductionism. The essence of ecosystems and the nature of their responses to new factors is likely to be missed entirely by the more naive matrix compartmentlizers. Yet if the overall program of study deals effectively with whole-system features, then at a secondary stage of analysis, use of multi-dimensional disaggregation may be justified. But incorporation of synergisms, antagonisms, feedback loops, etc. will almost certainly render such models complex and ungainly.

ECOLOGICAL FACTORS OR STRESSES

As in the case of the human organismal system, we can learn a great deal about responses of ecological systems to many exogenous and endogenous factors even though we seem to understand relatively little about what is ultimately that which relates homeostatic processes or leads to their collapse (Rapport, Thorpe and Regier 1980).

Consistent with what is implied in Figure 2 above, whole-ecosystem approaches are not necessarily the best or most effective way to deal with particular ecological issues. If, from prior study, it seems clear that an ecosystem will retain its overall self-regulatory capability in the face of some challenge and if a possible effect or some component is of concern for considerations other than whole-system homeostasis, then it may be pointless to address the study at a larger system level.

STIMULUS-RESPONSE INTERACTIONS

From practical, scientific and systemic viewpoints it is often advantageous to characterize the nature of the stimulus as to its "loading characteristics". Is it applied continuously at one point in space or diffusively and discontinuously at many points in space and time? These two cases -- each somewhat extreme -- are becoming type cases both for theoretical and practical study. A third idealized type might be added to complement these: loading across a broad front geographically, oceanographically, or atmospherically.

It seems clear to us that different types of stress loading processes might stimulate different kinds of ecosystem responses, even where it is the same factor or material that is being loaded into the system. Certainly the scientific challenges to map, monitor and model them would be very different with respect to sampling, estimation and stimulation.

With respect to response processes, ecosystems tend to be subject to non-linear surprises for response and recovery sequence. This does not mean that they behave in reasonably predictable manner physiologically.

However for some ecosystems, characteristic response symptoms or syndromes may be exhibited to particular kinds of influences or stresses. Following cessation or relaxation of a stress, a relatively stereotyped recovery process may occur. A novel stress for which an ecosystem has no regulatory preadaptation may trigger a spectacular collapse. Some ecosystems may have vulnerable components -- Achilles' heels -- which can readily be crippled to the detriment of the whole system (Rapport, Thorpe and Regier 1980). The dynamic processes by which an ecosystem tends to maintain holistic integrity may be analyzed into numerous causal mechanisms with markedly different time parameters and highly complex interactions.

EVER ONWARDS, OUTWARDS

Though we have indicated what we believe to be wrong-headed scientific approaches to major man-environment interactions, whether in the context of impact assessment or some other political instrumentality, we do not dismiss what has already been done as trivial or in error. Clearly much has been achieved. The principle of the blunt ax may be invoked: if a particular tree has been chopped down using that ax, then it was clearly sharp enough. But the next tree may be of harder wood, as will very likely be the case with future challenges to impact assessment. Then the present ax may not be sharp enough.

There is growing indication that Western societies are swinging towards a world view that is more consistent with a systemic holistic paradigm than has been the case in recent centuries. If so, it augurs well for natural systems and for systemic ecologists.

Three groups of workers should now seek to make effective contact: the methodological innovators (e.g. experimentalists, simulators) the conceptual transformers and theoreticians (e.g. systemic scientists of various hues); and the planners concerned with evolving institution structures and processes, say of the impact assessment instrumentality. The three groups appear to be covering toward mutually compatible viewpoints. Again vast charisma might help to catalyze such a consensus-building venture, but is not really essential. Most resources devoted specificall for this purpose might be a sufficient precondition to ensure its success.

The sketches of this paper are not proposed as the best framework for such a venture -- they are submitted as evidence that a sufficient framework and process can be developed using existing published material No new, great creative discovery need occur prior to an effective start on the whole matter.

THE SCIENCE-EDUCATION-INNOVATION SYSTEM

With respect to major trends in the man-nature interaction -- e.g., concerning environmental impact assessment, renewable resources such as fisheries and forestry, and national accounts of the state of the natural environment -- energetic consideration leading toward consensus should be directed to what is happening in the science-education-innovation system Those who are currently innovating with the new powerful methodologies, with evolutionary systemic concepts, and with institutional planning and design should be induced to identify what they share in common and wherein they may differ.

When and if a working consensus emerges, the various ad hoc transfer sciences now gradually evolving to deal with various aspects of the man-nature interaction should be examined critically, singly and jointly. Their current inadequacies should become readily apparent, and proposals for major improvements should be specified.

An alternative to these two top-downwards suggestions is to address far more limited questions on a piece-meal basis and hope that a lot of smaller changes will add up to a sufficient solution. This is unlikely to succeed for two reasons. Numerous workers, including the most capable leaders, are already competent to deal with the larger issues and would simply be too bored by the piece-meal approach to participate. Secondly, the time is right to move forward now -- before the inadequate initiatives now dominating the approaches to various man-nature issues crystallize to the long-term disbenefit of all of society.

METHODOLOGIES, CONCEPTS AND PLANNING

To fill out these proposals in a little more detail, consider recent progress on methodologies, concepts and institutional issues.

a) Methodologies: A variety of international organizations, institutes and programs have during the past decade focused on the new scientific methodologies. These include the Organization for Economic Cooperation and Development, the International Council of Scientific Union's Scientific Committee on Problems with the Environment, the International Institute for Applied Systems Analysis and Unesco's Man and the Biosphere programme. The United Nations Environment Program has shown strong commitment to support further work. In the United States the National Science Foundation is supporting quite a number of studies of interdisciplinary methodologies. Clearly with so much already done or currently underway, any additional new initiative specifically along these lines would have to be justified very carefully.

b) Concepts: On man-nature problems rather less research and experimental emphasis has been directed toward concepts than to methods. A variety of new international journals have recently sprung up, some of which are quite specifically directed toward concepts. Again a lot has been written recently that has not permeated far into the ranks of the ecologically-oriented workers and planners.

c) Planning: As already indicated (see Taylor 1976), the technical-administrative aspects of planning are coming to be well understood in Western societies. But how to animate the process so that it is politically useful, from the viewpoint of the citizen, is another matter. Clearly the educational sub-system should be more fully involved, as well as the fully non-governmental organizations such as the press and other media. What seems to be lacking is an adequate consensus among various groups of innovators as to the likely practical implications for science and technology of the broad evolutionary transformation now underway. This need no longer be a dim, dark mystery -- with some modest resources it would not be difficult to make rapid progress in clarifying these matters and implementing the necessary changes.

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EVALUATION OF CHRONIC AND SUBLETHAL TOXIC EFFECTS IN THE ASSESSMENT OF AQUATIC ENVIRONMENTAL IMPACT

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INTRODUCTION

One of the greatest difficulties in the review and analysis of environmental impact statements involves the interpretation of the biological variability characteristic of most aquatic ecosystems. During a 3-year period, our laboratory was responsible for the review of over 40 proposed or operating nuclear power generating stations. There was really little difference between these reports. There were vast amounts of qualitative and quantitative data describing all kinds of aquatic populations and communities. For existing plants, the applicant attempted to conclude whether or not observed variations were correlated with plant operations. The applicant typically concluded that there was no correlation, principally because natural or sampling variability was excessive. On the other hand, many reviewers would conclude:

1. That too few samples were collected or sampling periods were insufficiently long;

2. That had replicate sampling been conducted an impact would have been evident; or

3. That there was, somehow, a correlation between field data and plant operation.

Any of these conclusions resulted in additional expenditures of funds and effort.

For proposed plants, this difficulty in interpretation is alleviated somewhat since, in these instances, all assessment of environmental impact is of a predictive nature. Even so, descriptive data are needed for the principal populations and community relationships that exist in the vicinity of the proposed operation. These data are used together with operational data in an attempt to predict whether or not there would be unacceptable impact over a range of probable natural conditions such as rainfall, flow, temperature, water quality, etc.

Again, one of the principal differences between the evaluation of environmental impact statements for existing or planned facilities has been the dependence on predictability characteristics of proposed operations. Such predictability implies a high degree of reliance on experimental data from field and laboratory studies and observations.

An additional difference between impact statements is that on-site studies of existing operations are conducted over a period of several years, whereas studies of proposed operations need fewer data since an evaluation of the latter is less dependent on annual or seasonal variability.

A point that needs some consideration in this context is that existing operations can also be evaluated based on predictability. There is no justifiable reason to rely only on attempts to observe environmental impact when together with the use of laboratory and field studies on cause-effect relationships a more complete analysis can be performed. In fact, it may be possible to compare observed with predicted results in order to determine, for that site, the best type of analysis.

A brief specific example will provide additional clarification of these comments. Typical studies of relatively new power generation plants include a few years of biological studies in a pre-operational mode. Several more years of post-operational studies are conducted to determine if any significant adverse effects might have occurred. It is not at all difficult in these instances to demonstrate short-term negative impacts on phytoplankton, zooplankton or meroplankton entrained in the cooling water. Negative impacts can also be observed in the near-field zone. Far-field effects are rarely detected. However, these negative effects may not be significant in relation to a population or some community. A specific example of this is a plant in western Lake Erie that is killing over $3X10^5$ young yellow perch. The generation of comparable data is simple compared to explaining its ecological meaning. This is when it is necessary to make predictions since it is frequently unlikely that any subtle but significant environmental impact could be related to a single point source.

DATA REQUIREMENTS FOR PREDICTIONS

Laboratory and field data are both important in an attempt to determine if an adverse environment impact is likely to occur. Site specific field data are obviously necessary to describe the dominant species and community structures. In addition, results of field studies of existing comparable facilities with comparable aquatic forms may be useful in predicting the impact of such operations. Emphasis should be placed on dominant species since the removal of one of these species would result in important changes in the community and in some instances the physical environment. The availability of experimental data is generally greater for species which are dominant.

Improvements in waste treatment technology, dredging operations, construction procedures, and other operations have reduced the likelihood of drastic adverse impact resulting from acute mortality. This trend is likely to continue. Consequently, we are required to consider more and more the sublethal and chronic impacts that may ultimately result in a loss of dominant species but at a rate that is rarely perceptible using standard site studies. Ten years ago we would consider ourselves successful had we prevented a potential fish kill or equivalent damage. Now such occurrences have to be the result of carelessness, oversight, or willful neglect. Today's concerns involve growth, reproduction, residues, tainting, or off-flavor of edible species, migration, avoidance, and other behavioral characteristics.

TOXICITY

Our past, and unfortunately at times our present, preoccupation with lethal or other acute, dramatic impact is probably the result of our inability to detect any other kind of change. Ecological and sampling variability certainly make it difficult to detect behavioral changes that would require several life cycles to demonstrate an ultimate sublethal impact. Sublethal effects can also occur in a short time and to understand them does not demand that lengthy, chronic toxicity data be available. The following examples should clarify this point. A variety of studies with many industrial and municipal effluents have shown that fish flesh can accumulate sufficient chemicals in 1-3 days to cause detectable unpleasant flavor. Sublethal threshold concentrations for flavor impairment was determined for 22 organic compounds (Shumway and Palensky 1973). Seven additional compounds did not impair the flavor at or near lethal levels. Paper mill and sewage effluent also caused tainting at sublethal concentrations. When channel catfish were placed in cages at various locations in the Ohio River, a taste panel could differentiate between fish held upstream and downstream from wastewater discharges. Native fish were also studied and it was shown that caged fish exposed for only 3 days acquired a minimum of 70 percent of the off-flavor of native fish.

The presence of excessive turbidity or chemicals that cause an avoidance response can result in an immediate impact on migration of anadromous species. Since migration is commonly of short duration, it is not likely to be adequately studied during site specific surveys.

Avoidance is one of the better studied behavioral patterns of fish, both freshwater and marine. Data are available for some heavy metals, pesticides, temperature and other stresses. These results have shown that, for some materials, fish will avoid sublethal concentrations in the field and in the laboratory. An experimental stream study was conducted (Geckler 1976) that involved the addition of copper to a natural, freshwater stream for three years. During that time observations were made on fish behavior, survival, reproduction, and growth. Fish barrier screens at the point of addition of copper and about 800 meters downstream permitted quantitative determination of fish movement. Several resident species significantly avoided this area and were detected in large numbers on the downstream screens; few upstream fish (control) were found on the upstream screens. Sprague et al. (1965) observed that Atlantic salmon migrating up the Northwest Miramichi River avoided sublethal copper and zinc originating from a base metal mine. Between 10 and 20 percent of the migrating salmon returned downstream before spawning.

Data on the chronic effects of many environmental stresses have been determined and should be used to evaluate the potential impact of new or even existing operations or facilities. Most chronic bioassays or toxicity tests involve all or most of the life cycle of the test species. For freshwater fish, effects on growth, reproduction, spawning behavior, viability of eggs, and larval growth are generally studied (Mount and Stephan 1967). Methods are under development for similar studies with marine fish species. Only a few dozen of these chronic tests have been completed but the principal consistent conclusion is that there is usually a great difference between lethal concentrations and those concentrations that significantly impair growth, survival, or other important functions. Table 1 contains some examples of this relationship between lethal and "no-effect" concentration (Andrew et al. 1976). Admittedly, there are many components of discharges to aquatic systems for which chronic test data are unavailable but for which there are acute toxicity results on mortality. For each toxicant there is obviously a numerical value for the relationship between the safe concentration and the acutely lethal concentration. Such values are called application factors and will be discussed later.

Studies of shorter duration than all or most of a life cycle are also useful in the evaluation of environmental impact. Numerous studies of effects on growth have provided data in a variety of organisms exposed for 30 to 60 days. These tests are of sufficient duration to permit their use as predictive tools for sublethal impact.

There are also quite a few data available on the effects of turbidity or suspended sediment on aquatic populations and communities. Many of these have involved field studies and one good example was reported (Gammon 1970) which studied a midwestern stream below a crushed limestone quarry for 4 years. No other pollution source was present to confound his data. There was a 25 percent reduction in macroinvertebrate density during periods of low input that increased the suspended solids load by only 40 mg/l. Population diversity indices were unaffected by changes in density because most taxa responsed to the same degree. The standing crop of fish decreased drastically when heavy sediment input occurred in the spring. Fish populations would increase after winter floods due to removal of sediment deposits.

Suspended sediment can also influence the behavior of fish. Heimstra et al. (1969) exposed largemouth bass and green sunfish to two levels of turbidity for 30 days. Their activity was reduced. There was also evidence that turbidity disturbed normal social hierarchies in green sunfish.

Both of these studies demonstrated sublethal responses that must be considered for any dredging, construction or discharge that would result in slight increases in turbidity over a period of time. The predicted impact on light penetration and subsequent reduction in primary productivity must also be estimated.

When sublethal or chronic effects are considered in evaluating environmental impact, numerous potential problems must be weighed before being discarded as inapplicable for a specific location.

For example, temperature increase may affect the incidence of infectious diseases of fish. Sneiszko (1974) reviewed the effects of increased temperature on the occurrence of outbreaks of bacterial and viral diseases and concluded that water temperature may affect these diseases if the potential pathogens are present. Mortality rates for salmonids due to *Chondrococcus columnaris*, *Aeromonas salmonicida*, and *Aeromonas liquefacians* were increased with an increase in temperature over the range of 4-21^{o} C (Fryer and Pilcher 1974). Mortality of coho salmon exposed to *Ceratomyxa shasta* was also increased with increasing temperature. A disease stressed fish is probably more sensitive to a variety of other stresses. This condition would not occur at all times but the possibility does exist. Vaughan and Coble (1975) have evaluated the influence of ectoparasites on the resistance of fish to thermal stress. They found that brook trout with gill lice (*Salmincola edwardsii*) had a 50 percent mortality within 22 to 32 hours at an exposure to 25^{o}C. Trout without gill lice did not reach a 50 percent mortality during the experiment. They also found that yellow perch with black-spot (*Neascus* of *Crassiphiala bulboglossa*) were actually more resistant in relation to survival time at 32^{o}C.

RESIDUES

For some pollutants, the principal concern is not for fish and their food chain but for predators such as birds and mammals including humans. It has been well documented that some organic compounds have bioconcentration factors of 10^5 to 10^6 and even higher. In these instances, such as for DDT, organomercury, polychlorinated biphenyls (PCBs) and others, the writers and reviewers of impact statements must be aware of the sublethal bioconcentration potential. The recent series of bans on the sale of freshwater fish with excessive PCBs in their tissues highlights this point. Bioconcentration factors in some wild fish have been observed to exceed 10^6. Based on such data and the known effects of PCBs on consumers of fish, the maximum permissible concentrations of PCBs in water would

Table 1. Relationship of 96-hr. LC50 Values and Maximum Acceptable Toxicant Concentrations (MATC) (from Andrew et al. 1978)

Chemical	Species	96-hr. LC50 (mg/l)	MATC Range (mg/l)
Atrazine	brook trout	6.3	0.065-0.12
Atrazine	bluegill	8.0	0.095-0.50
Atrazine	fathead minnow	15	0.213-0.52
Cadmium	flagfish	2.5	0.0041-0.0081
Cadmium	fathead minnow	7.2	0.037-0.057
Cadmium	bluegill	21.1	0.031-0.080
Chromium	fathead minnow	36	1.00-3.95
Chromium	brook trout	59	0.20-0.35
Copper	fathead minnow	0.075	0.0106-0.184
Copper	brook trout	0.10	0.0095-0.0174
Copper	bluntnose minnow	0.23	0.0043-0.018
Copper	fathead minnow	0.46	0.038-0.060
Copper	fathead minnow	0.47	0.0145-0.033
Copper	bluegill	1.1	0.021-0.040
Diazinon	flagfish	1.6	0.054-0.088
Diazinon	fathead minnow	7.8	0.0032-0.0135
Lead	flagfish	2.75	0.0312-0.0625
Lead	brook trout	4.1	0.058-0.119
Lindane	brook trout	0.0443	0.0088-0.0166
Lindane	bluegill	0.100	0.0091-0.0125
Lindane	fathead minnow	0.100	0.0091-0.0235
Malathion	bluegill	0.11	0.0036-0.0074
Malathion	flagfish	0.349	0.0086-0.0109
Malathion	fathead minnow	10.5	0.20-0.58
Methylmercury	fathead minnow	0.065	0.00007-0.00013
Methylmercury	brook trout	0.075	0.00029-0.00093
Methylmercury	flagfish	0.24	0.00017-0.00033
Zinc	fathead minnow	0.6	0.078-0.145
Zinc	flagfish	1.5	0.075-0.139
Zinc	brook trout	2.0	0.532-1.368
Zinc	fathea' minnow	9.2	0.030-0.180

be 1 nanogram/liter or lower. I doubt if very many of us have ever reviewed an impact statement that discussed the discharge or use of DDT, PCBs, or mercury, but the purpose of my point is that there are other compounds that may pose a similar potential problem. In such cases, direct toxic effects alone are insufficient; we must also consider this residue and food chain relationship.

CRITERIA

Over the last ten years several reports have become available that have scrutinized available data and developed recommended environmental limits of a variety of toxic materials or conditions. Water Quality Criteria (National Technical Advisory Committee 1968) was the first significant effort by a large group of people of diverse backgrounds. Not many numerical criteria were recommended because of the paucity, at that time, of data on sublethal and chronic effects. The authors concluded that substantial data on long-term effects and safe levels were available for only about ten toxicants and the effects on reproduction was nearly unknown yet this function is a very important aspect of all long-term toxicity tests.

During succeeding years there was a significant effort to conduct the necessary toxicity tests to be used in the development of criteria for aquatic life. The National Academy of Sciences undertook a revision of Water Quality Criteria at the request of the United States Environmental Protection Agency. Their effort (National Academy of Sciences 1973) produced a more comprehensive report that recommended more criteria for aquatic life using appropriate sublethal and chronic toxicity data. The Environmental Protection Agency has completed a report recommending criteria for a comparable number of conditions and toxicants (USEPA 1976).

In these three reports are summarized most of the available data necessary to predict long-term or sublethal effects of proposed discharges or operations. For many of the more important pollutants there are discussions of the aqueous chemistry and fate of these materials and this information will be needed to evaluate proposed discharges. There are also discussions for certain pollutants such as ammonia, cyanide, hydrogen sulfide and others that deal with the toxic forms of these pollutants. A good example is ammonia. Nearly all monitoring programs are oriented to measurements of total ammonia; engineering planning and evaluations deal with total ammonia. However, it is the non-ionized form that is toxic to aquatic life and the percentage of total ammonia that non-ionized ammonia represents is temperature and pH dependent and will vary from less than one percent to nearly 20 percent.

APPLICATION FACTORS

The term 'application factor' means different things to different people. To correct a common misunderstanding let's begin with a statement of what the application factor is not. It is not a safety factor, or equivalent to the common concept of a safety factor. The application factor in the field of aquatic toxicology is the relationship between a safe concentration of a pollutant over life cycles and the short-term lethal concentration. A safety factor is principally applied to some estimated value in case the estimate was wrong. There is no safety as such designed into the application factor.

There are two kinds of application factors. An 'experimentally-derived' one is determined after completion of life cycle laboratory tests that study the effects of a pollutant on survival, growth, reproduction or other critical life processes. These application factors have been developed for only about three dozen chemicals and range from approximately 0.2 to 0.001. Certainly, this is too wide a range to permit a generalization to all other chemicals of a single 'predicted' application factor. However, when necessary predicted application factors may be used to assist in the evaluation of environmental impact. The National Academy of Sciences (1973) recommended the following application factors in lieu of experimentally-derived application factors:

> Concentration of materials that are nonpersistent or have noncumulative effects should not exceed 0.1 of the 96-hour LC50 at any time or place after mixing with the receiving waters. The 24-hour average of the concentration of these materials should not exceed 0.05 of the LC50 after mixing.
>
> For toxicants which are persistent or cumulative, the concentrations should not exceed 0.05 of the 96-hour LC50 at any time or place, nor should the 24-hour average concentration exceed 0.01 of the 96-hour LC50.

Sublethal or chronic effects of mixtures are also of great importance. Unfortunately, only a few experimental studies have been completed to evaluate this problem. The National Academy of Science (1973) also recommended a procedure to handle mixtures of pollutants:

When two or more toxic materials are present at the same time in the receiving water, it should be assumed unless proven otherwise that their individual toxicities are additive and that some reduction in the permissible concentrations is necessary. The amount of reduction required is a function of both the number of toxic materials present and their concentrations in respect to the permissible concentrations. The following relationship will assure that the combined amounts of the several substances do not exceed a permissible concentration:

$$\frac{C_a}{L_a} + \frac{C_b}{L_b} + \ldots + \frac{C_n}{L_n} < 1.0$$

This formula may be applied where C_a, C_b, . . . C_n are the measured or expected concentrations of the several toxic materials in the water, and L_a, L_b, . . . L_n are the respective concentrations recommended or those derived by using recommended application factors on bioassays done under local conditions. Should the sum of the several fractions exceed 1.0, a local restriction on the concentration of one or more of the substances is necessary.

C and L can be measured in any convenient chemical unit as proportions of the LC50 or in any other desired way, as long as the numerator and denominator of any single fraction are in the same units. To remove natural trace concentrations and low nonadditive concentrations from the above formula, any single fraction which has a value less than 0.2 should be removed from the calculation.

This procedure, until it has been experimentally verified, can only be used to crudely estimate the potential impact of mixtures of toxic materials. It doesn't attempt to incorporate the influence of other stresses such as pH, temperature and suspended solids.

SUMMARY

There is only one principal point to this presentation. Sublethal and chronic toxicity data from field and laboratory studies are available for direct and indirect effects of a wide variety of toxic materials or conditions and should be extensively used in the preparation and review of environmental impact statements or related documents. For proposed discharges or operations these data are necessary in order to predict effects that might result from subsequent practices. Even for existing discharges these data are useful for predictive purposes and these calculated effects could be compared to ecological data generated during site specific studies.

The use of acute lethality data or results from comparable, gross effects studies are only useful generally to estimate impacts within the near-field or mixing zone. We are too advanced to rely exclusively on such crude evaluations. Subtle effects on growth, reproduction, residues, and various behavior patterns may ultimately impact greater areas and require longer time periods before they are detectable during routine ecological surveys. Also, attempts to correlate these effects of existing operations to specific discharges are very difficult and unlikely to succeed, which increases the necessity of predictions and subsequent decision-making on that basis.

We can look upon environmental impacts as a sometimes selective, sometimes nonselective predator. In unaltered environments species diversity is directly related to the efficiency with which predators prevent monopolization by one or a few species. Moderate predation often reduces the density of dominant species and the result is acceptable diversity. Excessive predation, whether animate or inanimate, would select for monocultures of potentially less beneficial species, an impact that in most instances would be an unacceptable level of environmental impact.

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RISK ANALYSIS FOR AQUATIC ECOSYSTEMS

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INTRODUCTION

Ecologists have a dual responsibility to society related to environmental problems: (1) to identify potential or existing problems and alert laymen to their existence, and (2) to estimate as accurately as possible the ecological consequences of various alternative courses of present and proposed actions and communicate this information in an understandable form to decision-makers. Since the first Earth Day, many ecologists have publicly criticized a vast array of societal decisions despite their comparative passivity before then. But criticism is a responsibility rather easily satisfied since it is easier to criticize than to synthesize. Ecologists have been understandably reluctant to synthesize or to develop means of estimating ecological risks associated with a particular course of action for a number of reasons, some of which follow.

1. Many of the courses of action are based on technological innovations which are completely untried as operating systems and for which direct evidence of environmental impact is not available.

2. Our understanding of the ways in which ecosystems function and are structured is primitive; therefore, in dealing with incredibly complex and highly variable systems, the probability of error is substantial.

3. The public and professional "image" of an ecologist who prevents any use of an ecosystem was once that of enlightened defender of Mother Nature intervening to save a threatened ecosystem from Big Business. This image has been somewhat tarnished by the use of unacademic and unprofessional tactics such as altering data to accomplish these ends. In addition, ecologists sometimes appear to be the cause of loss of badly needed jobs in an area with high unemployment.

4. Even if one predicts disaster as a consequence of a particular course of action and no adverse effects are immediately apparent, one can always evoke the specter of either low-level or long-term effects not likely to be immediately visible with current assessment methodology.

5. Requiring other people to justify what they are doing is always easier and safer than recommending a course of action.

6. Developing a reasonably sound estimate of risk would involve working with disciplines, such as engineering, which most ecologists feel are alien to their way of thinking. Developing a functional working relationship would require a major effort on both sides. Neither ecologists nor engineers have been exemplary in developing such a relationship.

7. The consequences of error to one's professional reputation are likely to be much more serious than a comparable error in a scientific journal if only because of the vastly larger number of people and substantial sums of money involved.

There are a number of other reasons some of which may be more important or compelling than these, but this list should indicate the magnitude of the problem to be overcome in resolving this issue.

Another important component of this analysis is the type of biological monitoring following the implementation of a proposed course of action to determine whether or not the estimates of safety and/or damage were valid. Data generated by such a program should be used to initiate corrective action. There is no general agreement on what parameters should be monitored nor how frequently, but the term biological monitoring appears in current legislation. Without question, biological monitoring deserves serious attention not only in the selection of methods and parameters but also in the quality and quantity of professional "person power" needed to gather the necessary data and interpret it.

Some generalized statement of the experiences which preceded this paper is probably in order primarily because several people in an audience where an earlier verbal presentation was given on this general topic got the impression that it was purely speculative, entirely unsupported by evidence. The section on inertia (resistance to displacement) is

Geckler, J. Q.H. St ...rily on Cairns' 31 years of professional experience which includes studies ...ly 400 water ecosystems in this ...phere. During the course of these in...igations, a wide variety of freshwater ...cosystems was observed both before and after the implementation of a particular course of action (most frequently the installation of an industrial plant). Almost without exception these field studies were accompanied by laboratory bioassays using algae, invertebrates, and fish. As a consequence, the stress response was noted under laboratory conditions and checks (post-operational field studies in the receiving system) could be made of the accuracy of the estimated safe concentrations. Unfortunately for the ecosystems but fortunately for the development of the inertial hypothesis, the recommended safe levels were occasionally exceeded and degradation of the system resulted. These cases were not numerous and represented only a very small percentage of the total, but even the few that did occur were quite enlightening.

An excellent illustration of this type of evidence was presented by Patrick (1977). Unfortunately, the evidence on the factors that produce ecosystem inertia is mostly circumstantial and more solid evidence is badly needed. Despite the large number of environmental catastrophes that have occurred, some illustrations are documented in Dickson et al. (1976) very few had baseline ecological studies preceding the catastrophe. Possibly the best way to obtain this evidence is not through manmade catastrophes in natural ecosystems but rather simulation of such catastrophes in artificial ecosystems with substantially more biological complexity than is common in bioassays. The best body of evidence about ecosystem inertia is available from the bioassay literature in which the mediation of toxicological effects by varying environmental conditions is extremely well-documented. In addition, the engineering literature is replete with the factors governing the dispersion and transformation of wastes entering water ecosystems. There is some evidence of the ability of various organisms and their developmental stages to resist pollutional stress. This body of evidence provides us with a preliminary means of estimating ecosystem inertia and an indication of the types of additional evidence that will be required for more accurate estimates.

The estimate of elasticity is on somewhat firmer ground than the one for inertia because it is based on direct evidence from a number of case histories -- most notably the Clinch and Roanoke Rivers (e.g., Cairns et al. 1971) and studies of acid mine drainage (e.g., Herricks and Cairns 1974; Cairns et al. 1971). Additional references on recovery may be found in Cairns et al. (1977). Despite the availability of case history information, there are indeed a substantial number of parameters for which inadequate information is available. For example, dissemule transportability can be estimated from the life histories of the organisms, etc., when this information is available, but there is no body of information comparable to that for terrestrial plant seed transport. Nevertheless, some crude estimate of this parameter is possible.

The information on biological monitoring is also in an early developmental stage although development has proceeded somewhat further than elasticity and inertia. Cairns has been involved with inplant monitoring systems since 1966 and was co-author of one of the early papers in this field (Schier et al. 1968) so that experience with the development of the field has been extensive. Although much remains to be done, these systems have been operational for approximately 12 years and have been, for the better part of a year, in pilot operation in a major industrial plant.

The conceptual part of the instream monitoring has been developing for many years (e.g., diversity indices, etc.). The contributions made by Virginia Tech in this area have been (1) a simple diversity index (Cairns et al. 1968; Cairns and Dickson 1971), and (2) instrumentation to identify diatoms very rapidly so that any index based on numbers of individuals per species, numbers of species, and/or kinds of species could be generated very rapidly (Dickson et al. 1977).

We do not feel that the ideas expressed in this paper are incompatible with those expressed in the superb paper by Holling (1973), although the orientation of this paper is substantially different from that of Holling. The word *resilience* is used in a different way -- at first we attempted to find an alternate word to avoid confusion but decided that the use of *inertia, elasticity,* and *resiliency* in this paper would not be confusing if we indicated an awareness of Holling's paper and a recognition that these words were used somewhat differently for diverse purposes.

ESTIMATE OF ECOSYSTEM VULNERABILITY

Although generalizations about the effects of pollutional stress upon ecosystems are useful, it is clear that it would be disastrous to use the same assessment methods for determining the effects of these on all types of water ecosystems. Clearly the mix of methods used should be determined on a site-specific basis using ecological criteria rather than making the prime determinant administrative convenience. A series of decision matrices patterned after those given in "Principles for Evaluating Chemicals in the Environment" (National Academy of Sciences 1975) could be developed to systematize both the method selection process and the types of data to be gathered. In addition to the types of methods and data, it is also important to know how much effort should be expended and how frequently assessments would be needed. A strong case can be made for differential assessment efforts which would be determined entirely by certain qualities of characteristics of the particular ecosystem involved. A list of these characteristics follows.

1. Vulnerability to irreversible damage.

2. Degree of elasticity or ability to recover from damage.

3. Inertia or ability to resist displacement of structural and functional characteristics (i.e., ability to resist being placed in disequilibrium).

4. Resiliency or the number of times a system can snap back after displacement.

VULNERABILITY TO IRREVERSIBLE DAMAGE

This is an exceedingly difficult characteristic to define since one might well hypothesize that, given sufficient time, no damage is irreversible. However, it seems reasonable to be anthropocentric and define irreversible damage as that damage requiring a recovery period longer than the human life span. (Excluded from this discussion are irreversible changes that are part of the normal evolutionary or successional process.) All water ecosystems are not equally vulnerable to irreversible damage nor are they subjected to the same intensity or frequency of perturbations of human origin. A committee of persons with experience in a variety of water ecosystems should be charged with producing a rank ordering of vulnerability. Regulatory agencies should be able to estimate frequency of societal perturbations. The degree of ecological vulnerability will depend to a large extent upon an ecosystem's elasticity (ability to snap back after displacement) and inertia (ability to resist displacement).

ELASTICITY

It is quite likely even if adequate preoperational studies are carried out and accompanied by ecological monitoring programs, some deleterious effects will occur due to accidental spills such as the ones reported by Cairns et al. (1971). Some means of estimating the elasticity of an ecosystem (its ability to snap back following severe stress) is badly needed. Such an index would be useful not only in studying the rate of recovery following accidental damage to an ecosystem but also in estimating the ecological vulnerability of various sites proposed for development. If an ecologist were included on an industrial site-selection team, some approximation of the relative vulnerability of ecosystems adjacent to the proposed industrial sites could be made and incorporated into the series of factors considered in site selection. In addition, if severe ecological damage did occur, the fine to the offending discharger might include not only the value of the organisms killed but also the expenditures based on the recovery time. The speculations which follow are based on studies of damaged rivers previously cited and a symposium on recovery and restoration of damaged ecosystems (Cairns et al. 1977). During the course of the recovery symposium just cited, it was evident that the factors affecting recovery are sufficiently general to apply fairly well to terrestrial and marine ecosystems as well as freshwater ecosystems although they are based on information derived entirely from the latter. However, it should be noted that the influence of residual toxicity or altered substrate conditions would be markedly different from standing water than for flowing waters. Nevertheless, despite this differential that exists due to the ecological disparity of the systems, the factors in the following discussion are undoubtedly important in each.

The factors important to the recovery process follow. In view of our present state of substantive knowledge regarding the recovery process, it seemed ludicrous to attempt a more elaborate equation. On the other hand it is quite clear that there is a "multiplier" effect between the factors involved and also that some of the factors, such as management or organizational capabilities, are of less importance if the other components are weak. The factors which appear important in the development of a recovery index follow with a brief discussion of each.

a. Existence of nearby epicenters (e.g., for rivers these might be tributaries) for providing organisms to reinvade a damaged system. Rating system - 1-poor; 2-moderate; 3-good. In a series of studies carried out on the Clinch River (e.g., Crossman et al. 1973, 1974) it was clear in the initial stages of the recovery process that some tributaries contributed more colonizing organisms than others. It was also evident that some of the organisms recolonizing damaged areas came from the headwaters of the mainstream. The presence of these comparatively healthy tributaries and headwaters which furnished organisms to recolonizing damaged areas were a key factor in the very rapid recovery which occurred. These tributary and headwater areas might be considered epicenters from which organisms departed to invade and subsequently colonize the damaged areas. A substantial reduction in the sources of potential recolonizing organisms would have undoubtedly altered the recovery pattern of the Clinch River. Therefore, the epicenters are a prime factor in the recovery pattern of a damaged ecosystem since without new potential colonizers the process obviously cannot occur.

b. Transportability or mobility of dissemules (the dissemules might be spores, eggs, larvae, flying adults which might lay eggs, or another stage in the life history of an organism which permits it to either voluntarily or involuntarily move to a new area). Rating system 1-poor; 2-moderate; 3-good.

The Clinch River studies demonstrated quite clearly that some groups of organisms have a greater potential for becoming reestablished in a damaged area than others. Fish, for example, moved into the damaged areas relatively soon after the fly-ash-pond spill occurred which temporarily destroyed the biota. The same was true for an acid spill which occurred sometime later but which affected a more limited area. Aquatic insect larvae which "drift" downstream and are, therefore, good recolonizers also became reestablished rather soon. On the other hand, the mollusks were rather slow to reinvade damaged areas, and at the time this manuscript was being prepared, there were species of the mollusks which had not returned to the damaged areas although years have passed since the last spill. If the damaged community consisted almost entirely of organisms with a high degree of dissemule transportability, the prospects for rapid recovery would be high. If it consisted primarily of those not easily transported, thus less likely to reinvade, the prospects of rapid recovery would be rather poor.

c. Condition of the habitat following pollutional stress. Rating system - 1-poor; 2-moderate; 3-good. The fly-ash-pond spill and the acid spill on the Clinch River had marked effects on the indigenous biota but had only small short-term effects on the physical habitat of the river and on the chemical characteristics of the water. On the other hand, had extensive siltation blanketed the riffle areas, this would have resulted in marked alteration of the habitat which might persist for a substantial period of time.

d. Presence of residual toxicants following pollutional stress. Rating system - 1-large amounts; 2-moderate amounts; 3-none. The two Clinch River spills changed the pH of the river, the first to a high pH, the second to a low. In both cases, the "slug" of water differing markedly from the ambient pH passed through the river system leaving no residual effects. On the other hand, the intrusion of biocides (e.g., dieldrin, aldrin, mercury, or lead) would almost certainly have left residuals which would probably have persisted in the system for a considerable length of time. The presence of residual toxicants might well impair the recovery of a damaged ecosystem by maintaining toxic conditions unsuitable for potential colonizing organisms. Thus, the presence of such residual toxicants should diminish the recoverability potential of a system.

e. Chemical-physical environmental quality following pollutional stress. Rating system - 1-in severe disequilibrium; 2-partially restored; 3-normal. In some cases the pollutional stress, either through alternation of the substratum or other portions of the system or elimination of certain biota, which affect chemical-physical environmental quality will put the chemical-physical environment of an ecosystem into severe disequilibrium. For example, a reservoir or lake with a substantial algal growth might normally have a dissolved oxygen concentration at saturation during daylight hours and well above two or three ppm even during the longest periods of darkness. If, however, these plants were wiped out, the additional decaying organic load added together with the absence of the plants as a source of oxygen might alter conditions in certain parts of the system from aerobic to anaerobic. This change might be of considerable duration if recovery were left entirely to natural processes. If one assumes that the recovery will involve a return to an approximation of the original conditions, this system could then be considered either displaced or in disequilibrium relative to its original condition. In systems such as the Clinch River, where the flow-through rate was quite high, this portion of the restoration process required only a few hours because the offending materials were rapidly removed from the original spill site. On the other hand, a substantial portion of the river biota was damaged during the passage of the slug. The return to an approximation of the original chemical-physical conditions is an important prerequisite for the reestablishment of a community characteristic of that particular locality.

f. Management or organizational capabilities for immediate and direct control of damaged area. Rating system - 1-none; 2-present; 3-thriving with strong enforcement prerogatives. In some cases river drainage authorities or other management groups exist which may be capable of aiding the recovery process. For example, if an oxygen disequilibrium exists in a reservoir or lake, an approximation of the normal oxygen regime might be achieved by artificial aeration (e.g., Fast 1977). This would presumably enhance the conditions for reestablishment of organisms characteristic to that system, and thereby enable the natural balance to be restored more quickly than might otherwise occur. The cleanup of oil following spills (excluding ecologically damaging cleanup methods, e.g., Nelson-Smith 1977) by organizations charged with the management of a specific ecosystem is another example of such an activity. Reintroduction of certain types of species not likely to reinvade the area on their own is another rather simple example of management intervention in the recovery process. Probably the most valuable contribution a management organization might provide is the establishment of baseline or "normal" conditions so that the degree of disequilibrium can be documented when an accident occurs. When the displacement from normal is known, the necessary corrective steps are usually reasonably clear and the resources available to aid the recovery process can be more efficiently directed to achieve the desired goals. As the organizations charged with ecosystem management become politically and operationally stronger, their role in the recovery process will become increasingly important.

   The corrective actions used as illustrations are relatively simple and straightforward. However, knowing which corrective action is appropriate requires a fairly substantial knowledge of the system and a relatively large pool of background data regarding its "normal" condition. This is probably where most management groups fail.

This information just discussed concerning elasticity is summarized in Table 1.

Using the characteristics listed in Table 1, one can arrive at a rather crude approximation of the probability of relatively rapid recovery. This would mean that somewhere between 40% and 60% of the species might become reestablished under optimal conditions in the first year following a severe stress; between 60% and 80% in the following year; and perhaps as many as 95% of the species by the third year. Natural processes with essentially no assistance from a management or a river basin group accomplished this on the Clinch River spills (e.g., Crossman et al. 1974). The usefulness of this estimate has also been confirmed with data provided by some acid mine drainage studies (Herricks and Cairns 1974). The equation follows.

Table 1. Rating the Critical Factors in Elasticity

	Rating 1	2	3
Existence of nearby epicenters	Poor	Moderate	Good
Transportability of dissemules	Poor	Moderate	Good
Condition of habitat	Poor	Moderate	Good
Presence of residual toxicants	Large Amounts	Intermediate Amounts	Small Amounts
Chemical-physical water quality	Severe Disequilibrium	Partially Restored	Normal
Regional management capabilities	None	Present	Strong

RECOVERY INDEX = a x b x c x d x e x f

400+ : chances of rapid recovery excellent

55-399 : chances of rapid recovery fair to good

less than 55: chances of rapid recovery poor

During the development of this equation, considerably more complicated equations were considered and rejected because the refinements seemed meaningless in view of our present state of knowledge. On this basis, one might reject even the modest effort just made. On the other hand, there seems to be a very definite need to formalize the estimation of recovery. One hopes that more precise equations properly weighted will evolve from this modest beginning.

INERTIA

For the purposes of this discussion, inertia is defined as the ability of an aquatic community or ecosystem to resist displacement or disequilibrium of either structural or functional characteristics. As was the case for the recovery index, the factors are listed in order of importance. However, the justification for this rank ordering is substantially less scientifically justifiable than for the recovery index. Nevertheless, it seems quite clear that the factors are interacting and the justification for multiplying the ratings is considerably stronger than for the rank ordering. The time element is exceedingly difficult to address when evaluating inertia because there may be a substantial lag between the onset of stress and the subsequent symptoms of displacement recognizable to ecologists. Therefore, one should view this index with considerably more caution than the recovery index which is only used following recognizable displacement.

Although time lag and displacements much removed from the onset of stress are a serious problem, they are not as hopeless as they might at first appear. One can make estimates of the probability of effects not surfacing initially by going through the protocol outlined in "Principles for Evaluating Chemicals in the Environment" (1975). Such procedures would, with some modification of the methodologies used, enable one to categorize other stresses and estimate the probability of a lag response. A brief discussion of the primary factors influencing inertia follows.

a. Indigenous organisms accustomed to highly variable environmental conditions. Rating system - 1-poor; 2-moderate, 3-good. One would intuitively expect organisms in an estuary, certain deserts, and other environments where temperature and other environmental conditions may shift rapidly to have developed various physiological, behavioral, and structural capabilities for resisting the deleterious effects of these stresses. Some, but not all, of these mechanisms (such as the ability of a clam to isolate itself from the environment for brief intervals) provide protection against both naturally occurring stresses and those induced by human activities. Heilbrunn (1943) noted that coral reef organisms which inhabit a comparatively stable environment may be killed at temperatures only a few degrees above those which they regularly inhabit. While it is highly unlikely that one would be able to categorize every organism within a system regarding its tolerance of highly variable environmental conditions, a person knowledgeable about the system should be able to make a sound estimate of the degree of resistance to changing conditions the majority of indigenous organisms might be expected to have.

b. System has high structural and functional redundancy. Rating system 1-poor; 2-moderate; 3-good. As Odum (1969) has shown, the early stages of ecosystem evolution are relatively simple systems and as a consequence have relatively low functional redundancy. That is, the loss of a particular species might well mean the loss of a particular trophic level or function because no other species capable of fulfilling this role is present. On the other hand, a mature system with great complexity in which the fractionization of activities and roles is substantial is likely to have a high functional redundancy which minimizes the loss of a single species (although the exact role or function was lost and may not be entirely replaced or taken over by other species present, a substantial portion of this may well be). A system with a high functional redundancy should therefore be less vulnerable to a loss of a single component than one with low functional redundancy, and therefore should be better able to resist displacement of both structure and function.

c. Stream order, flow dependability, turbulent diffusibility, and flushing capacity. Rating system - 1-poor; 2-moderate, 3-good. These characteristics, and others omitted for the sake of brevity, essentially have to do with the volume of water available for dilution, the rapidity with which a waste or other form of stress would be dissipated, and the rate at which it would be removed from the system. A system in which these characteristics are very dependable would be less vulnerable to structural or functional displacement than one which periodically had substantial losses or reductions in one or more of these characteristics In considering these characteristics relative to the inertial stability of a system, one should not lose sight of the fact that wastes which are not degraded or transformed but are merely mixed and carried away will have an impact elsewhere. Those that are degraded and transformed may also have an impact, but most probably a lesser one.

d. Hard, well-buffered water antagonistic to toxic substances. Rating system 1-poor; 2-moderate; 3-good. The literature on water pollution is replete with illustrations of alterations of the impact of toxic chemicals due to differences in water quality such as hardness, pH, temperature, etc. Some hard, well-buffered waters may substantially reduce the impact of many toxic materials, whereas very soft, well-buffered waters may not. With some knowledge of the causative factors of pollution stress, one should be able to estimate whether or not water quality will significantly affect the toxicity or stress dose-response curve. In addition to utilizing the literature for this purpose, it is always well to carry out the site-specific tests with indigenous organisms which also will enable one to define the relationship between the organisms, water quality, and dose-response curve to a particular pollutional stress.

e. System close to a major ecological transitional threshold (e.g., from a cold- to a warm-water fishery). Rating system - 1-close; 2-moderate margin of safety; 3-substantial margin of safety. With regard to thermal loading, one might say with reasonable confidence that the Columbia River is closer to a major transitional temperature threshold (which might cause the loss of salmonoid fisheries) than the Savannah River (which would cause the loss of the channel catfish, bass, and other organisms characteristic of that water system). Long-term continuing studies are necessary to estimate when a system is beginning to approach a major transitional threshold, and for those systems where such studies do not exist such an estimate will be extraordinarily difficult. Even when data do exist, the task will not be easy. It is clear that the inertial stability of a system approaching a major ecological transitional threshold will be less than one substantially away from this point.

f. Presence of a drainage basin management group with the water quality monitoring program. Rating system - 1-poor; 2-moderate; 3-good. The river basin management group can protect against displacement or disequilibrium in two primary ways.

(1) On-going studies which will enable the investigators and decision-makers to know when a major ecological transitional threshold is being approached.

(2) The development and maintenance of an environmental quality control system with rapid information feedback to detect the onset of a pollution stress which might cause displacement or equilibrium (Cairns *et al*. 1970; Cairns 1972, 1975a, b).

In order to be effective this group would, of course, have to have the capability of taking immediate remedial action either before the waste enters the receiving system or, if it has already entered, of taking appropriate measures to reduce the impact upon the system. For both point and non-point source discharges, the long-term studies to provide information about the system which would enable the identification of ecological transitional thresholds appears to be the most important task. However, since power plants frequently use chlorine or other slimicides and since other toxic materials such as heavy metals may be found in the waste discharges, a biological-chemical-physical monitoring system which would enable the group to detect the appearance of toxic materials and take remedial action immediately is also important. A summary of the factors influencing inertial stability is in Table 2.

INERTIAL INDEX = a x b x c x d x e x f

400-729 :inertial stability high

55-399 :inertial stability fair to good

Less than 55:inertial stability poor

RESILIENCY

Resiliency was defined earlier as the number of times a system can snap back after displacement. A very informative illustration of resiliency has been provided by Brian Dicks (1977) in his investigation of the effect of oil spills on salt-marsh plants in Great Britain. Simulating a series of rather small oil spills restricted to a limited area, Dicks found that the salt-marsh organisms could recover relatively rapidly after two or three spills in reasonably close succession. Even four or five exposures in reasonably close sequence were tolerated with subsequent recovery. When 16 or 17 insults were given with about the same frequency and at the same volumes to a comparable area, there was no recovery -- at least within a time span considerably longer than that in which recovery had been previously demonstrated. This suggests that the salt-marsh ecosystem had a "reserve" which would carry the system through a limited number of repeated stresses but that the number of these that could be tolerated was finite even though the area exposed and the volume of oil spilled were kept constant for each exposure. Thus, the resiliency of this system could be determined by a field bioassay with repeated exposure in which the exposure intervals and volumes of oil used in each were controlled, but in which no other extraneous materials were placed in the natural system. Perhaps there are other systems for which resiliency could also be easily determined, although it is quite evident that for the Great Lakes, oceans, and other large and complex ecosystems the determination of resiliency will be difficult or impossible. Recognition that this problem exists and even a crude estimate of the degree of resiliency may be enormously useful in developing management plans.

BIOLOGICAL MONITORING

Precise quality control for any dynamic system depends upon frequent or continual feedback of information. Most regulatory agencies depend more upon pipe standards (i.e., regulating what leaves a waste treatment plant) than upon receiving system standards (i.e., using the condition of the ecosystem itself including the organisms as a standard for waste loading). Control measures applied to aquatic ecosystems, in the absence of continuing information on the condition of the system, will probably be inappropriate and thus may overprotect the receiving system at times and underprotect it at other times since the capacity of ecosystems to receive wastes is not constant (Cairns 1967, 1975b). The precision and efficiency of environmental quality control and the lag time in the information feedback loop are related. If the lag time is too great, the control measures may repeatedly overshoot and then undershoot the desired goal as a thermostat with too slow a response will cause first underheating then overheating of a house. A more extensive discussion of biological monitoring systems was presented to the Ecological Society of America in 1975 (Cairns et al. 1976). A statistical method for in-plant monitoring systems may be found in Hall et al. (1975) and an array of biological monitoring techniques are given in Westlake and van der Schalie (1977). The methods are, of course, less important than the rationale.

CONCLUSIONS

There is a definite need for a more structured means of estimating risk to an ecosystem *before* a proposed course of action which might stress the ecosystem is undertaken. The risk analysis should include both the vulnerability to displacement in structure and function and the probability of returning to an approximation of the original condition if displacement occurs. Displaced ecosystems should be examined to determine the probability of partial or complete recovery including the costs and means of accomplishing this. Biological monitoring systems are needed to prevent displacement by assessing waste toxicity before it enters the receiving system so that an early warning system can be used to prevent damage. Different biological monitoring units placed in the receiving system itself will help maintain and/or improve environmental quality or at worst insure that degradation does not go undetected for extended periods of time. Ecologists must provide methods and data to make environmental quality control and enlightened management a reality.

Table 2. Rating the Critical Factors in Inertia

	Rating 1	Rating 2	Rating 3
Indigenous organisms accustomed to variable environment	Poor	Moderate	Good
System has high structural and functional redundancy	Poor	Moderate	Good
Mixing capacity	Poor	Moderate	Good
Hard, well-buffered water	Poor	Moderate	Good
Closeness to ecological threshold	Close	Moderate Margin of Safety	Substantial Margin of Safety
Regional management capabilities	Poor	Moderate	Good

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It is difficult to properly acknowledge all of the contributions others have made over a 28-year period toward an awareness of the recovery process for one of us (Cairns) and 8 for the other (Dickson). However, several were clearly landmark events. In the 1950's Ruth Patrick developed a new channel on Ridley Creek, Pennsylvania (Patrick, R. 1959. "Aquatic Life in a New Stream." Water and Sewage Works. 106:531-535), and Cairns participated in the study of the colonization process. This was a major pioneering study and one hopes that more detailed results will be forthcoming. The second was a study of the Savannah River before and after channel dredging for which Ruth Patrick was also principal investigator. The third major event was the fly-ash-pond spill on the Clinch River, subsequently followed by partial recovery and then an acid spill. John S. Crossman, then a graduate student at Virginia Polytechnic Institute and State University, spent four years studying this system, and we are deeply indebted to him for a major role in generating the recovery process (a list of publications on the Clinch River follows: J. Cairns, Jr., J.S. Crossman, and K.L. Dickson. 1972. "The Biological Recovery of the Clinch River Following a Fly-Ash-Pond Spill." Proc. 25th Ind. Waste Conf., Purdue Univ. Eng. Bull. 137(1):182-192. J. Cairns, Jr., J.S. Crossman, K.L. Dickson, and E.E. Herricks. 1973. "The Effect of Major Industrial Spills Upon Stream Organisms." Proc. 26th Ind. Waste Conf., Purdue Univ. Eng. Bull. 140(1):156-170. J.S. Crossman, R.L. Kaesler, and J. Cairns, Jr. 1974. "The Use of Cluster Analysis in the Assessment of Spills of Hazardous Materials." Am. Midland Nat. 92(1):94-114. J.S. Crossman, and J. Cairns, Jr. 1975. "The Effect of a pH Neutralization Unit Upon the Aquatic Macroinvertebrates of the Clinch River." Proc. 28th Ind. Waste Conf., Purdue Univ. Eng. Bull. 142(1):425-437). The studies of acid mine drainage problems by Edwin E. Herricks while a graduate student at Virginia Polytechnic Institute and State University were equally helpful in understanding the recovery process (a list of publications on this subject follows: E.E. Herricks, and J. Cairns, Jr. 1972. "The Recovery of Stream Macrobenthic Communities From the Effects of Acid Mine Drainage." Pages 370-398 in Fourth Symposium on Coal Mine Drainage Research, Inc. E.E. Herricks, and J. Cairns, Jr. 1974. "The Recovery of Streams Stressed by Acid Coal Mine Drainage." Pages 11-24 in Coal and the Environment. Fifth Symposium on Coal Mine Drainage Research, National Coal Association, Kentucky). Finally, we are most grateful to colleagues who participated in the Symposium on the Recovery and Restoration of Damaged Ecosystems (Cairns, J., Jr., K.L. Dickson, and E.E. Herricks, eds. 1977. Recovery and Restoration of Damaged Ecosystems. University Press of Virginia, Charlottesville), for showing us how ecosystems resist displacement, recover from displacement, and even evolve to a dependance upon perturbation (Vogl, Richard J. 1977. "Fire: A Destructive Menace or a Natural Process?" J. Cairns, Jr., K. L. Dickson, and E. E. Herricks, eds. Recovery and Restoration of Damaged Ecosystems. University Press of Virginia, Charlottesville).

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THE BASELINE STUDY AS A TOOL IN ENVIRONMENTAL IMPACT ASSESSMENT

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INTRODUCTION

With the advent of the environmental movement, and particularly in response to the National Environmental Policy Act and other legislation, the environmental baseline study has become an accepted element of many federal resource development and environmental protection programs. Currently, baseline studies conducted by various governmental agencies or required by regulations address a wide range of environments, resource developments and potential impacts. They include terrestrial, freshwater and marine ecosystems.

As part of an accelerated program to develop geothermal resources in the western United States, U.S. Geological Survey regulations require a one-year environmental baseline study prior to initiation of geothermal production from federal leases. Bureau of Land Management lease stipulations governing a prototype oil shale development program in Colorado and Utah require the lessees to conduct two-year environmental baseline and monitoring studies prior to initiation of development. The Department of the Interior has initiated an accelerated program to lease and develop Outer Continental Shelf oil and gas reserves in response to national energy needs. During the last two years, as part of that program, the Department's Bureau of Land Management has funded a wide ranging series of marine environmental baseline studies extending around the coasts of the United States from the Beaufort Sea in Arctic Alaska to the South Atlantic. In anticipation of probable need to prepare an Environmental Impact Statement on a program of deep ocean mining for manganese nodules, the National Oceanic and Atmospheric Administration is undertaking baseline studies in the central Pacific Ocean. Environmental baseline studies are being conducted by the electric utility industry in rivers, estuaries and coastal areas to meet Environmental Protection Agency and Nuclear Regulatory Commission requirements relating to power plants development. An Environmental Protection Agency program to regulate ocean dumping of wastes has generated baseline surveys of various dump sites ranging from locations on the Outer Continental Shelf to a deepwater dump site at the edge of the mid-Atlantic Continental Slope at depths extending to almost 3000 meters. The State of Washington is undertaking a program of baseline studies of Puget Sound in advance of trans-shipment of Alaskan oil.

Major resources are being committed to such investigations. For example, the fiscal year 1977 budget of the Department of the Interior requests \$55 million for the Bureau of Land Management's Outer Continental Shelf study program described above. The costs of establishing baselines for prototype oil shale development programs have been estimated at between \$12 and \$18 million. As a conservative estimate, perhaps \$10 to \$15 million has been spent by the electric utility industry in collecting baseline and related environmental data on the Hudson River Estuary.

Large numbers of scientists in many disciplines are involved in baseline studies. In Alaska the magnitude of federally sponsored marine baseline studies seems to be straining the supply of qualified personnel and suitable research vessels. In some areas of the Northern Great Plains, so many scientists are criss-crossing the land in pursuit of baseline data that local ranchers have invoked the Heisenberg Principle, observing that the studies may create more environmental disturbance than the projected coal mining.

In short, the environmental baseline study has assumed major importance. Heavy reliance is being placed upon baseline studies to help decision-makers meet the intent of NEPA and other environmental regulations. These programs are being justified as necessary to provide understandings which can help minimize environmental impact of various developments and reconcile the inherent conflict between environmental protection and economic development that has become a major public policy issue in recent years.

In addition, for many of the large ecosystems under study, such as remote marine areas whose investigation requires expensive equipment and logistic support, current

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support for baseline study programs represents an unprecedented opportunity to develop synoptic, interdisciplinary approaches which can add to our fund of information and understanding. Thus, at a time when usual federal sources of research support are relatively limited, these study efforts are of added importance to ecologists.

At the same time, there is considerable evidence of concern about the utility of the baseline study approach. For example, the Department of the Interior has established an Outer Continental Shelf Environmental Studies Advisory Committee to provide scientific advice concerning its environmental studies program. For over two years the scientists on this Committee have continued to debate the rationale of the baseline study approach with seemingly little agreement.[1] An evaluation of baseline data being collected on the prototype oil shale leases has pointed to the need for more precise data guidelines to assure that a scientifically sound program will emerge for monitoring potential environmental changes (Fish and Wildlife Service 1976). The adequacy and value of extensive baseline studies conducted for evaluation of power plant impact in such coastal systems as Chesapeake Bay and the Hudson River Estuary continues to be questioned. Clark and Brownell (1973) for example, state that large sums of money have been wasted on power plant baseline studies. A recent editorial in Science (Schindler 1976), while not referring specifically to baseline studies, decries the ineffective design and execution of many environmental impact studies, citing an emphasis on indigestible descriptive data. Although the author's interpretation of the causes (emphasis on silencing the "ecofreaks" without regard for study content, lack of scientific competence, complex committee hierarchies, etc.) may be subject to challenge, his observations concerning the results ("diffuse reports containing reams of uninterpreted and incomplete descriptive data," studies that begin "with little or no logical background," "enormous sums...spent with little or no scientific return") seem all too accurate.

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[1]Many of these discussions are documented in the minutes of the Department of the Interior's OCS Environmental Studies Advisory Committee and its predecessor organization, the OCS Research Management Advisory Board. An ad hoc committee of this group has also attempted to grapple with the issue of baseline study design, and the report of that effort has provided useful input to this paper (1976).

Several key issues underlie these debates and criticisms. They are: (1) What role should baseline studies play in the evaluation of environmental impact? (2) What are some important considerations governing the design of baseline studies? and (3) How should baseline studies relate to some of the other approaches to evaluation of environmental impact?

ROLE OF BASELINE STUDIES

The 1970 Study of Critical Environmental Problems (SCEP) was a pioneering effort to focus interdisciplinary attention on problems of measuring wide-scale environmental change. The Conference's Work Group on Monitoring discussed baselines as follows: "...our report is concerned not only with monitoring in its sense of providing warnings of critical changes but also with measurements of the present state of the system (the 'baseline')...." The report stated, "We recommend early implementation of a set of ecological baseline stations in remote areas that would provide both specific monitoring of the effects of known problems and warnings of unsuspected effects." In describing the components of a proposed ocean baseline sampling program as a precursor of a monitoring program to detect long-term oceanic changes the report stated, "...both one time and continuing surveys are needed: these surveys will help us establish a baseline for analysis."

Subsequently, the need for establishment of environmental baselines has received attention at the 1972 United Nations Conference on the Human Environment and follow-up efforts to implement a Global Environmental Monitoring System (NAS 1976).

This concept of baseline studies has also been incorporated in various federal documents and requirements. The Coast Guard's 1975 "Guide to Preparation of Environmental Analyses for Deepwater Ports," for example, refers to "... comprehensive information on the basic human and natural conditions which constitute the area's 'pre-deepwater port' environment. Baseline environmental information must be provided for the area which may be affected by the deepwater port project to establish existing background levels and conditions so that future changes can be ascertained."

The Bureau of Land Management's Oil Shale Lease (1974) states: "The Lessee shall compile data to determine the conditions existing prior to any development operations under the lease and shall, except as provided below, conduct a monitoring program before, during and subsequent to development operations. The Lessee shall conduct the monitoring program to provide a record of changes from conditions existing prior to development operations, as established by the collection of baseline data..."

Proposed revisions to Environmental Protection Agency Ocean Dumping Regulations and Criteria (1976) currently undergoing review describe baseline surveys of ocean disposal sites as follows: "The purpose of a baseline or trend assessment survey is to determine the physical, chemical, geological, and biological structure of a proposed or existing disposal site at the time of the survey. A baseline or trend assessment survey is to be regarded as a comprehensive synoptic and representative picture of existing conditions; each such survey is to be planned as part of a continual monitoring program through which changes in conditions at a disposal site can be documented and assessed."

I have been unable to find a relevant dictionary definition of the word "baseline." However, a reasonable definition of the baseline concept as used by the highly qualified SCEP scientists and as reflected in a number of federal guidelines would be, "A description of conditions existing at a point in time against which subsequent changes can be detected through monitoring." If this definition is accepted, it delimits to large extent the role of baseline studies in environmental impact evaluation. Under this definition, the baseline study is not a predictive tool; its principal use is for post hoc detection of change. As such, a baseline study would be of limited utility in meeting the requirements of an Environmental Impact Statement, which are basically predictive in nature.

Yet there is considerable evidence to suggest this sharp definition of baseline studies is not universally accepted, and that the rationale and expectations for baseline studies are less clear-cut. For example, in a memorandum on improving Environmental Impact Statements, the Chairman of the Council on Environmental Quality stated, "Specific baseline inventories and environmental research will often be needed initially to determine if there are environmental problems that should be analyzed in an impact statement" (Peterson 1976). A critique of an Environmental Impact Statement in the report of the Institute of Ecology's Environmental Impact Assessment Project states, "The EIS does not provide either enough relevant baseline information or enough project-specific discussion of the possible impacts of the proposed alternatives, including 'no action,' to allow informed independent judgments to be made by agency decision-makers or the public." (Winder and Allen 1975). Statements such as these suggest that in actual practice the term "baseline" is used quite loosely to cover a range of information required for purposes of environmental impact assessment.

The need to sharply define the purpose of baseline studies and the role and inherent limitations of the baseline approach is more than an effort to establish a semantic strawman. At least some of the problems concerning adequacy of baseline study design and utility of the findings seem to stem from imprecision concerning the basic purpose.

PREDICTIVE VERSUS POST HOC STUDIES

Both predictive and post hoc environmental impact assessments are required. Predictive capability is needed to guide those decisions that can be taken to avoid or minimize environmental damage in advance. However, since our ability to predict is quite unreliable and will never be completely adequate, a post-development monitoring program is needed to support a feedback loop by measuring actual impacts. This information can be used to take remedial action where technology permits and where the damage is not irreversible.

The post hoc assessment, or retrospective study, will also improve our capability to predict similar circumstances in the future. In this regard, we need to improve our ability to transfer findings gained from impact studies in one ecosystem to other similar systems, thus enabling us to make meaningful management generalizations concerning impact. Ecological classification systems, such as the one described at this Symposium by Montanari and Townsend (1976) in their paper on the National Wetlands Inventory can facilitate this by providing means of aggregating information and extrapolating research results and management experience among systems with similar properties.

Descriptive information is required for both predictive and post hoc assessments, but the attributes of the information needed for each purpose are somewhat different. I believe that many descriptive studies of large scale ecosystems conducted under the broad aegis of "baseline" address neither set of attributes well. Therefore, it may be useful to distinguish between two interrelated but distinct study approaches conducted for the purpose of describing ecosystems subject to impact: (1) ecological characterization, and (2) baseline and monitoring studies.

ECOLOGICAL CHARACTERIZATION

Clearly, as an early step in the environmental impact assessment process, efforts must be made to understand the most salient features of the ecosystem involved. This includes such features as the biological resources important to man (e.g., fish, bird and mammal populations, endangered species) and particularly important components of their habitat (e.g., breeding, spawning and migratory areas). It includes identification of key biological processes such as trophic relationships, and driving forces such as climatic conditions and transport mechanisms. Environmental hazards such as storms, floods or earthquakes should also be assessed.

This kind of information will provide at least an initial basis for predicting some of the anticipated impacts of development. For example, in its Outer Continental Shelf Oil and Gas Leasing Program, the Department of the Interior is currently using information on distribution of important biota; prevailing wind and current patterns; and probability of storms, earthquakes or other spill-inducing hazards in risk analyses which can be used to exclude particularly hazardous tracts from development.

The need for good reconnaissance information of this type is well-recognized. However, descriptive information on large-scale ecosystems could prove more meaningful if structured to accomplish what I will term "ecological characterization." An ecological characterization is a description of the important components and processes comprising an ecosystem and an understanding of their functional relationships. A guiding element in the characterization is a conceptual or descriptive model.

The characterization should address such major elements as physiography and geology; climate; and physical transport mechanisms such as hydrology, sediment flux, physical oceanography (in the case of marine systems), and atmospheric transport. It should describe the important species, communities and populations in the study area, with particular emphasis on those organisms perceived as being of importance to man or critical to the functioning of the ecosystem. Population estimates can be approximate but they should, where feasible, attempt to address the extent and causes of natural variability. The characterization should describe ecological processes, such as trophic relationships, food chains, and energy flows, particularly those considered to be or known to be controlling. It should describe social and economic features of the area (e.g., population distribution, land use, industrial development), and address significant man-induced or natural influences on the ecosystem such as successional processes, existing man-made modifications and extent of pollution.

The characterization should also address transboundary effects -- that is the relationship of influences outside the ecosystem on the system itself. In establishing meaningful boundaries for complex, open ecosystems, we are trying to force natural conditions into organized units where the critical interactions tend to be more within the system than with adjacent systems, and a measure of arbitrariness will be involved. Ecological classification systems based on hierarchical concepts, combined with conceptual ecosystem modelling, should help provide a more structured approach to the definition of reasonable study boundaries.

The first emphasis in ecological characterization should be compilation, analysis and synthesis of all available and relevant data structured around the conceptual ecosystem model. The initial characterization should identify important gaps to which subsequent field or laboratory investigations should be directed. For many areas which have already been extensively studied, although in a fragmented way, a meaningful initial characterization can be developed based on existing information. In other areas, extensive field reconnaissance may be required even to complete a rough or initial characterization.

Some of the follow-up studies required after the initial characterization may be straightforward inventories, needed to fill gaps in descriptive information. Frequently, more dynamic study approaches will be indicated. For example, this may involve development and verification of functional predictive models for specific system interactions or controlled ecosystems experiments.[2] As studies such as these are completed, the initial characterization can be upgraded and refined.

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[2]Barrett, et al. (1976) in a recent paper outline guidelines for testing and evaluating perturbations on total ecosystems, many of which have direct application to the issues being discussed here.

Unlike the baseline study, many of the elements described in the characterization are important, not because they are expected to change as a result of proposed development, but because they are needed to help understand the system and how it functions. Although different considerations determine the data required for characterization and baseline studies, some current study programs comprising a mixture of both approaches fail to recognize these differences. As a consequence, data may be collected which meet neither purpose. An example is continued sampling for parameters whose features are already adequately understood for initial characterization purposes, but where the additional sampling will not be adequate to provide statistically reliable baseline data because of the level of natural variability involved.

To some it may appear that my description of an ecological characterization is nothing more than the information required in preparation of an Environmental Impact Statement. Yet many Environmental Impact Statements fall woefully short of reflecting such characterizations, as the report of the Institute of Ecology's Environmental Impact Assessment Project indicates.

Various environmental atlases, inventories and summaries of existing literature are prepared either in conjunction with an environmental impact assessment program or for some other purpose. Examples are the Washington Environmental Atlas (U.S. Army Corps of Engineers 1975) and the Coastal and Offshore Environmental Inventory, Cape Hatteras to Nantucket Shoals (Marine Experiment Station, University of Rhode Island 1973). Many of the elements of this proposed ecological characterization are embodied in such documents. However, while efforts such as these represent excellent starting points, they do not fully meet the criteria for ecological characterization as described above. They frequently represent a compilation of information available in individual disciplinary areas and lack the data synthesis and integration which is particularly necessary to describe ecosystem functions. As such these efforts fall short of providing the most useful end-product for initial impact analysis and orderly guide to future study design.

An initial characterization should be an early or first step in analysis of any ecosystem under major study for impact analysis purposes. Once completed, the initial characterization will help us make some reasoned judgments about the impacts of the anticipated development. Since the time scale for completing the initial characterizations is fairly short, the information can be provided at the front-end of the developmental process to assist in decision-making. It will also be of major assistance in establishing priorities guiding future work, a critical issue as anyone who has experienced both the conceptual and administrative difficulties involved in integrating large-scale interdisciplinary ecological investigations can attest. It can serve as a guide for design of baseline and monitoring studies, as will be discussed below. (In serving this purpose, the characterization approach has some direct analogies with the IBP biome study approach.)

Improved techniques for developing, maintaining and refining ecosystem characterizations are an important need. In this regard, the Fish and Wildlife Service is currently experimenting with a pilot program to characterize selected coastal ecosystems, with an initial project underway in the Chenier Plain on the Louisiana/Texas coast. For many ecosystems, initial efforts in this direction may have a much higher pay-off than field programs to collect additional data. Further, since the characterization describes the ecosystem and is not impact specific, it can have multiple utility for assessing various proposed developments as these emerge.

The characterization approach can be combined with detailed technology assessment in which the range of technologies involved and their anticipated perturbations are analyzed as a basis for designing field programs and for assessing impact. This seems elementary, and there are probably few, if any, studies mounted for purposes of evaluating a specific development that do not take into account the obvious stresses such as hydrocarbon discharges in the case of offshore oil and gas development or surface land disturbance in the case of strip mining.

However, there has been less attention in study design to anticipation of the effects of secondary and tertiary development. For example, in the case of Outer Continental Shelf development, many of the anticipated environmental impacts will occur in onshore and coastal areas as a result of secondary and tertiary developments. Monitoring designed to detect hydrocarbon increases in marine organisms may overlook the impact of increased salinities on shrimp and oyster production associated with estuarine dredging. Similarly in the case of anticipated coal mining in the Northern Great Plains, the impact of changed population patterns, involving such effects as increased hunting pressure, use of off-road vehicles, and feral dog and cat populations, may well prove to have more impact on wildlife resources than habitat destruction resulting from strip mining itself.

DESIGN OF BASELINE AND MONITORING STUDIES

The desirability of baseline and monitoring studies which could supplement our limited predictive capability by providing an early warning of environmental change is apparent. However, a number of formidable obstacles exist to the establishment of baselines for large-scale ecosystems which will actually serve as a basis for monitoring and detecting subsequent change over time, particularly those changes of a subtle, sub-acute, non-catastrophic nature.[3] These obstacles involve natural variability and cause and effect relationships.

NATURAL VARIABILITY

Means of dealing with the enormous variability in many of the systems under study, the so-called noise-to-signal ratio, is a basic issue. The question is whether a monitoring program can be devised through which deviations or trends can be determined against the background of natural spatial and temporal variation. The investigator may be faced with spatial variability problems, such as those associated with patchiness in various populations, or with temporal variability involving diurnal, seasonal and long-term fluctuations of enormous amplitude.

Thus a first step in study design must be attention to this problem. This involves several related aspects: selection of parameters, statistical design, establishment of control areas and logistic and cost considerations.

1. Selection of parameters to be measured is a key issue in dealing with the question of variability. Parameters for the baseline and monitoring program may be estimates of species distribution and abundance, community structure (e.g., diversity indices), physiological condition (e.g., growth rate, fecundity) or processes (e.g., primary productivity, benthic respiration).

[3]The baseline is usually considered to be a description of conditions existing prior to development, and monitoring to be a program of measurements subsequent to development for the purpose of detecting changes. However, in actuality, the two phases may frequently represent a continuum, with subsequent monitoring strengthening the statistical validity of the initial baseline. Conversely, a program of monitoring may reveal changes without an initial baseline study of the area concerned.

A first consideration must be to select parameters known to be sensitive indicators of the anticipated environmental stress. In many cases these may be difficult to identify; this points to the need for continuing research to identify meaningful environmental indicators.

Top predators or organisms high in the trophic structure can serve as integrators, and thus provide more information on issues such as the distribution of contaminants than may other organisms lower in the food web.[4] Species that are relatively long-lived and have low natural mortality in the adult stages may provide considerable historical information through age and growth rate analysis.

In contrast to the characterization phase, where heavy emphasis must be placed on obtaining information on biota important to man, in designing baseline and monitoring studies organisms or processes which are sensitive and reliable indicators assume key importance. In actual practice, however, often the same groups of organisms are involved. For example, the SCEP Report (1970) states, "We recommend central coordination and, where necessary, modification of national and regional surveys of critical populations of fish, birds, and mammals from commercial catches, harvests and surveys. This would provide an early warning system by monitoring highly sensitive and vulnerable species."

A further consideration in parameter selection may involve identifying organisms or populations whose distribution or habits lend themselves to statistical sampling. Thus benthos may be more useful than plankton; colonial nesting birds with well-established colonies may be more useful than birds with dispersed distribution and nesting habits.

Parameters directly linked with the development under study, such as levels of petroleum hydrocarbons in the case offshore oil development or levels of fecal coliform bacteria in monitoring ocean dump

[4]Some investigators have taken a contrary view. Glover, _et al._ (1974), for example, argue that, "Preferably, also, we should monitor populations near the beginning of the food chain because they are most likely to reflect direct effects of natural changes in the environment -- and it is in this part of the ecosystem that events of major significance are likely to have their origin."

sites, can assist in establishing baselines which can separate out the effects of natural variability and related observed changes to the development under study. Contaminant monitoring may be particularly useful in those instances where a baseline can be established in a relatively uncontaminated area prior to development.

2. As a closely related matter, the nature and magnitude of the variability involved must be addressed before a detailed baseline and monitoring program is established. In some cases, historical records or existing information concerning the factors influencing variability can provide part of this information; I have already argued that such information should be compiled and analyzed in the characterization phase. In other cases, intensive initial efforts must be made to define spatial and short-term temporal variability through an experimental approach to sampling design. In some baseline study programs, however, there appear to have been a tendency to begin a broad-scale baseline program with a predetermined and somewhat arbitrary sampling pattern based more on logistic convenience and feasibility than on the characteristics of the variables to be measured.

3. If representative control areas can be established, this provides a means of comparison with changes within areas subject to impact which helps to delineate the effects of temporal variability. Selection of control areas requires a clear understanding of transport mechanisms in relation to the extent and distribution of the anticipated impact. In large, open ecosystems it may not be possible to establish sufficiently homogeneous control areas outside the area of probable impact.[5]

[5] In this regard, the baseline study can be considered as one element of experimental design. If control areas can be established, controlled ecosystems experiments may provide an alternative or complementary approach to the observation of actual impact. Such approaches have been widely used in terrestrial applications such as range management research. Efforts are also underway to develop techniques applicable to more difficult open ecosystems, such as marine environments. An example is the Controlled Ecosystem Pollution Experiment (CEPEX) sponsored by the National Science Foundation's International Decade on Ocean Exploration, in which marine communities are maintained in situ in large, flexible plastic cylinders and stressed by the addition of low level chemical pollutants.

4. Finally, in the selection of parameters for baseline and monitoring purposes, considerable attention must be given to issues of costs, logistics, availability of reliable sampling and analytical methods and similar matters. In the final analysis, these issues can also have a major impact on the parameters selected. For example, sampling or analytical error can compound the already difficult problem of variability and add to the "noise." Further, if costs for measuring and analyzing a given parameter are high, this in turn will reduce the number of observations that can be made within any given sampling budget, and thus the statistical reliability.

CAUSE AND EFFECT

Even where a statistically valid sampling program can be devised which can detect trends or departures from a "norm" (e.g., decreases in species diversity, reduced reproductive success, changes in age class structure), a second major question is -- to what extent are these changes related to the man-caused perturbations under study? Can we ascribe the change to a specific environmental stress, man-caused or natural?

Apart from those cases where the source and nature of the disturbance are relatively discrete and the effects are relatively well-understood (e.g., site-specific sites of the impact of industrial pollutants on streams), the answer is frequently "no." For large, complex ecosystems subject to a variety of natural and man-induced stresses, cause and effect determinations can be extremely difficult without intensive study. Baseline and monitoring data can trigger the need for further study, but often may not in themselves provide information needed to induce remedial action and reduce impact. I will cite several examples.

Concentrations of mercury in the tissues of various species of marine fish have been well-documented. However, there continues to be disagreement concerning the extent to which these concentrations result from naturally occurring mercury or from man-induced discharges (Hammond 1971 and Krehl 1972).

Long-term records of the distribution and abundance of zooplankton populations in the North Sea and eastern Atlantic obtained by marine laboratories in Great Britain for the period 1948 to 1972 indicate a number of shifts in species distribution and abundance over time. However, the cause of these shifts is unknown: "Our inability to explain systematic changes and trends is unsatisfactory from a purely scientific standpoint but in recent years it has become potentially dangerous. Any fairly linear trends such as those illustrated in this paper could be related to almost any activity of man because most of man's activities are changing in a cumulative manner. It would be no more than flippant to relate the plankton trends to the illegitimacy rate in teenage girls (because we hope nobody would impute a causal relationship) but it might be dangerously misleading to relate them to the quantities of suspended matter in the atmosphere, or the rates of industrial production of mercurial fungicides and organochlorine insecticides (because there are many people who would undoubtedly impute a causal relationship without the essential evidence from all the interacting complex of factors that produce variability in nature)." (Glover et al. 1974).

The utility of biological monitoring for measuring environmental contaminants is widely recognized. Work conducted at the U.S. Fish and Wildlife Service's Patuxent Wildlife Research Center has demonstrated that wading birds, such as herons, can be used effectively to assess regional extent of environmental contamination by organochlorine chemicals (Ohlendorf 1974). This work is now being extended to consider whether measurements made in wading bird colonies along the Atlantic coast can be used to monitor other physical changes in the coastal environment, such as those stemming from dredging or wetlands destruction. Indications are that statistically valid observations can be made of changes in abundance, species composition and reproductive success. However, the question of relating observed changes in these variables to specific man-caused impacts is proving much more difficult and may not be feasible.

All these complexities indicate that, to be meaningful, baseline studies must be designed with selectivity and great analytic rigor. However, it appears that in many cases the "court everything" approach prevails, with compilation of exhaustive species lists assuming great importance.

SIGNIFICANCE OF CHANGE

Even if these major obstacles to the design of meaningful studies can be overcome, the baseline approach is probably of quite limited value unless it is an integral part of a much larger effort to address ecosystem characteristics and dynamics. Where environmental changes can be monitored and related to the development under study, a final set of questions relates to the significance of the change, both ecologically and to man. This has been termed the "so what?" question.

There is now substantial evidence of widespread petroleum contamination in many parts of the world's oceans (IDOE 1972 and NAS 1975). Estimates have also been made of the sources of this contamination, involving such inputs as atmospheric fall-out of hydrocarbons from automobile emissions and other sources, tanker accidents, offshore production, natural seeps, and discharges from rivers and coastal areas. Thus an increase in contamination has been detected and the cause at least roughly quantified. However, there is no consensus on the ecological impact. The National Academy of Sciences (1975) review, Petroleum in the Marine Environment, states, "A basic question that remains unanswered is "At what level of petroleum hydrocarbon input to the ocean might we find irreversible damage occurring?" Unless and until this question is answered, there is unlikely to be agreement at the international level as to the need for additional controls that ought to be applied to reduce ocean contamination.

In the case of icthyoplankton populations it may be possible to estimate the total population and to predict or measure fairly accurately the loss of fish eggs and larvae which would result from impingement and entrainment from specific power plants. However, the significance of this reduction to the mature catchable population of fish will be much more difficult to estimate. For one thing, a number of density dependent factors operating to limit the adult fish population (e.g., cannibalism, disease, predator-prey interaction) may act to partially compensate for the induced mortality.

Questions such as these point to the need for continued ecological research to provide an underpinning for ongoing efforts at ecological impact assessment. In the first example cited above, research on chronic toxic effects and possible food chain up-take of petroleum hydrocarbons is called for. In the second case, better understandings are needed of the population dynamics of the fisheries concerned.

Once the ecological "so what?" question has been answered and the extent and consequences of environmental damage have been reasonably clearly documented, the trade-off between that damage and the benefits of the proposed development still remains to be made.

That issue falls outside the arena of environmental impact assessment, and into the consideration of alternative social, political and economic values and raises "so what?" questions of a different sort. However, it is the task of the environmental impact assessment to contribute the information which will make the value choices involved more clear.

In some cases, social objectives specifying degree of environmental impact acceptable can be stated in advance. Examples are legally adopted air and water quality standards. Such levels can then assist in study design, by indicating the level of impact to be predicted or monitored for. This, of course, still begs the issue of the adequacy of the legal standards in relation to actual environmental impact, which in many cases is still a matter of debate and an important area for additional research.

SUMMARY AND CONCLUSIONS

Current requirements and sources of financial support for environmental baseline studies provide a major opportunity to improve our capability to assess and predict environmental impact, and thus to improve decision-making and increase the chance of protecting the nation's environment and natural resources. However, the adequacy of current study approaches continues to be contested.

On the one hand, in funding environmental impact studies directly supportive of operational or regulatory requirements, administrators have had a tendency to select descriptive studies, such as baselines. Such studies can provide concrete data products within fixed time constraints, and thus a sense of security, however false. More experimental or dynamic approaches often have been regarded as too uncertain and relegated to the area of "long-term research." On the other hand, some scientists have decried the pressure to produce short-term results and protested the institutional mechanisms involved in management of large-scale interdisciplinary studies in the name of academic freedom -- incidentally, thus reinforcing the administrators' concerns.

I believe that most decision-makers would recognize the continuing need for fundamental or long-term research focused on important questions of environmental stress. At the same time, ecologists should also recognize the hard reality that in many cases the imperatives of development (whether real or perceived) will not await the findings. To contribute more effective information for environmental impact assessment in real world situations, we must usually operate within or near the state-of-the-art. We must also recognize that we are dealing with decision-making uncertainty and that we already possess the capability to reduce that uncertainty, even if we cannot resolve the environmental unknowns.

There appear to be significant opportunities to improve performance at this level. Evidence suggests that we do not do as well as we know how because of problems that are more managerial than scientific. They relate to difficulties in designing and organizing large-scale studies involving a variety of investigators, institutions and disciplines. To the study manager it may sometimes seem that he is attempting to conduct a symphony orchestra comprised entirely of solo performers.

Then too, a sense of urgency sometimes overtakes cool planning logic when development projects are initiated. For example, major construction projects are often well-developed from an engineering standpoint before any consideration is given to environmental planning. A crash program of environmental studies may result from urgency associated with documenting the predevelopment state of the environment. Once a program of predevelopment sampling is established it may generate its own momentum for continuation into the monitoring phase. This, therefore, locks money and often scarce technical resources into a program which may have very limited payoff and little flexibility.

A major challenge confronting those who fund, manage and design impact assessment studies of large-scale ecosystems must be to find ways of assuring more rigorous study conceptualization, design and integration. We need to direct attention towards:

1. Distinguishing between those data which are required principally for initial predictions of environmental impact and those required to detect the post hoc effects of development.

2. Continued efforts to develop as an early step in the impact assessment process ecological characterizations of major ecosystems facing stress. This includes development of better techniques of characterization, with emphasis on information synthesis.

3. Careful consideration of the need for and value of baseline data in relation to their inherent limitations.

4. Careful attention to selection of parameters and statistical design in conduct of baseline and monitoring studies.

5. Efforts to select the combination of study approaches most appropriate to the ecosystem and impact being assessed, including such techniques as predictive models and controlled ecosystem experiments.

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ECOSYSTEM PROFILE ANALYSIS AND PERFORMANCE CURVES AS TOOLS FOR ASSESSING ENVIRONMENTAL IMPACT

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An overall ecological paradigm that provides a guideline for the practice of environmental assessment is, in our opinion, expressed quite adequately by the familiar adage that the forest is indeed more than a collection of trees. In more formal terms this paradigm can be stated something as follows: As living and non-living components are combined to produce successively larger and more complex levels of organization there is vertical integration resulting in new or emergent properties not discernible or assessable on the basis of identification and study of sub-components alone. In our opinion, most impact statements are inadequate because they focus on the wrong level -- often, for example, on the species or factor level when the questions and decisions involve the ecosystem level. Accordingly, environmental impact assessment should be evolving rapidly from component analysis (wherein factors and organisms are scaled and weighted as if they were independent entities with no interaction function) to more holistic approaches (whereas interactive and integrative properties are also included).

Although systems ecology, as a manifestation of the holistic approach, has become a vigorous theoretical science, there has yet been little spin-off into the applied field. In fact, many practitioners in the impact business have expressed disappointment in, or outright skepticism about, the value of large-scale ecosystem models such as those generated by the U.S. IBP (International Biological Program) and other team projects that focus on particular environments. While the time-lag between theory and practice tends to be shortened when the need or demand is intense, it still takes time to bridge the gap. In our opinion, large-scaled computerized mathematical models have a way to go before they will have much utility in the day-to-day need for decisions on how, when, where (or if) natural systems are to be modified or impacted by man-made systems. Despair not, however, because there are less sophisticated holistic approaches and models that can be applied in the meantime to augment the present state of the art which, as already noted, is becoming daily more inadequate and frustrating to both the preparators and the users of EISs.

Based on another well-known adage that a picture is worth a thousand words, we suggest that pictorial and graphic models provide the logical procedure intermediary between the piecemeal and the holistic assessments. We propose to discuss and illustrate several forms for such graphic models. For one thing, use of graphic models could greatly reduce the size of EISs which now often end up as thick tomes that nobody ever reads. Theoretically, an Impact Statement need not be any longer than the average journal paper, with perhaps an Appendix of raw data and an outline of the computer program, if one was employed, in case future reassessments are needed.

First, however, let us reaffirm some of the advantages of a holistic approach. Table 1 contrasts selected component measurements that might be appropriate for a body of water with analogous but more functional measurements which more nearly assess system properties. The items in the left-hand colum represent the kind of static or "standing state" physical and biological "factors" which often provide the primary basis for an Impact Statement. Yet, by themselves, these items reveal very little useful information about the body of water. In contrast, the more holistic properties in the right-hand column not only serve as indices to important metabolic functions, but also provide considerable information on interactive and integrative functions. For example, measurement of diurnal oxygen metabolism gives a picture of the net interaction of photosynthesis (P) with respiration (R). The ratio between P and R, of course, indicates whether the aquatic community is autotrophic, heterotrophic, or roughly steady-state, information that would be very important in judging the potential impact of a procedure that might increase the input of organic matter or change the temperature of the water. Likewise, indices of species diversity reveal how species and individuals interact and, in some cases at least, give a clue as to the developmental status of the community, thus providing more information than would a mere list of species. And so on down the list in Table 1.

Table 1. Comparison of the Component and Ecosystem Approaches to the Assessment of a Body of Water.

Factor-level Measurements (Standing States)	Ecosystem-level Measurements (Dynamic States)
Dissolved Oxygen (D.O.)	Diurnal Oxygen Metabolism
Dissolved Phosphate	Phosphate Turnover Rate
Phytoplankton Biomass	Chlorophyll Concentration (as index to primary production)
List of Species	Indexes of Species Diversity
Density of Fish	Fish Production

Admittedly, system properties are more difficult to measure than standing state factors in that more time and greater technical skill may be required. However, the total assessment time and expense need not be greater because half a dozen or so well-chosen systems measurements are worth a whole host of miscellaneous component factor measurements. In practice, we find it effective to combine a few judiciously selected systems properties with a few "red flag" components, that is, factors or species which are of special concern in the local situation, as for example, an important game organism, an endangered species, a heavy metal or an organic poison that, by itself, threatens the health of the community and man.

A holistic approach to preparing EISs must involve ultimately an integration of economic and environmental values. There are many ways, as we shall see, to scale and weigh these seemingly uncomparable components so that they can be assessed together. Unfortunately, environmental and economic assessments usually are made by different teams or individuals who never communicate with one another (another example of the futility of the piecemeal approach). Environmental and economic assessors should be on the same team, or at least there should be a coordinated plan to integrate the results of the study of different groups of specialists. In the real world most important decisions are going to be made on the basis of some kind of economics. Considering environmental properties in monetary terms and vice-versa at least insures that benefit-cost will be based on a long-term analysis which includes secondary and tertiary impacts. Since we at the University of Georgia have for some time promoted the idea of merging ecology and economics, and since we have had some success in practice, a couple of case histories may be of interest.

Our first baptism under fire, so to speak, came prior to the enactment of the Federal NEPA Law. A large industrial company's request for permission to strip-mine phosphate ore which lies under the marshes and estuaries near Savannah had created a lot of controversy within state government and concern among the public, about possible adverse affects on the environment. The Governor of Georgia requested that the Chancellor of the University System of Georgia set up an ad hoc commission of faculty to study the situation so as to provide an objective basis for decision. The senior author served on this study commission which included marine biologists, geologists, engineers and resource specialists from both the University of Georgia and Georgia Tech. In addition to a detailed consideration of the possible biologic and economic impact of the mining on shrimp and sport fishing, we also had the University's Business Research Bureau make a study of the impact of phosphate mining on the general economy of Savannah and the coastal region of the state. This study clearly showed that the proposed mining would be a "carpetbagger operation" in that the out-of-state company proposed to haul off the ore to a fertilizer factor somewhere else where, of course, the major economic benefits would accrue. Thus, we could project that there would likely be only a small and temporary benefit to the local economy. Incredibly, some economists and many environmentalists as well seem unaware of the fact that there is little or no money in a natural resource at its source; money is made in processing or converting the resource to usable or consumable products. Unless one plans otherwise mining in particular will leave a local mess while money and its benefits go elsewhere. Again, one must consider the entire cycle of events, the holistic approach again!

On the basis of our report (see Cheatum, et al. 1968) the state turned down the lease request. Although this decision could have been based on any one of several impacts revealed by our study, including the probability of salt water intrusion into the freshwater aquafers that lie just under the ore vein, we believe that it was the combination of low economic appeal and high probability of environmental damage that clinched the matter. The publicity generated by the case resulted in a strong public demand for a Marshland Protection Law which was passed by the state several years later, thus insuring that any future proposals for major alteration of the estuarine zone will receive even greater attention and study than did the first test case. The best feature of the situation is that the resource is still there. If the world ever really needs the phosphate, we are confident it can be removed with far less environmental damage and with greater local economic benefit than would have been the case had the "quick and dirty" approach been allowed.

We were also encouraged by the experience to seek new ways to evaluate the economic worth of natural ecosystems. In collaboration with two Louisiana colleagues, a report on "The Value of the Tidal Marsh" was prepared in which energy provided the common denominator for converting the work of nature to monetary values, with emphasis on potential waste assimilation capacity. We have long ago lost track, but requests for the published bulletin on this (Gosselink, Odum and Pope 1974) are running into the thousands, which suggests that a lot of people are interested in the integration of economic and ecologic values.

Our next major experience with impact assessment came when the State Department of Transportation requested our help in routing an interstate highway north of Atlanta. The route originally chosen would cross a large lake, a state part, and cut into a sparsely inhabited forested area which conservationists felt should be preserved as a recreational green belt and as an air and watershed for Atlanta. As a result of the controversy, several alternate routes were surveyed, but the Department of Transportation (DOT) found itself unable to decide which route would be best for all concerned. Accepting the challenge, and on contract with the state, we set up a small study team of staff with diverse interests and backgrounds, including two postdoctoral systems ecology students. A linear vector analysis approach was adopted which allowed us to utilize the power of the computer for multifactor analysis, error estimation and validation. Data and/or expert opinions were available for more than 50 values which were grouped in four categories: economic and engineering considerations, environmental and land-use considerations, recreation considerations, and human and social considerations. We then numerically scaled the values so that the "apples and oranges" could be compared and summed. Next we weighted the values both as to the immediate impact and as to estimated impact 10 years later. A Delphi approach was used within the team to reach a consensus on weighting. To show the importance of including future or secondary impacts, let us consider the impact of a highway on a wilderness The immediate effect of cutting a narrow path through the wilderness is quite small, but a major effect comes as commercial and other development takes place in an everwidening band along the route, assuming that there is little or no restriction on future land use, as would usually be the case with a public interstate highway.

A computer program was written so that the scale and weighted values could be summed to obtain a single impact index for each route. As in the case of any impact study, many components, even strictly economic or engineering ones, represent, at best, "expert" judgments or estimates and are thus subject to error. Accordingly, we introduced into the program an error factor based on the assumption that any one of the component values is subject to 50% error. As a matter of fact, we did not think many of the values were that far off, but we wanted to put in a generous estimate for human frailty! The scaled and weighted components were then summed to obtain a single impact index for each route. In Figure 1 the mean impact index, together with the 95% confidence interval, are displayed for the route originally proposed and the best available alternative route, that is, the route showing the lowest total impact on a relative scale. The best separation of routes was obtained in the totality run (all factors and their interactions considered), but the same general pattern of separation was obtained when either economic considerations or environmental considerations were left out. But

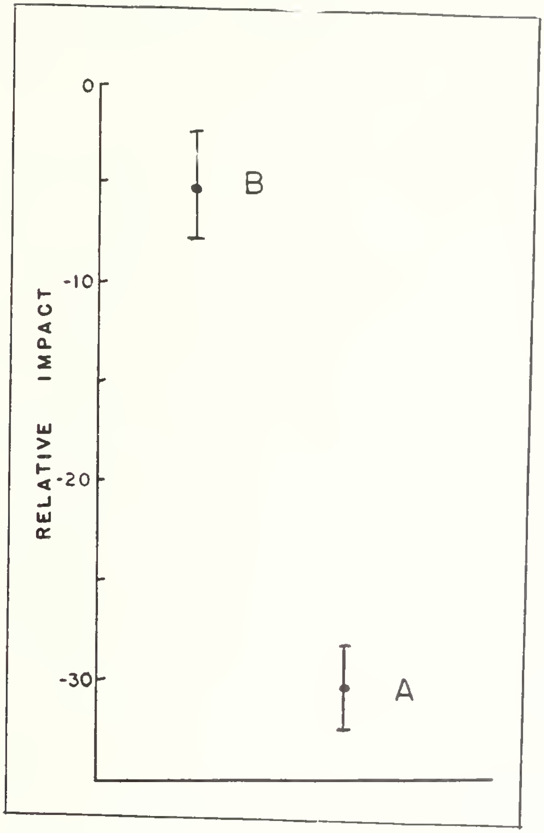

Figure 1. Mean impact index for the originally proposed route, A, and the best available alternative route, B, for Highway I-75 north of Atlanta.

leaving out future impact greatly reduced the separation, verifying the point already made that secondary impacts are often more important than primary impacts when it comes to deciding on options. Although the lowest impact alternate route was three miles longer than the original route, the estimated cost of these extra miles was less than the cost of the long bridge required for the other route. In this case the best route for the totality of man and environment was not more costly, a situation that was by no means evident at the beginning of the study. For more details on this test case, see Odum et al. (1976).

One advantage of the procedure just described is that it is thoroughly quantitative, yet sufficiently straightforward and uncomplicated so as to be understandable to the public as well as to professionals. With the aid of a few charts or slides we had no difficulty presenting the case at public hearings that were a part of the decision-making process. We were fortunate to be involved in the whole process down to the final decision when both state and federal DOT approved the alternate pathway. For example, the federal DOT engineers felt we had not given sufficient weight to certain factors and interactions so we were able to rerun the program with altered weighting until everyone was satisfied that the best alternative had been chosen. Too often the team that writes the EIS is completely isolated from the group that makes the decision, so that in essence the assessment is never validated, and neither group learns anything from the other. Under such a ridiculous and fragmented situation how can the art and science of technology assessment possibly advance?

PROFILE ANALYSIS

Returning to our graphic model theme, Figure 1, of course, represents one form of picture model from which both visual and statistical comparisons can be made at a glance. In this case all the properties or values are combined into a single index to show relative impact. Another approach would be to display separately component and ecosystem properties in the form of a profile. In Figure 2 the impact of an experimental eutrophication on an old-field community is shown. Properties and indices are arranged in two groups, those relating to community metabolism (left hand side of the diagram) and those relating to species structure (right side). In this case, adding macronutrients to the ecosystem elevated metabolic and biomass properties, but depressed diversity measures in comparison to the control profile. Since this pattern of response has been observed frequently in a variety of ecosystems, Figure 2 becomes a generalized model for the impact of eutrophication with mineral nutrients. In the absence of unexpected or unusual interactions one can confidently predict an increase in productivity and its related functions and a change in species structure in the general direction of reduced diversity. The initial state is important in determining whether such a predicted response will indeed occur. If, for example, the productivity is already very high, eutrophication could easily become a metabolic stress and reduce the rate. Likewise, if diversity is very low to begin with, nutrient enrichment can very well increase certain components of diversity, especially the evenness components. Thus, the baseline positions and the slopes of the profiles convey useful information at a glance.

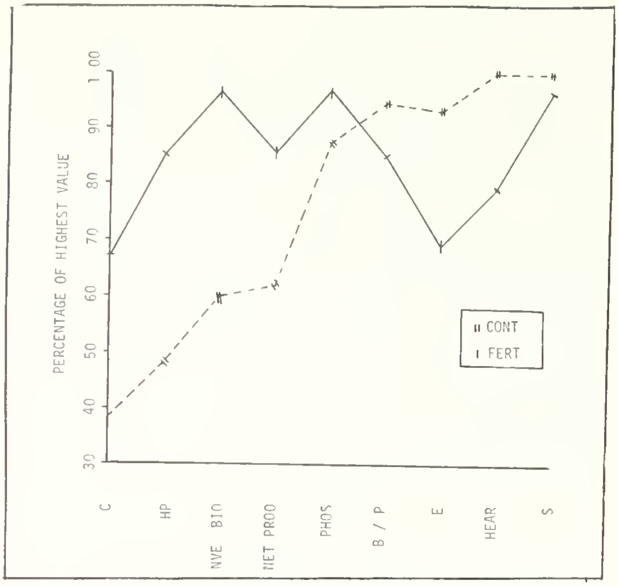

Figure 2. Ecosystem profile as graphic model of the impact of fertilization on the plant community and old-field community. Properties compared are: C = concentration of dominance; NP = net primary production; Ave Bio = Biomass; Phos = phosphate concentration in tissues; B/P = ratio biomass/NP; E = Evenness index of diversity; Hbar = Shannon index of diversity; S = species richness index of diversity (Bakalaar and Odum 1978).

Whether an impact, as shown in Figure 2, is considered to be desirable or undesirable depends not only on the assimilative stability of the system (i.e., ability to absorb a perturbation with minimum deflection of properties), but also on what is judged to be the most desirable future use of the environment by man. In the case of a body of water, for example, the impact of eutrophication may be undesirable if the water is to be used for drinking or swimming or trout fishing among other uses requiring very "clean" water. If, on the other hand, production of food or fiber is judged to be important, then an increase in productivity would be desirable, at least short of stressing some vital function such as oxygenation. Again, we see that future impacts and economic values must be included in the assessment if it is to result in a decision of lasting value. These considerations can also be displayed in profile fashion.

It is perhaps interesting to note that an ecological profile such as we have been discussing is analogous to a "biochemical profile" now widely used in medical practice as a quick and ready index to the general health of an individual.

Whenever practitioners meet to assess impact assessment, as it were, discussion and debate is almost sure to develop on the subject of the value of diversity indices. Since these indices are averaged or summed ratios often arbitrarily defined or based on assumptions not yet completely verified, it is widely recognized that a single index figure may obscure as much useful information as it reveals. One solution, of course, is to profile several different indices, each emphasizing a different component of diversity as was done in Figure 2. Another, and we think a better procedure, is to plot the relative importance of each kind of organism, as is shown in Figure 3, so as to display all of the information in the form of a profile. Importance values (numbers, biomass, or other indicators of importance) for each species or kind are plotted on a log scale in order of relative abundance and the evenly spaced points are then connected to form a curve. Robert Whittaker (1965) has called this type of profile a "dominance-diversity curve" since the first part of the curve depicts the relative position of the most important or dominant species and the long trailing part of the curve gives a picture of the number and relative standing of rare species. EIS practitioners would do well to review Whittaker's early paper since he also discusses theoretical significance of different profile shapes, possible mathematical models for basic shapes and what all of this may reveal about how organisms divide up niche space.

In Figure 3 are shown diversity profiles for the benthic fauna in three streams which provide a gradient from heavily polluted (with domestic wastes) to relatively pristine. It can be immediately seen that moderate pollution affects markedly the relative abundance of fairly common and rare species since it is the middle and terminal section of the curve that is most depressed below the level of the unpolluted profile. In the case of heavy pollution, all components are affected since the entire profile is markedly steepened. While diversity indices calculated from these data follow the pollution gradient (see Figure 3), the profiles exhibit additional information not evident in the index, namely the segment in the abundance sequence that is most affected.

So, if you are uncertain about diversity indices or not sure what they mean, why not

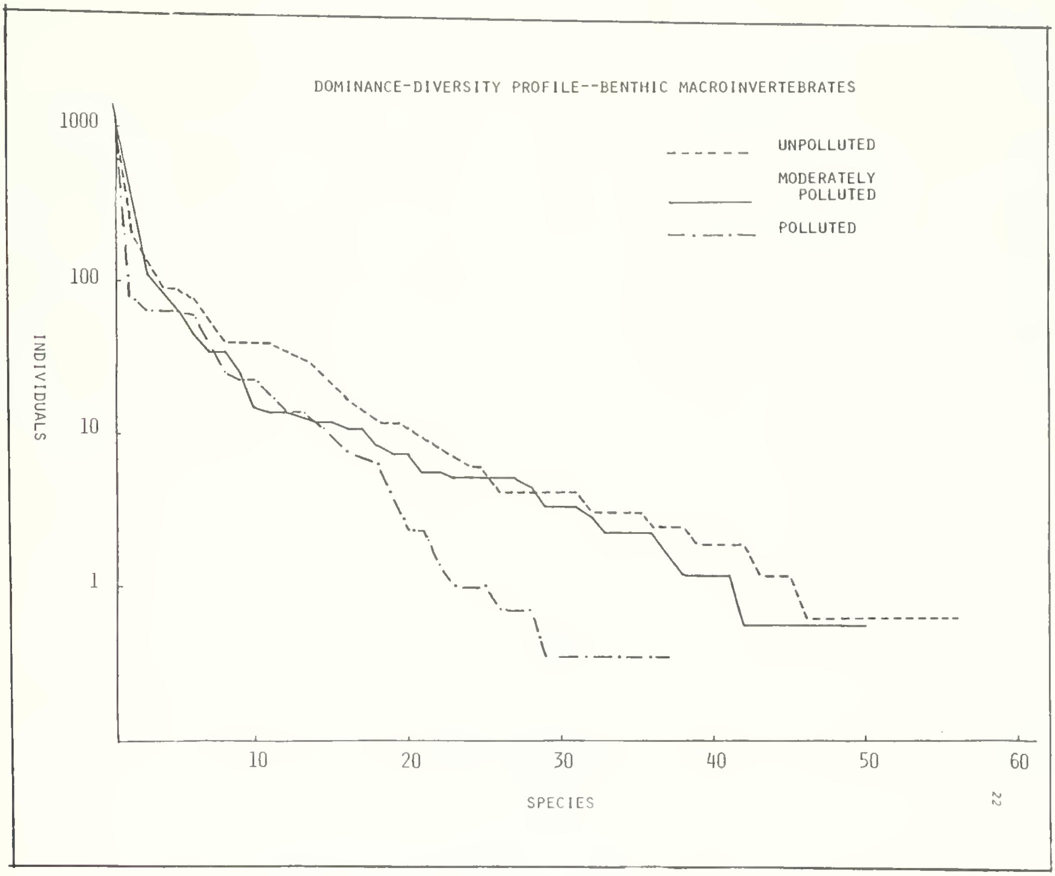

Figure 3. Dominance-diversity profiles for 3 parallel streams in the same watershed but which differ in the degree of pollution from urban domestic wastes. The Shannon diversity indexes for the streams are: unpolluted, 3.31; moderately polluted, 2.80; polluted, 2.45 (unpublished data of J.L. Cooley and Homer Sharp).

just get a piece of semi-log paper and plot your data as a profile, then let the eye and common sense be the judge. Remember that it is not necessary to identify or name all of the species; it's only important to be able to distinguish between kinds. Since larvae often occupy a niche that is different from the adult stage, it does not hurt, but probably helps if you classify larvae and adults as different "species" even if they are not. It is a lot better to classify everything that is distinctly different in basic appearance (body feature, color, etc.) as a different "kind" than it is to throw out all the immatures and other organisms that even the expert cannot identify as to species. Also, as already noted, one can convert profiles into mathematical formulas (curve fitting) and one can apply statistical methods to determine if profiles differ if it is necessary to go that far. Finally, diversity profiles of non-living components, as, for example, nutrient "species" or organic chemical "species," should also be instructive, although we must admit there has, as yet, been little effort to apply diversity concepts to the non-living portion of ecosystems.

But we have applied diversity concepts to the assessment of habitat diversity of large landscapes. Recently, we used a grid overlay on aerial photos to assess forest-type diversity on the Savannah River Plant reservation, an atomic energy experimental site which has recently been designated as a National Environmental Research Park. Despite the fact that the former agricultural lands in the area have now mostly been converted to pure pine plantations, the overall habitat diversity remains high because of the intermixture of a variety of natural vegetation types. As shown in Figure 4, the habitat diversity is very similar to the diversity of soil types which can be considered a good baseline index. However, if pine monoculture were to be extended to 50% or 75% of the land area, as has been suggested by U.S. Forest Service as a means of increasing wood pulp yield, then we can show that landscape diversity would be drastically reduced (Figure 4, points II and III). When we add to this undesirable effect the cost of conversion (expensive vegetation removal, drainage, channelization of streams, etc.) and the possibility of increased disease and insect control we can present a strong case against any further extension of pine monoculture.

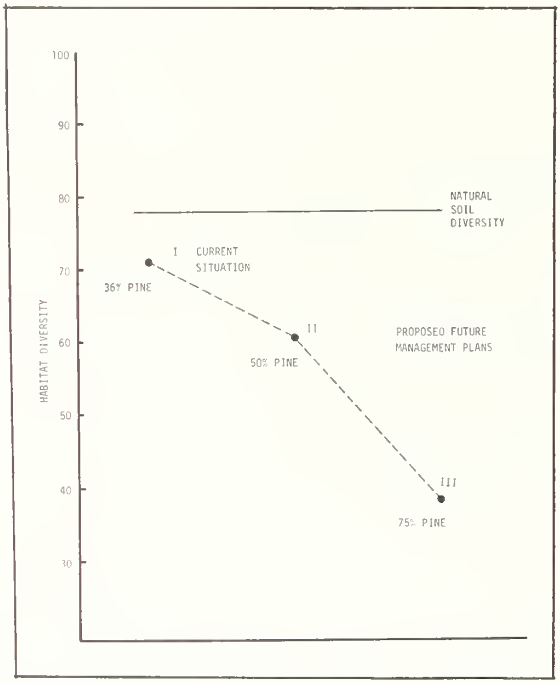

Figure 4. Habitat diversity of vegetation types and soil type of diversity (solid line) on the Dept. of Energy's Savannah River Plant Reservation under current (36% pine) and proposed future forest management plans that involve increasing use of pine monoculture. Diversity is plotted on scale where 100 equals maximum diversity possible for the number of forest or soil types present (Odum and Kroodsma 1977).

PERFORMANCE CURVES

Nearly everything man does has a gradient of impact possibilities on nature, ranging from enhancement or subsidy to severe stress, often depending on the intensity of the perturbation. The performance curve is a graphic form with possibilities for assessment of such a gradient. As shown in Figures 5 and 6, a performance curve is obtained when perturbation intensity is plotted along the horizontal axis and the response of one or more systems properties is plotted on vertical scales. Or, in more general terms, it is a plot of input against the output response of the ecosystem. A humped-backed or convex curve form would normally be expected. If a man-made input into the ecosystem involves a

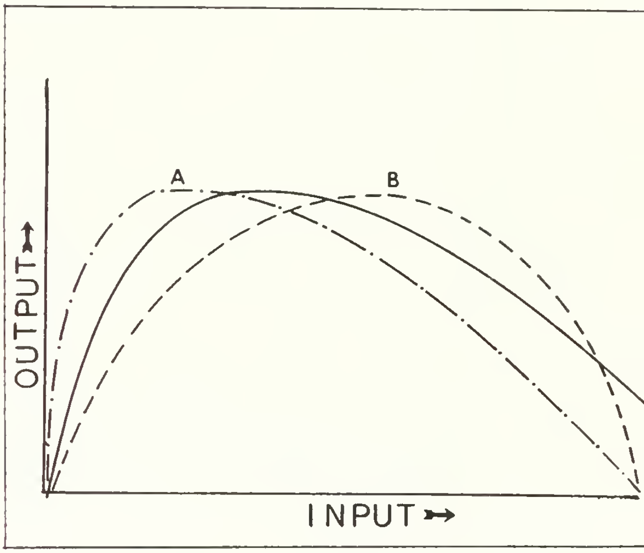

Figure 5. Generalized performance curves ranging from highly skewed-to-the-left to more symmetrical forms.

deadly poison, then the curve would be shifted to the left so that the optimum response is at zero discharge. However, in many cases man-made perturbations have the effect of enhancing at least certain functions when the input levels are low, only to become stresses when a certain plateau level is exceeded. Thermal discharges into a body of water that is naturally rather cool is an example. At low levels primary productivity, fish yields or waterfowl populations may be increased, but at high levels these desirable properties would be decreased. The problem in such cases is to determine which properties are enhanced or depressed and what levels are allowable or perhaps even desirable. Something like thermal pollution is not inherently good or bad. Reasonable decisions about its control can only be made when its "performance" in the subsidy-stress gradient is known, and the properties that are judged important to protect have been identified.

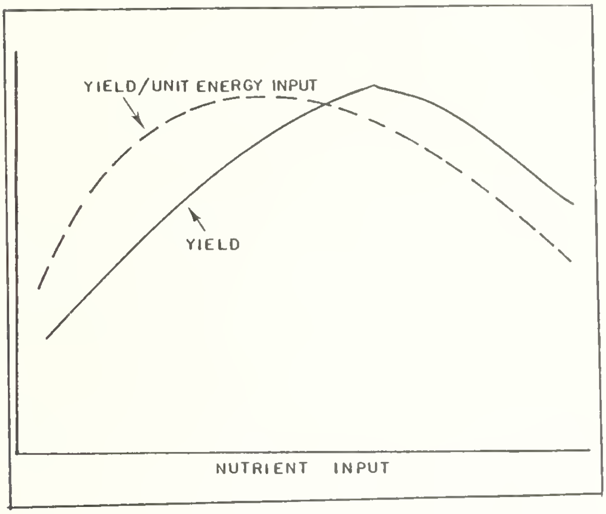

Figure 6. Hypothetical case where the plateau level of nutrient input comes at a lower level when yield is considered in terms of efficiency of energy use than when gross yield alone is the major consideration. There is some evidence that this situation applies to fertilizer-crop yield relationships.

A generalized performance curve takes the skewed-to-the-left form shown as curve A in Figure 5. The subsidy effect is marked, but restricted to a narrow zone and is soon followed by a broad plateau where the system is able to tolerate or assimilate the input without further change. The stress response takes the form of a long, gradual downhill slide as the intensity of the perturbation increases. This form is insidious because the favorable effects, as it were, are dramatic and easily detected, but there is no clean-cut, cut-off point where too much of a good thing can be judged to be undesirable. A common sense approach would be to stop at the very beginning or just before the plateau since it is probable that small, difficult to detect, stress, perhaps involving reproductive physiology or survival of young of key species, may begin in the plateau region (and produce a future undesirable effect) even though the overall function is stabilized. Assessment is much easier when the shape of the performance curve is more symmetrical, as shown in curve B in Figure 5.

We believe that specific curve forms may be linked with specific types of interactions between a particular class of ecosystems and a particular class of perturbations. If this proves to be true, then impact assessment can be made from a theoretical curve, perhaps generated by computer without the necessity of experimental testing. Or to be more cautious, such curves can provide a basis for experimental testing.

The hypothetical curves for Figure 6 illustrate what may be a general principle, namely, that the optimum level for efficiency of energy use comes at a lower, or at least at a different, level of input from that which produces maximum energy flow. For a crop, for example, the optimum yield per unit of energy input required is projected to come at a lower level of fertilization than does maximum net production. We need to find out if such a relation holds for the eutrophication of natural ecosystems. For additional discussion of performance profiles see Odum, Finn and Franz 1979.

Finally, we call your attention to H.T. Odum's energy language diagrams and flow charts as another form of graphic model which can be expanded into computerized systems analysis if needed and, therefore useful for impact assessment. In addition to recent books (H. T. Odum 1971 and H.T. and E. C. Odum 1976) which describe in detail this approach, he has written a short article that outlines specific ways that energy diagrams can be used for Environmental Impact Statements (H. T. Odum 1971).

SUMMARY

We have suggested that environmental impact assessment should evolve as rapidly as possible from the present largely descriptive component approach towards a more holistic approach which combines the use of broad ecosystem properties with specific local factors (i.e., "red flags") that are of public concern. The integration of economic and ecologic considerations was also stressed and two test cases were outlined to show how this combines the work of the impact assessor and the decision-maker was also emphasized. Several types of graphic models were presented and discussed as convenient devices for combining large amounts of information into easily understandable forms for comparative analyses and presentation.

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MANAGING THE UNKNOWN: APPROACHES TO ECOLOGICAL POLICY DESIGN

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HOW ECOLOGICAL SYSTEMS BEHAVE

Past efforts in resource management, and indeed in applied science in general, have been essentially trial-and-error approaches to cope with the unknown and the unexpected. And indeed that is the way our societies have advanced since the Industrial Revolution. Existing information is mobilized and organized to suggest a trial, and if an error is detected, then that provides additional information to modify subsequent trials (Lindblom 1959). Such "failures" have provided an essential probe into the unknown; a probe that generates new information upon which knowledge feeds. But we are now at a time where intensity and the extensiveness of our trials can generate errors that are potentially larger than society can afford. That is at the heart of the issue of "hypotheticality" raised by Haefele (1974). He argues we are locked in a world of hypothesis because we dare not test our hypotheses. Trial-and-error approaches will always be essential, but without a broader strategy to deal with ignorance and with the unexpected it increasingly seems to be a dangerous method for coping with the unknown.

The origin and magnitude of the problem depend on the way the systems we design and manage respond to unexpected events. And that response is directly tied to the stability properties of systems and, more accurately, the way we perceive those stability properties. A system that is globally stable, for example, is admirable for blind trial-and-error experimentation. It will always recover. It is that paradigm of infinitely forgiving nature that seems implicity to have been assumed in the past.

But if a system has multiple regions of stability, then nature can play the practical joker rather than be infinitely forgiving. Policies, trials, or management can seem to be operating effectively as long as the system remains within known or desired stability domains. But if the system moves close to a stability boundary, then slight incremental change can suddenly generate qualitatively different behaviour of potentially high cost. Even more troublesome, the stability boundaries themselves, because of management activities, may implode around the system, again suddenly generating a step change of behaviour. By that time there may have been such a history of "success" that institutional inflexibility, let alone the potential for ecological recovery, will make resolution impossible -- an effectively irreversible condition.

It becomes centrally important, therefore, to have a clear understanding of the stability behaviour of the topology of ecological systems and, as well, the institutional and societal systems with which they are linked. Two lines of evidence are now accumulating. The first comes from recent efforts to develop structurally simple differential equations of complex systems that emphasize the qualitative form of the functional relationships. Much more reasonable and realistic functional relations have been included for ecological models (Bazykin 1975), institutional systems (Holling, Huang and Vertinsky 1976) and societal systems (Haefele 1975). Even with these simple structures and simple but realistic assumptions, an extremely rich topology emerged whose key characteristic is that under different parameter ranges multiple regions of attraction are a universal feature. With different parameter conditions the size and number of these regions can change, suggesting that biological or cultural evolutionary forces working on parameters could cause the presumed stability properties of a managed system to change in quite unexpected ways.

The other line of evidence comes from empirical studies of specific systems. Without going into exhaustive detail, a collection of examples has been accumulated from ecological systems, water resource management situations, engineering technology and cultural anthropology. These examples show a significant number of cases of multi-equilibria behaviour and shifts of behaviour between equilibria as a consequence of perturbations or management actions. Among the ecological examples there are cases concerning freshwater fisheries (Holling 1973), terrestrial grazing (Noy-Meir 1975), and tropical and temporal forest ecosystems (Holling 1973). There is, in addition, a larger range of much more anecdotal examples that are rarely documented but are part of the community wisdom of the resource manager, such as the irreversible development of the Scottish moors after deforestation, development of deserts in the Middle East, and of persistently unproductive tropical terrestrial systems as a consequence of extensive and intensive agricultural practices.

In brief, Mother Nature does not seem to be infinitely forgiving but, indeed, to be mischievous. It is this focus on multi-equilibria phenomena, the number and size of stability regions and the possibility for changes in these stability regions that is at the heart of our efforts to develop a science of ecological policy design that explicitly deals with the unknown and the unexpected. It had led to a concept of systems resilience (Holling 1973) and the need for policy robustness. The concept provides at least a hint of a direction to proceed, focusing not on the prediction of future surprises, but on the designing of management systems that have the internal resilience to absorb those surprises when they inevitably appear. The three steps to the design of resilient policies are to (1) mobilize the existing available knowledge, (2) identify what is unknown or uncertain and where "surprises" are likely to come from, and (3) select the management policies so that they can cope with surprises when they occur.

In this paper we discuss how the above view of the behaviour of environmental systems affects our view of environmental impact assessment. A series of "myths" which appear to be accepted for environmental impact assessment is followed by a series of alternatives to these myths. Techniques for mobilization of data for EIA and sources of the unexpected, primarily mechanisms that lead to unexpected events, will be discussed. We then propose several methods for designing environmental management policies that are resilient to unexpected events, and finally propose specific changes which we believe will make the Environmental Impact Assessment process more responsive to unexpected events.

COMMON MYTHS ABOUT ENVIRONMENTAL IMPACT ASSESSMENT

The literature on EIA is replete with motherhood statements and implicit assumptions about the conduct and content of impact studies. Some of these ideas are meaningless in practice, others are deceptive, and some are downright false. The intent of this section is to help point the way toward better approaches by indicating some of the more obvious pitfalls and misconceptions that have found their way into present practice.

Myth #1: EIAs should consider all possible impacts of the proposed development.

> This myth hardly deserves comment. The really interesting question is: does the fact that it is physically impossible to foresee all (or even most) of the impacts have any serious implications in terms of how the basic development plan should be structured?

Myth #2: Every new impact assessment is unique and must be designed as though there were no relevant background of principles, information, or comparable past cases.

> It is certainly true that every environmental situation has some unique features (rare animal species, geological features, settlement patterns, etc.). But most ecological systems must face a variety of natural disturbances and all organisms must face some common problems. The field of ecology has accumulated a rich descriptive and functional literature which makes at least some kinds of studies redundant and some predictions possible. The same is true for economic, social, and physical aspects of the assessment.

Myth #3: Comprehensive "state of the system" surveys (checklists, etc) are a necessary first step in EIA.

> Survey studies are often hideously expensive, yet produce nothing but masses of unreliable and undigested data. Also they seldom give any clues as to natural changes that may be about to occur independent of development impacts. Environmental systems are not static entities which can be understood by simply finding out what is where over a short survey period.

Myth #4: Detailed descriptive studies within subsystems can be integrated by systems analysis to provide overall understanding and predictions of system responses (impacts).

> The predictions from systems analysis are built up from understanding of relationship between changing variables. Descriptive studies seldom give more than one point along each of the many curves which would normally be used to express such critical relationships. In short, what a complex system is doing seldom gives any indication of what it would do under altered conditions. Again the interesting question is: what are the policy implications of the fact that even comprehensive systems models can only make predictions in sharply delimited areas.

Myth #5: Any good scientific study is useful for decision-making.

> The interests of scientists are usually quite narrow and are usually geared to a particular history of disciplinary activity. If you are concerned about the impact of a pesticide on some animal population, how would you use the scientific information from a study on the animal's reproductive physiology if no one had bothered to study juvenile rates (which might improve to balance any reproductive damage)?

Myth #6: Physical boundaries based on watershed units or political jurisdictions can provide sensible limits for impact investigations.

> Modern transportation systems alone can produce environmental impacts in unexpected places. Transfers of impacts across political boundaries can lead to a wide range of political and economic reactions from the other side. A narrow study that fails at least to recognize these impacts and reactions may be worse than useless to the decision-maker.

Myth #7: Systems analysis will allow effective selection of the best alternative from several proposed plans and programs.

> This assertion would be incorrect even if systems models could produce reliable predictions on a broad front. "Comparison of alternatives" involves assessment of values placed on system components. Rarely is this assessment a part of the environmental impact work.

Myth #8: Development programs can be viewed as a fixed set of actions (e.g., a one-shot investment plan) which will not involve extensive modification, revision, or additional investment as program goals change over time and unexpected impacts arise.

> Unexpected impacts may trigger a sequence of corrective investment decisions which result in progressively greater economic and political commitments to make further corrections if the initial ones are not successful. Thus decisions can have decision consequences as well as direct environmental ones, and these induced decisions can generate greater environmental impacts than would ever seem possible based on the original development plan.

MOBILIZATION OF EXISTING INFORMATION

There exists a very large body of information that is relevant to EIA. This information is both theoretical and numerical, and has been collected, filtered through countless reviewers and eventually made it into the scientific literature for the last 60 years. The preliminary task of an environmental impact assessment team is to filter through this knowledge and extract what is relevant to the specific problem under study. We contend that there is generally a large body of useful and relevant information, but that methods usually employed make little use of this information. Indeed many EIAs act as though there were no pertinent information and literally begin from scratch. Rather than list the errors in the methods we see being used, we will briefly describe the methods we have found useful.

Environmental impact assessments are an interdisciplinary problem and most of the failures to utilize the existing information come from difficulties with interdisciplinary communication. These problems arise not only from difficulties of specialists of different disciplines to communicate with each other, but from the inability of technical specialists to communicate with a decision-maker at the end of the assessment. We have found that the fastest and most successful way of getting specialists to work together is by means of a very intensive workshop session whose purpose is to produce a working computer simulation model in a very short period of time, usually one week. Over the last 10 years we have been involved in over 30 such workshops, dealing with such diverse problems as environmental impacts of a very large-scale hydroelectric development, spruce budworm management, and the impact of tourism on an Austrian ski resort.

We have consistently found that using a simulation model as a tool to promote communication was successful at breaking down interdisciplinary boundaries during a very short period of time. Details and examples of this process are discussed at length in Walters (1974). We shall mention here the more important general features.

The trend among EIAs has been to request statements of effects from different specialists. An ecologist might be consulted about the effects on big game, an economist about effects on recreation, a hydrologist about effects on the water, and a fisheries biologist about effects on the fishes. The major failures have occurred because these assessments were done separately and the linkages between the disciplines ignored (Walters 1975). The use of intensive workshop sessions eliminates these problems since the different specialists do not have time to go away and be specialists but must work together to produce a result before the end of the workshop. They must communicate immediately about such things as units of measurement, cross linkages, etc. The major problems we have encountered have occurred when too much time was allotted for the initial model building as it allowed the hydrologist to go away and say "I know how to handle the water, you take care of the fish."

Another integral aspect of the workshop is that management and decision-makers must also be involved from the beginning in the model development. This forces the model to meet the real needs of the managers and prevents the specialists from making a model that is interesting to himself but of no use to the decision-maker.

By the end of this one-week session we have brought about an incredible flow of information between disciplines, we have guaranteed that the model will be responsive to the manager's need, we have identified the major interconnections between the disciplines and we have built a running computer model. The next stage is to refine and test this model for later use as an EIA tool. Recently, we have been involved in testing the predictive power of a number of EIA techniques (Yorque 1976), and have found that computer models are by far the most powerful predictive technique. However, it is a long way from the model produced in a one-week workshop to the model used for prediction.

In the testing and refinement of the model the specialist's detailed knowledge can now come into its own. Here the hydrologist makes sure that the hydrology works, while the one-week intensive workshop was to make sure that the hydrologist provided the needed information to the fish biologist. In the one-week session the fisheries biologist could not say that he did not know how species A responded to oxygen depletion in this area, he had to call upon his knowledge of how species A responded in another region. In the refinement and testing phase he can go out and measure the response to oxygen depletion in this particular area.

After the refinement and testing phase is complete (Clark, et al. 1979), the model contains much of the available wisdom from all the disciplines involved in the study. It should be an encapsulation of the current state-of-the-art. Unfortunately it will always be incomplete. There will always be some factor that was omitted, something that was unknown, or some unexpected perturbation. The next step in designing a resilient management policy is to identify where these uncertainties lie, and where the unexpected might arise.

SOURCES OF THE UNEXPECTED

The most common source of uncertainty comes from attempting to extrapolate beyond the bounds of previous observation. Generally, we have little trouble predicting what the effect of a perturbation will be if we have made that perturbation before. This is trial-and-error learning. Where we run into trouble is when we must predict what a perturbation will do if it pushes the system beyond the bounds of previous observation. This is the problem of hypotheticality posed by Haefele. Figure 1 presents an example of this type of problem from the sockeye salmon fishery on the Fraser River. For many years we have observed what the population does at low stock densities and we know what kind of harvest we can sustain. What is unknown is what would happen if the harvest were reduced for several years to allow the population to increase. Drawn on Figure 1 are several alternative hypotheses. This is an example of the most frequently recognized source of uncertainty, but we contend it is also the least problematic because it is recognized. Environmental impacts run into trouble when an uncertainty has to be faced which was not previously recognized.

Another source of uncertainty much less frequently recognized is that some things are in principle unpredictable. This is due to two causes, (1) uncertain future events such as environmental changes, and (2) some levels of detail will always defy prediction. Asking an ecologist how many fish there will be in a stream 10 years from now is like asking the

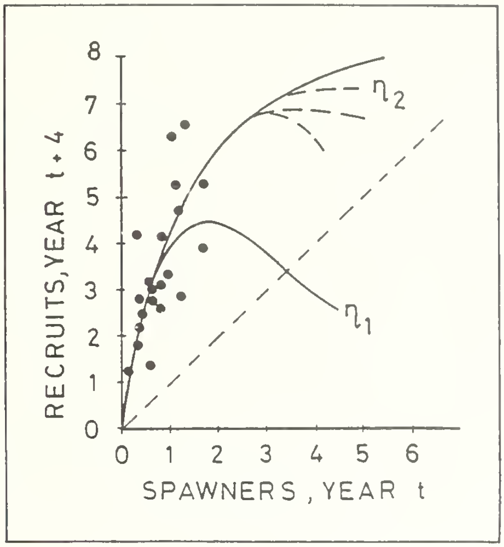

Figure 1. An example of the uncertainty due to extrapolation. It is uncertain if more fish or fewer fish would be produced if the harvest rate were reduced. There is no way to truly find out without trying.

weatherman if it will rain on June 3, 1986. He could give you a probability distribution of population sizes, but could not tell you what the exact size would be. Almost all EIAs have outside perturbations that are in some way stochastic and no one, given the largest budget in the world, will be able to predict some of these factors.

Emerging from the meteorological literature (Charney 1975) is the belief that many phenomena that involve spatial distributions are in principle unpredictable even over such short time periods as weeks. It has been shown that some aspects of meteorology, even in a completely deterministic world, could not be predicted more than several days in advance. Many ecological phenomena involve analogous spatial problems and it may be that some environmental factors are in principle unpredictable. We mention this simply to point out the possibility that it could happen, not because we see it as an important factor in EIA.

The most troublesome type of unexpected event in an EIA is caused by an outside influence that was not considered in the scope of the analysis. A good example of this, again taken from fisheries, is the planning process for salmon stock enhancement in western Canada. Analysis of the biology of the fish showed that stocks could be increased by artificial spawning grounds, but at the time of the analysis only the biology was considered. As the enhanced salmon runs have begun to be developed, the fishing fleet has grown in power so that the system is close to being out of control. The Antarctic whale regulations suffered from a similar myopia: looking at the biology separate from the fleet investment dynamics. These problems arise not because of any lack of understanding of the outside systems, but because the analysis was too narrow.

Another source of unexpected events concerns the societal end of the analysis. When a biologist is asked what the environmental impacts of a development will be, he uses to some extent a set of values to determine the importance of certain impacts. This is almost necessary, because there is always a very large number of effects, and the biologist must screen out the important ones. It is usually necessary in EIA to produce a short executive summary, and this requires the biologist to make some value judgments. Yet the time span of the impacts is frequently very long (hydroelectric developments generally produce impacts over many decades) and during that time people's perceptions of the importance of different factors may change drastically. The great emphasis put on "The Environment" in the last 10 years is an example of such a change. If an EIA had been done in conjunction with the large hydroelectric projects of the 1930s, it is likely that the adverse effects would not have been predicted largely because at the time the value placed on jobs and development. The point we want to make is that it is difficult to avoid value judgments in an EIA; yet the time scales of the programs are so large that we are bound to make mistakes because social perception of what is important will change.

FACING UNCERTAINTY: WHAT CAN BE DONE

To recognize that we face uncertainties is a significant but incomplete step. To find creative methods of dealing with them is the challenge. We have found three methods for dealing with uncertainty. The first method is a technique to determine the interactions and boundaries of a problem, such as avoiding being too narrow, and is called "looking outward." The second method involves qualitative descriptions of the system (as opposed to quantitative simulations) and uses the techniques of topology and catastrophe theory to aid one's limited understanding of a system. The third method intentionally uses management to experiment with the system in order to explore the unknown. This is called adaptive management.

(1) LOOKING OUTWARD

The "looking outward" approach was developed by our modeling group at the University of British Columbia through various attempts to encourage traditional discipline-oriented scientists to go beyond a reductionist way of thinking. In model building (and impact assessment) exercises and workshops, each specialist is asked to devise lists of variables and relationships needed to describe the dynamics of the subsystem which is his specialty. His natural tendency then is to come up with a list that reflects current scientific interest within his discipline. This list is usually unnecessarily complex and often has little relevance to the development problem at hand.

In the "looking outward" approach, we simply turn the question around. Instead of asking "what is important to describe subsystem x," we ask "what do you need to know about subsystem y in order to predict how your subsystem x will respond." That is, we ask the specialist to look outward at the kinds of inputs which affect his subsystem.

After iteratively going through this questioning process for each subsystem, we can present each specialist with a critical set of variables whose dynamics he must describe before we can generate any picture of overall system responses. Also by asking him to identify the inputs to his subsystem we ask him to think more precisely and broadly about how the subsystem works. Of course, the subsystem modeling process is also much simplified when the desired outputs are precisely known.

Input-process impact tables are a variant of the cross-impacts or action-impacts matrices commonly used in environmental assessment. The idea is to list a series of inputs (proposed development actions, materials involved in development, pollutants released into the environment, etc.) as the rows of the table, and a series of important processes as the columns of the table. The columns might be, for examples:

transportation substitution of inputs plant siting effluent release migration	economic processes
choice of recreational sites demography (birth-death)	social processes
material transport mass balance relations dispersal	physical processes
competition predation	ecological processes

Then for each input-process combination in the table we ask two questions:

(1) Will the input directly affect the process in relation to at least one subunit (economic sector, social group, physical area or material, type of organism, etc.)?

(2) If so, what spatial and temporal consequence can be expected for each subunit being affected?

Thus the input-process questioning tends to focus expert attention on mechanisms which might produce unexpected impacts. Once the table has been developed (and it is usually not even necessary to write down any answers to the two questions above), it is easy to move on to a more specific table where particular impacts or indicator changes are identified in relation to inputs.

We have discovered that a common assumption in EIA is that environmental impacts get less severe the farther you move away in space from a disturbance (see Myth #6 earlier). Yet spatial distance is a poor description of "connectivity." We prefer to think of distance in terms of transport media for transfer of material, energy, and information. These media are:

(1) watersheds -- impacts go downstream;

(2) atmospheric transport -- complex dynamics can produce effects in unlikely places;

(3) human transport -- roads, railways, airports, etc.;

(4) energy transport -- transmission lines, pipelines, etc.;

(5) economic transport -- where the dollars flow;

(6) food webs -- DDT to the brown pelican.

A better paradigm than "the effect is a function of the spatial distance" is "the effect is a function of the distance using the above 6 measures of connection." This most likely is also a false paradigm, but at least it is better than the spatial distance one. To think about these connections should help avoid some of the "unexpecteds" that result from improperly bounding the problem.

(2) TOPOLOGICAL DESCRIPTIONS

A potentially powerful technique which we have recently begun to use involves developing qualitative system descriptions to encapsulate the behaviour of the system. These frequently involve manifolds and come under the classification of "catastrophe theory" (Jones 1975). The principal issue is that the basic qualitative patterns of behaviour of systems are directly traceable to the number and interrelation of regions of attraction (equilibria). It relates as well to our central question concerning the resilience of ecological systems and the robustness of policies. In our experience, models are not usually constructed with the initial intent of generating multiple equilibria. Rather, they were based on detailed biological descriptions of the systems (Holling, Jones and Clark 1979). Nevertheless, multiple equilibria have almost always emerged as a consequence of the biological interactions. A typical representation for the spruce budworm, a major forest pest in eastern North America, is shown in Figure 2. In this figure the recruitment factor, i.e., the ratio of budworm population in generation t+1 to the population in generation t, is plotted against the density in generation t. This recruitment factor represents a condensation of all growth and survival functions within a detailed biological model. Whenever the recruitment factor curve crosses the horizontal "replacement" line, a stable or unstable equilibrium results, assuming that forest conditions remain constant. The dip in the curve at low budworm densities is largely the result of avian predators, augmented to a degree by parasitism. When the forest is of an intermediate age, this introduces a lower stable equilibrium which persists until forest conditions improve and the recruitment factor curve lifts above the replacement line. At this point an outbreak occurs. But an outbreak can also occur by "swamping" the "predator-pit" through dispersal immigration of budworm from other

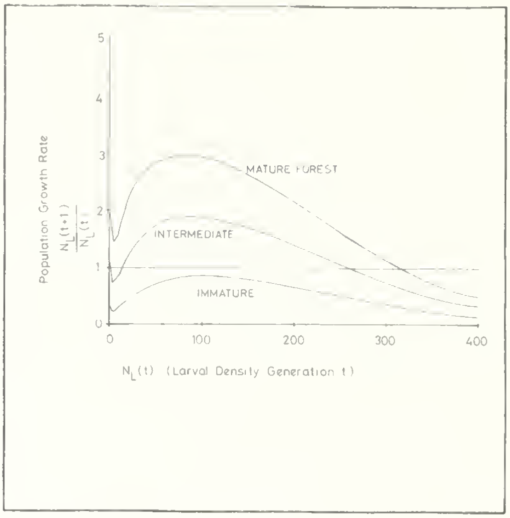

Figure 2. Growth rate curves for budworm populations at various budworm densities and three forest conditions. Potential equilibria occur whenever the growth rate intersects the horizontal replacement line.

areas. The curves generated for this example do not include the stochastic elements of weather which affect both survival and dispersal. When these are included, we obtain a third trigger for outbreak with the occurrence of warm, dry summers which can raise a recruitment factor curve above the replacement line. The highest density crossover point is introduced largely through competition by budworm for foliage. Although it represents a stable equilibrium in the budworm plan, it is, in fact, unstable because of the response of trees. At these high budworm densities defoliation is so heavy that tree mortality increases and the forest collapses, taking the budworm with it.

A more complete and succinct summary of these multiple equilibria can be obtained by plotting all the equilibrium points in a three-dimensional space representing the condensed versions of the three key variables -- budworm, foliage condition and tree volume (Figure 3). This represents an equilibrium manifold of the kind found in topology and catastrophe theory (Jones 1975). The undercut portion of this fold is introduced by the effect of avian predators. Such representations provide a particularly revealing way of interpreting outbreak behaviour. The temporal pattern of the unmanaged system can be understood by following the trajectory of the system over this manifold. An example of a typical movement is shown in the figure for the

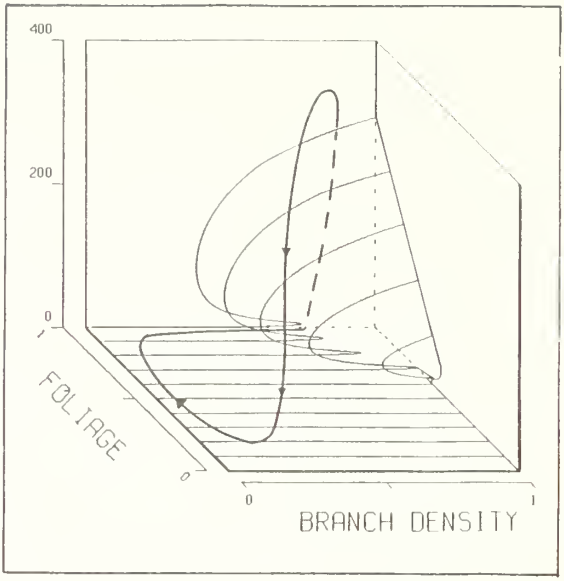

Figure 3. Budworm manifold (position of all equilibria levels of budworm) for different amounts of living foliage per branch and different densities of branches per acre. The trajectory shows a typical path through this space describing one outbreak cycle in an unmanaged world.

no-management world.

The above example was constructed from a very detailed biological understanding of the dynamics of the spruce budworm. Such detailed understanding is atypical of EIA. A second example is drawn from another forest pest, the jackpine sawfly. This illustrates topological descriptions used for poorly understood systems, representative of an EIA situation.

Jackpine Sawfly/Jackpine Interaction

The jackpine sawfly system has some similarities and some differences when compared to the spruce budworm system. As with budworm there are periodic outbreaks that cause severe tree mortality followed by long periods when the insect is scarce. But there are important differences that make it a key case study in relation to our central interest in resilience and the development of robust policies. First, from a management point of view, it is more tractable. Infrequent modest spraying at low concentrations is sufficient to control the problem. Second, and most significantly, the qualitative pattern of changes in numbers over time is more complex. In the broadest sense, three distinct conditions have been observed historically (McLeod 1970). As in the budworm, during extensive periods of time the insect is present but very scarce. Very occasionally and erratically there will be a major outbreak similar to budworm in which sawfly numbers rise to very high levels and tree mortality causes an ultimate collapse of the outbreak. But, unlike budworm, there is an intervening condition in which populations are moderately high and persist in this condition with relatively modest fluctuations for a long time. The system can flip back and forth from the endemic, low-density conditions to the moderately dense conditions. Moreover, under the moderately dense conditions defoliation is not severe enough to cause significant tree mortality. It seems to be a truly stable equilibrium for both sawfly and trees. Occasionally the system will move from the moderate sustained condition to the true outbreak conditions during which tree mortality is a dominant feature.

These differences can be traced to differences in dispersal and differences in the recruitment factor curve. Jackpine sawfly, unlike budworm, have very low powers of dispersal and, as shown in Figure 4 for one condition of the forest, the recruitment factor curve is more complex. The lower stable equilibrium (A) and the upper one (C) are caused in precisely the same way as with budworm. That is, the lower one is caused

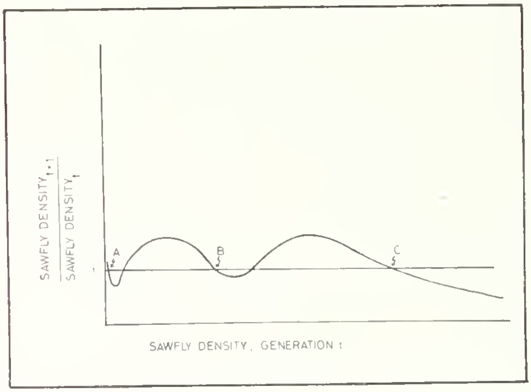

Figure 4. Diagrammatic recruitment factor for jackpine sawfly at various sawfly densities and a fixed forest state. A, B, and C represent stable equilibria in the sawfly plane.

by avian predation on large larvae and adults, and the upper equilibrium is introduced by competition for foliage. However, the additional dip in the curve producing a second stable equilibrium (B) is introduced by the action of small mammal predators. Jackpine sawfly overwinter in a cocoon stage in the soil where they are subject to a long period of predation by small mammals. The characteristics of the attack process are such as to introduce significant mortality over moderate ranges of density. If densities increase above these ranges, because of saturation of the attack response, the effect becomes swamped by large numbers of sawfly.

The qualitative pattern described earlier emerges from the generation of these equilibria conditions. (A) represents the lower endemic conditions, (B) the conditions of semi-persistent, moderate densities and (C) the true outbreak conditions when the forest collapses from under the sawfly. For the point emphasized in this section, the important thing is that the topological behaviour is richer than in the case of budworm through the addition of another stable equilibrium and, as a consequence, another stability domain. Again the point is made of the existence and importance of multiple equilibria, and the different consequences of alternative management approaches can be directly traced to the character and number of stability regions.

Although both of the above examples have drawn from forest pest management, we have explored other applications (Jones and Walters 1976). We believe at this time that topological descriptions are a useful but not fully developed method for dealing with some aspects of uncertainty.

(3) ADAPTIVE MANAGEMENT

One of the most promising techniques for coping with uncertainty is the use of adaptive management. In a formal sense, it uses adaptive control theory to find management policies that will balance the desire for future returns against the need to introduce management experiments that will determine system potential to produce the returns. Adaptive management can involve anything from a very simple pilot project type of design to rigorous statistical procedures (Walters and Hilborn 1976). The essence of adaptive management is to use the initial stages of development to gather information about the later effects of that development and then to modify the development plan after the initial developments have been made. The explicit assumption behind such a procedure is that there are some uncertainties in environmental effects which can never be resolved in advance. We must begin the development and then determine what happens. When there are no uncertainties, there is no need for adaptive management; but when there are important uncertainties, adaptive management can provide great assistance.

We need only look to economic ventures to see the way adaptive management is used. Pilot projects, market penetration studies, etc., are ways in which industry recognizes the uncertainties in production process or product acceptance. A corporation president does not expect his market analyst to tell him exactly how well a product will be accepted, yet an EIA director frequently expects his staff to tell him what the environmental impacts will be.

A distinction must be made here between experiments performed by the EIA staff and adaptive management. Adaptive management is needed when the only way to find out what the results of a project will be is by actually doing the project. Pre-impact experiments can be performed to reduce or eliminate some of the uncertainties, but some major uncertainties will remain unresolved until the project begins. Adaptive management theory seeks to prescribe how to modify the actual development in order to reduce the uncertainties as rapidly as possible and to be as flexible as possible toward the unexpected. This necessitates occasionally doing something that does not appear to be "optimal" because it will provide information. A somewhat heretical example for fisheries argues that the manager should occasionally "underfish" and "overfish" to make sure that his estimates of the productivity of the fish population are correct.

This is a particular problem for long-term management situations where a system tends to get held at a constant equilibrium. When a system is at equilibrium it provides no information about system behaviour, and if some element of the system changes, an equilibrium management strategy will provide no information about that change. We argue that such systems should be intentionally perturbed away from the equilibrium to provide information about the dynamics of the system.

Most development projects do not face the equilibrium problem. Usually involved is a set of construction projects to be built in a specific order. The tendency is to think that either you build them or you do not, that there is no room for adaptation. We argue that there is usually a great deal of room for adaptation, that there are many decisions that do not have to be made at time zero but can be made after the initial results of the program have been observed. A power generating station that is expected to have problems with waste heat does not have to build expensive cooling facilities from the start; they could be held off until the impacts of the heat effluent have been observed. Similarly, a coal burning plant does not have to be built initially at 5000MW, a smaller 1000MW plant could be built, the environmental impacts observed, and the further development decisions made later. We feel that the key to large-scale development programs is to break them into smaller units which can be implemented or eliminated. On the other hand, this strategy may sacrifice some economies of scale for future options (Waters 1975).

The above two examples were chosen because they point out the weaknesses in an adaptive management approach: some environmental impacts require either a minimum size due to a threshold effect or may have large time lags. Thus there may be no observable impacts from a 1000MW plant, but there might be significant effects from a 5000MW plant. Similarly, accumulation in food chains may prevent any impact from being noticed until the go-ahead decision is made to go to the 5000MW plant. The problems of DDT in marine food chains most likely would not have been detected by an adaptive management procedure. Although minimum size and time lags can pose problems for adaptive management, they pose even more serious problems for non-adaptive management. We must be aware that even using the best of techniques we cannot resolve all uncertainty.

Recognizing the need for adaptive management points out serious flaws in the current EIA procedure. We cannot, by means of EIA, predict what will happen in many developments. We can say that there are possible outcomes, and how we might resolve the uncertainties about the likelihoods of these outcomes. We should also point out that something totally expected may happen. What good EIA should do is point to some of the possible outcomes and suggest how management practices could be modified to gain information about the probabilities of the outcomes, and adapt to them when the results are discovered. This argues that the environmental impact procedure must be integrated with the development instead of being a one-time pre-development review. The current laws in the U.S. prevent this type of arrangement. They require that a statement be presented at a certain time and discourage any sort of creative integration of ecological knowledge with the management procedures.

CONCLUSIONS AND RECOMMENDATIONS

We have discussed some of the problems associated with environmental management and environmental impact assessment in uncertain environments. We argued that almost all environmental management takes place under uncertainty, and that since the world is not globally stable, a special type of management must be adopted to deal with multiple equilibria. We pointed out that there are many sources of uncertainty and proposed several methods for reducing it.

However, we contend that there will always be the unknown and that methods for dealing with the unknown present the biggest problems in environmental impact assessment.

Adaptive management policies appear to provide a useful method of dealing with the unknown. The use of adaptive management in the context of environmental impact assessment requires a restructuring of the EIA process. To facilitate this, we recommend that the following changes be made:

1. The current "Environmental Impact Statement" be modified to a "Statement of Expected Impacts." This statement would predict what impacts are expected, but would also contain a list of major areas of uncertainty that were identified.

2. The "Statement of Expected Impacts" should be accompanied by a plan for environmental management. This plan would detail the environmental factors to be monitored as the program proceeds and identify the key signals indicating that a major deviation from the expected impacts is occurring. Where possible, control methods should be described before deviations are observed.

3. Some provision should be made for an external review of the ongoing environmental impacts by an outside agency as the program proceeds. There should be an environmental management staff as part of the development agency, but there should also be occasional external reviews.

4. Development programs must explicitly recognize that there are substantial probabilities that something unexpected may occur with adverse environmental effects. Part of the cost of the program should be an insurance policy against this happening, similar to the $50 million insurance Dome Petroleum had to purchase before drilling in the Beaufort Sea. The size of the insurance, or contingency

fund, should be related to the uncertainties faced.

5. The decision-makers and the public should be made aware that there are always going to be unexpected outcomes which ecologists did not and could not predict, and the measure of success of the environmental impact procedure is not only how well it predicted the outcomes, but how well the management system responded to the unexpected when it happened.

ACKNOWLEDGEMENTS

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REGIONAL ANALYSIS AND ENVIRONMENTAL IMPACT ASSESSMENT[1,2]

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INTRODUCTION

The impact of man upon his environment has increased significantly over recent years as he has sought to make ever greater use of the resources available to him in nature. Subsequently, those involved in the assessment of environmental impact have been called upon to evaluate the magnitude of man's increased impact upon his environment. As the impact increases, it has been found that the influence of man's actions spreads over larger and larger spatial scales. Thus assessment scientists have been called upon to evaluate impacts over ever increasing spatial scales and to provide this information to decision-makers who must judge the full consequences of a particular set of actions.

Ideally, scientists involved in assessment activities should evaluate impacts over spatial scales great enough to encompass the total impact. In many cases, however, this would involve development of assessment techniques appropriate on a worldwide scale. This approach is not currently possible because knowledge in many ecological areas has not progressed beyond the local scale of resolution. However, some techniques do exist which permit assessment of impacts somewhat beyond the site of causal action.

The techniques applied beyond this area of causal action are said to have application on a regional scale. While selection of a spatial region is an important precursor to a modeling program, there is no currently accepted hierarchy of spatial scales for regional use. Although the term "region" does not have a definite spatial connotation, it is important to understand that the importance of environmental variables is different at different scales. Each spatial hierarchy has its own emergent properties (McCarthy, M.M., et al. 1976) and studies conducted on a regional scale must focus upon the variables of interest at the relevant scale. Techniques discussed in this paper are, in general, applicable to studies carried out on a scale large enough to encompass a multistate region.

An example of the evaluation of regional environmental impact in terms of ecosystem effect may be seen where a power plant is planned for a site on a highly channelized river system. In the case where fish spawning sites are limited below the proposed facility, consideration must be given to the impacts produced by plants sited further down the river. Eggs and larvae produced above the proposed plant will be subjected to impacts not only from the proposed facility, but also from facilities sited along the entire length of the river. Quite obviously, any impact assessment of the initial facility must also include considerations of the additional impacts of other facilities distributed over the larger spatial scale.

This paper presents a number of techniques that can be used to assess environmental impacts on a regional scale. Regional methodologies have been developed which examine impacts upon aquatic and terrestrial biota in regions through consideration of changes in land use, land cover, air quality, water resource use, and water quality. Techniques used to assess long-range atmospheric transport, water resource, effects on sensitive forest and animal species, and impacts on man are presented in this paper, along with an optimization approach which serves to integrate the analytical techniques in an overall assessment framework.

This paper on assessment techniques is meant to provide a brief review of the research approach and certain modeling techniques used within one regional studies program. While it is not an all-inclusive report on regional analyses, it does present

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[3]Present address Health and Safety Research Division, ORNL.

[4]Present address Environmental Assessment Department, Electric Power Research Institute.

an illustration of the types of analyses that can be performed on a regional scale.

ASSESSMENT PROGRAM

The objective of the program in Regional Studies at Oak Ridge National Laboratory is to provide assessments of the overall impacts of energy development options in the various regions of the United States and in the nation as a whole. Seven regional laboratories participated in the Department of Energy (DOE) funded program. Within this group the Environmental Sciences and Energy Divisions of Oak Ridge National Laboratory have responsibility for assessing the environmental, social, and economic effects of energy technologies in in the southern United States. The environmental aspects of the regional program are carried out in the Environmental Sciences Division at Oak Ridge National Laboratory.

The approach employed in assessing environmental effects in the Regional Studies Program goes beyond conventional impact analysis to include consideration of the impacts of multiple facilities sited on a regional scale. Also involved in the regional assessment is an evaluation of planned facilities so that the siting and operation of these facilities may be carried out with a minimum environmental impact. The regional impact analysis first involves use of screening techniques to isolate feasible areas for facility development (Frigerio, N.A. et al. 1975) and use of optimization techniques to plan the distribution of facilities among these feasible areas (Cumberland J.H. and R.J. Korback 1973). Detailed assessments are carried out on the resulting distribution of facilities, (Sharma, R.K., J.D. Buffington, and J.T. McFadden 1975) and these assessments are then used to further refine the siting criteria used in the initial site selection.

ATMOSPHERIC TRANSPORT

A regional assessment must include consideration of the various atmospheric processes which have a significant role in the transport of pollutants throughout a region. Many of the most significant impacts that occur within a region are found within distances on the order of 100 km from the point of release. These impacts may be important from the standpoint of effect on human health as well as effect on the environment. However, it is also necessary to assess the impact from releases of pollutants at much greater distances from the point of release. The long-term effects resulting from increases in levels of pollutants require study on a regional scale.

Atmospheric transport models have been developed which can be used to estimate deposition rates and ground level concentrations of pollutants over both short and long ranges. These models have been developed from considerations of atmospheric diffusion theory and the physics of material exchange in vegetation cover. The short-range transport of pollutants over distances of up to 100 km can be analyzed using a Gaussian distribution. The amount of dispersion depends on atmospheric turbulence determined from meteorological data. Figure 1 shows the average sulfur dioxide concentrations calculated by an ORNL version of the Gaussian plume model for releases from a coal combustion power plant located near Oak Ridge.

For longer range transport at distances up to a few thousand kilometers, wind trajectories within the troposphere must be analyzed. By analyzing wind speed and direction at various heights for numerous locations and interpolating, these trajectories can be plotted. Pollutants will move along these trajectories within the mixing layers of the atmosphere. By averaging the distribution of wind trajectories it is possible to determine the patterns of atmospheric pollutant loading for a region. A trajectory wind model developed by the National Oceanic and Atmospheric Administration (Heffter, et al. 1975) is being applied in this analysis. Long-range trajectories have been calculated at 6-hr intervals for the region surrounding Oak Ridge. Figure 2 shows the wind trajectories on a typical day as they pass over Oak Ridge and the surrounding five state area. Thus the contribution of sources from one part of a region to another may be assessed.

WATER RESOURCES

Water resource considerations must also be factored into an assessment of environmental impact on a regional scale. In general, description of water resource dynamics suffer because of the lack of sufficient data and the complexity of the system on a regional scale. A regional assessment requires that there be a screening capability to evaluate a number of potential sites from the standpoint of water resources. One means of assessing the potential availability of surface water is provided through use of standard drought frequency analysis (Matalas N.C. 1963). Flow data are retrieved from computer tapes and analyzed to determine the

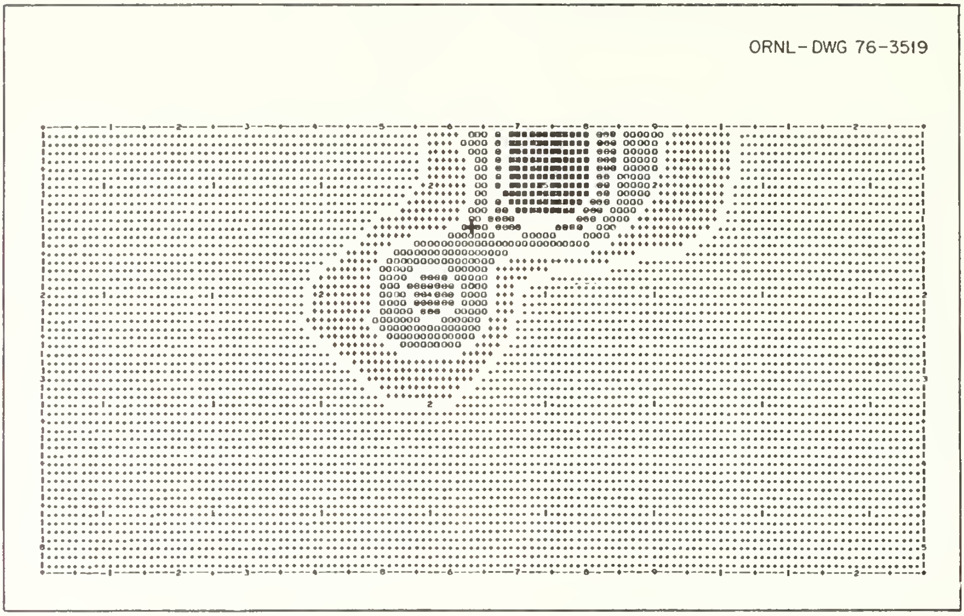

Figure 1. Relative SO_2 concentrations in the vicinity of Kingston Steam Plant for a typical winter month (50- x 90-km area). Isopleths represent 20, 40, 60, and 80% of maximum concentration at source.

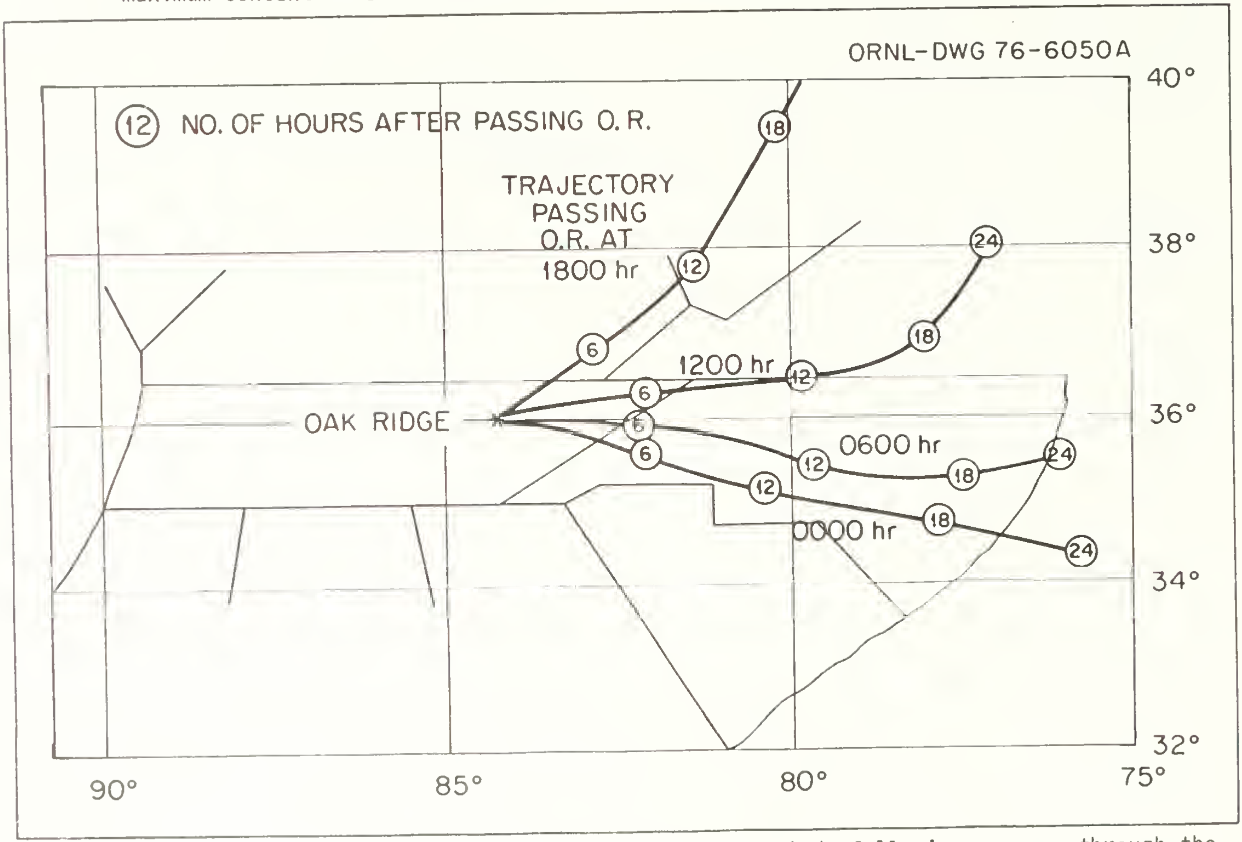

Figure 2. Twenty-four hour trajectories of lower atmosphere winds following passage through the Oak Ridge area at designed hours of the day.

probability that any given flow rate can be relied on for any year. Figure 3 shows such a relation for the South Fork of the Holston River in Tennessee, and indicates that the minimum 7-day average low flow can be predicted to be greater than or equal to a given number of feet per second with 95% probability in any year. The unregulated Emory River can be expected to stop flowing about one year in ten.

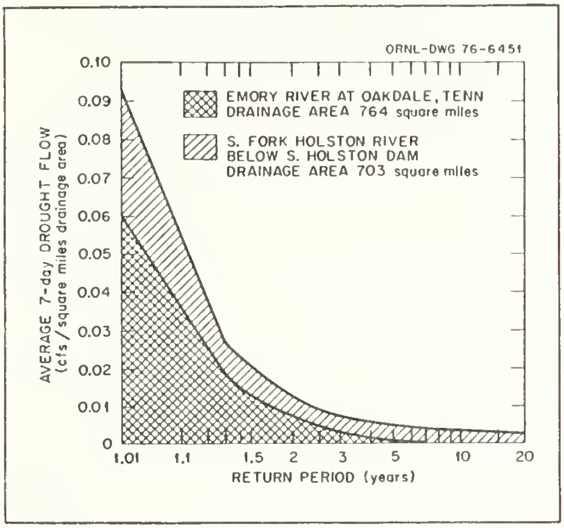

Figure 3. Low flow data for Emory River and South Fork of the Holston River.

A major factor affecting the water resources of a region is the installation and operation of a reservoir system. Such systems may completely change the flow regime of a river because the presence of a reservoir can enhance drought flows by storing water in wet periods and supplementing flow in dry periods. This effect can be simulated for specified reservoir operating rules through the use of a model such as the Streamflow Synthesis and Reservoir Regulation Model (SSARR) developed by the U.S. Corps of Engineers (Brooks, E.M. Davis, D.W. Kuehl, and D.M. Rockwood 1975). For example, if surface water is needed for cooling tower operation, it is possible to use the SSARR to examine the effects of cooling water withdrawals on downstream flows under alternative modes of operation. Figures 4 and 5 shows an example of natural flow in the Emory River in Tennessee and the effect a dam would have on flow rates downstream. Water stored during periods of high flow will be available for cooling towers during low flow periods.

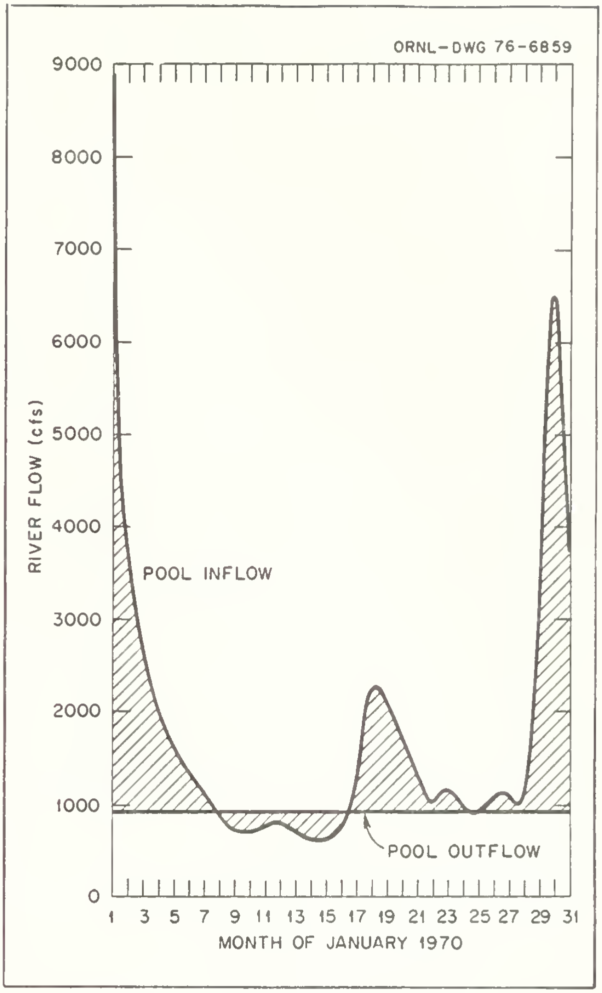

Figure 4. Illustration of the natural flow in the Emory River of Tennessee.

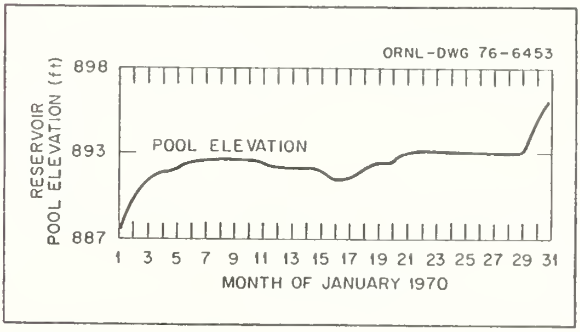

Figure 5. Stabilizing effect of siting a hypothetical dam on the flow of the Emory River.

By analyzing low flow frequency for all significant streams in a region, it is possible to evaluate the potential availability of surface water. By examining the downstream flow rates that would be created by impoundments and withdrawals, it is possible to determine the effects of energy facilities on low flow frequencies. These analyses can be used to select optimal locations for future facilities.

ECOLOGICAL EFFECTS

Major ecosystem processes on a regional scale may be examined through the use of environmental systems models. These models may examine such processes as succession, productivity and growth, and habitat selection, as well as transport and distribution within ecological systems. To this extent, much research has been directed toward the development of regional models which may be used to demonstrate the impact of significant natural or man-induced disturbances.

The manifestation of impacts on vegetation can be analyzed using a Botkin-type stand growth simulation (Botkin, D.B., J. F. Janak, and J.R. Wallis 1972). A model has been developed and is being verified in a case study designed to assess the impact of the American chestnut blight on forest succession (Shugart H.H., and D.C. West 1976). By simulating stand growth with and without American chestnut as a viable species, effects on stand succession and ultimate stand structure and composition are elucidated. Forest records prior to the chestnut blight and present stand information were used as reference points for validation of the model. The effects of pollutants such as sulfur dioxide on forest growth and succession can also be analyzed in this fashion. Through greenhouse experiments and models based on physiological relationships, alteration in mortality and growth parameters caused by increased concentrations of pollutants can be determined. These parameter variations are applied to the stand growth model to assess the short- and long-term effects of pollutants.

Aquatic ecosystem effects on a regional scale may be analyzed with a river basin simulation model. One example of such a model is that developed by Water Resources Engineers for the U.S. Army Corps of Engineers. (Chen, C.W., and G.T. Orlob 1972). After this model has been parameterized for a particular river basin, the chemical and biological effects of adding an additional impoundment can be characterized. Clearly, higher resolution aquatic ecosystem models are required for analysis of impacts in the immediate area of the facility. These models generally must be constructed on a site-specific basis to ensure adequate sophistication.

SENSITIVE HABITATS AND SPECIES

Consideration of the effects of energy technology development on sensitive bird and mammal species must also be factored into an analysis of regional impact. This aspect of the assessment effort is directed toward describing the distribution of sensitive bird and mammal species in the southern United States. The information being accumulated is designed to identify the spatial distribution of species by state, county, and habitat type. Mammal and bird species have been catalogued on a county basis, using distribution maps from various animal guides and journal papers. Initially, special emphasis has been placed on species designated as scarce, endangered or threatened. Concomitant with the compiling of distribution information is the listing of parameters which can be used to describe the habitat of each species. Figure 6 shows a computer-generated map of several animal taxa, including the Ipswich sparrow, burrowing owl, wood ibis, and Indiana bat. When the habitat information and distribution data are compiled and synthesized, it will be possible to utilize multivariate and discriminant function analysis to predict changes in the populations of bird and mammal species over the region. This type of data analysis is useful for considering not only existing threatened or endangered species but also those species which may become endangered through destruction of elements of their habitats.

HUMAN HEALTH IMPACTS

Programs designed to assess energy technology impact on a regional scale must include techniques to assess impacts on human health. In this regard research has been conducted to develop a series of transport models which may be used to assess the quantities of pollutants which reach man as a result of energy technology development (Killough, G.G., and L.R. McKay 1976). These transport models predict the fraction of the initial pollutant source term to which man will be exposed over time as a function of position relative to the source (Moore R.E. 1975, Booth R.S. and S.V. Kaye 1971). Each significant mode of human exposure is considered (Trubey, D.K., and S.V. Kaye 1973). Physiological uptake and retention models are coupled with the transport models to predict

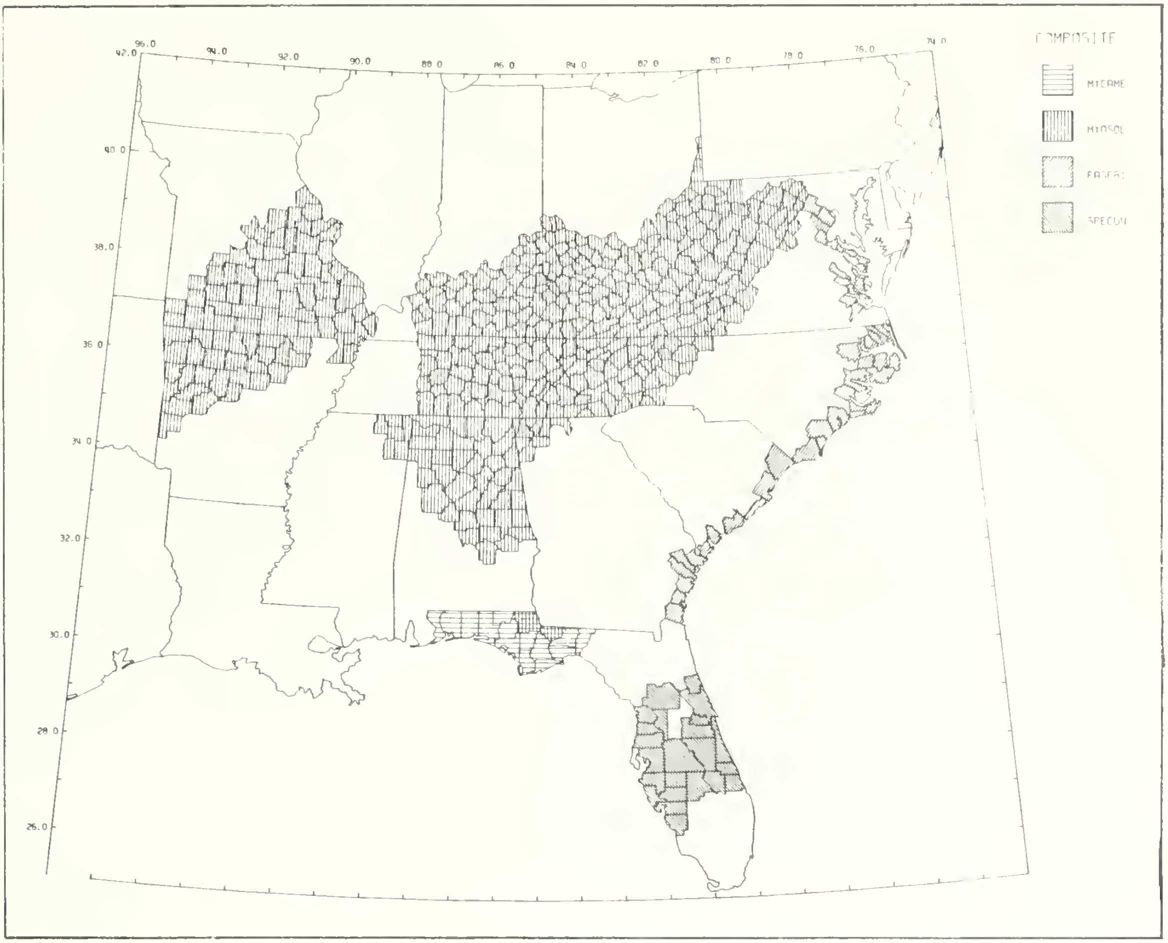

Figure 6. Computer-generated distribution map of Ipswich sparrow (PASPRI), burrowing owl (SPECUN), wood ibis (MYCAME), and Indiana bat (MYOSOL).

resultant tissue and organ concentrations in man (Killough, G.G., P.S. Rohwer and W.D. Turner 1975). An approach of this type permits assessment of environmental pollutant levels in terms of concentration limits established by regulatory statute or in terms of available data on human health effects for pollutants where regulatory statutes do not exist.

The development of transport models to assess the human impact of the various energy technologies draws heavily from models and dose codes which in the past have been used to predict the radiological dose to man. Figure 7 shows the assessment approach which has been used to calculate external exposure to radioactive pollutants, while Figure 8 illustrates the various factors that must be considered in a radiological assessment of internal exposure.

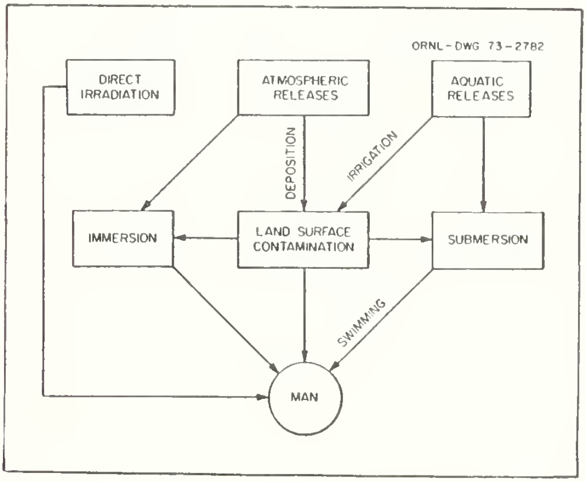

Figure 7. Pathways of external radiological exposure to man.

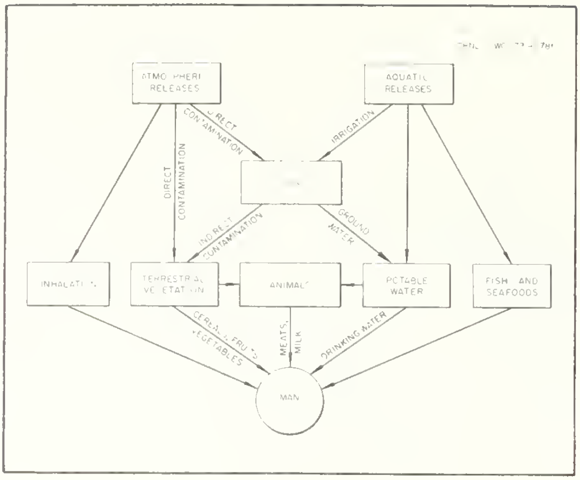

Figure 8. Pathways of internal radiological exposure to man.

Techniques now under development to assess the impacts of the various nonnuclear technologies complement extant radiological assessment models and permit realistic evaluations of human health impact. A set of transport models which are applicable to assessment of health impacts from nonnuclear technologies are currently being used to assess the potential health impacts resulting from releases of an industrial smelting complex. In this regard, an air transport model is being used to predict air concentrations and deposition in the vicinity of the smelter. A terrestrial food chain model is used to predict the pollutant concentration which reaches man through ingestion of contaminated food items. Exposure levels calculated through use of the air transport model and the terrestrial food chain model are then interfaced with physiological models (Booth, R.S., and S.V. Kaye 1971) and information on health effects to provide an assessment of the impact on human health.

OPTIMIZATION IN FACILITY SITING

A principle question in regional environmental analysis is where should energy facilities be sited. Both the location and size of the facilities must be considered as well as the type of facility within a given fuel cycle. A set of feasible sites for development determined through use of a screening technique serves as input to an optimization approach used to assign facility sizes to the sites. Various site requirements, including water availability, distance to load centers, fuel availability, etc., are mapped for the region. A comparison of these site requirement maps provides a guide to areas suitable for development, and a detailed study of these areas yields a set of feasible sites. As part of the regional environmental assessment, an optimization approach is used to determine the size of facilities which should be allocated to these sites for minimum environmental impact on a regional scale. The objective of minimum environmental impact is then considered in a tradeoff analysis with economic and engineering considerations.

Traditional approaches to optimization have relied very heavily on economic analysis. Where environmental "costs" have been considered, the method has frequently employed commensuration of environmental variables in terms of dollar values. In the process of equating money and environmental variables, the researcher functioning as analyst becomes a decision-maker and assigns an absolute price for environmental factors which possess other than monetary value. This has been done in the past as a necessary step in finding the least-cost solution to the problem of selecting a location, size, and type of energy facility from among the wide variety of possibilities.

The Surrogated Worth Trade-Off Method has recently been developed and used in water resources systems management (Haimes, Y.Y., W.A. Hall and H.T. Freedman 1975). The method avoids the necessity of placing dollar values on things that are non-marketable and allows for expression of environmental variables in terms of their basic units of measurement. Each aspect of energy facility siting is considered as a single objective optimization problem such as minimizing environmental impact or transportation cost. These single objective problems are then integrated into a multiple objective framework. The mechanism for this integration is a trade-off function which represents the decision-makers' willingness to sacrifice the attainment of one objective in the process of reaching another. In some cases, the trade-off function will be available in analytical form, but more often it will be developed by interrogating the decision-maker.

As a demonstration project, a case study for the Tennessee Valley region is being considered. Nine counties which are suitable for siting of energy facilities have been selected, using a screening program developed at Oak Ridge National Laboratory (Voelker, A.H. 1976). Initial emphasis is on the minimization of impact due to air-transported pollutants. For plants located at each feasible site the projected ground level concentrations of air pollutants over the region are calculated, using the air-transport model previously described. Exposure indices for human populations, sensitive vegetation species, or habitats of important animal species are then calculated by multiplying ground level concentration by population densities or degree of sensitivity. Power plants sizes can then be allocated among the feasible sites to meet a projected increase in demand for generating capacity while minimizing these indices of environmental impact. Using the Surrogate Worth Trade-Off Method, this minimum impact objective is then analyzed in terms of minimum cost objectives.

It should be noted that all of the analysis and assessment techniques previously described are incorporated in this siting problem. A link between the size of the facility and the degree of environmental impact as reflected by the value of the objective function must be determined. For the case study explained above, the air-transport model and sensitivity measures of animal populations and vegetation provide this link. In addition, a detailed assessment is required to analyze the regional impact of the distribution of facilities after the optimization process is carried out.

SUMMARY

A set of analysis techniques used in Oak Ridge National Laboratory regional environmental assessment program have been briefly discussed. These techniques illustrate some environmental areas deemed to be important from the standpoint of regional impact. While the major emphasis was placed on models developed to assess impact, the important role of data management techniques is also readily acknowledged.

A major factor in the regional impact of energy technology facilities involves the selection of sites from among a number of feasible locations. It is felt that the optimization of facility sizes among a set of feasible sites is a practical approach to this problem. The results of this optimization procedure require detailed interpretation and follow-up measurements. The indicated trends are generally more important than the absolute levels of facility size calculated. In this regard, the decision-maker will provide the final assessment of activity levels. The methods described here give the decision-maker the information necessary to develop this plan and to assess environmental impact on a regional scale.

ACKNOWLEDGMENT

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EVALUATING IMPACTS UPON ENDANGERED OR THREATENED SPECIES

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ENDANGERED SPECIES--THREATENED SPECIES -- CRITICAL HABITATS

These three terms, relative newcomers to the environmental jargon, are becoming more and more frequently heard--in the media, in the Halls of Congress and more recently in the Courts. They are of particular significance to those of us who are employed by agencies who manage lands, construct things, issue permits or other authorizations for others to carry out such activities or review the actions of those who do.

I will discuss these terms and their significance in the evaluation of environmental impact. The presentation is a bit legalistic, bureaucratic and procedural. I do not plan to present any "Gee Whiz formulas" for evaluating impacts upon critical habitat nor to provide any simple means of determining endangered species conservation versus development cost/ benefits. I do not think such short cuts exist, and even if they did I do not believe they would be applicable to the question of endangered species conservation.

Instead, I will dwell briefly upon just what an endangered species, a threatened species or critical habitat is, how such determinations are made, what benefits accrue to such a species. I will limit remarks to NEPA-type benefits as opposed to prohibitions-against-taking type benefits and the procedures being developed to insure the conscientious application of those benefits.

The term endangered species has been used and misused by the media and the general public for some time. However, since December 28, 1973, threatened species and critical habitat have had specific legal meanings and the application of those terms to a plant, an animal or a piece of real estate now carries with it a great deal of legal significance.

On that date the President signed into effect Public Law 93-205, better known as the Endangered Species Act of 1973. The law rapidly is becoming recognized as one of the strongest pieces of environmental legislation on the books.

A few quotes from the Act would be helpful in putting the rest of my comments into perspective.

The Congress's findings, their stated purposes and the intended policy of the Act are of interest and particularly relevant to this Symposium. Section 2 states:

SEC. 2. (a) Findings.-The Congress finds and declares that:

(1) various species of fish, wildlife, and plants in the United States have been rendered extinct as a consequence of economic growth and development untempered by adequate concern and conservation;

(2) other species of fish, wildlife, and plants have been so depleted in numbers that they are in danger of or threatened with extinction;

(3) these species of fish, wildlife, and plants are of esthetic, ecological, educational, historical, recreational, and scientific value to the Nation and its people;

(4) the United States has pledged itself as a sovereign State in the international community to conserve to the extent practicable the various species of fish or wildlife and plants facing extinction, pursuant to -

(A) migratory bird treaties with Canada and Mexico;

(B) the Migratory and Endangered Bird Treaty with Japan;

(C) the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere;

(D) the International Convention for the Northwest Atlantic Fisheries;

(E) the International Convention for the High Seas Fisheries of the North Pacific Ocean;

(F) the Convention on International Trade in Endangered Species of Wild Fauna and Flora; and

(G) other international agreements.

(5) encouraging the States and other interested parties, through Federal financial assistance and a system of incentives, to develop and maintain conservation programs which meet national and international standards is a key to meeting the Nation's international commitments and to better safeguarding, for the benefit of all citizens, the Nation's heritage in fish and wildlife.

(b) Purposes. - The purposes of this Act are to provide a means whereby the ecosystem upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve the purposes of the treaties and conventions set forth in subsection(a) of this section.

(c) Policy. - It is further declared to be the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of the purposes of this Act."

I doubt that many of us concerned with the rational use of our natural resources would quarrel with those findings, and the stated purposes of the Act certainly fall well within the realm of wise resource utilization. Likewise, the state Policy leaves little doubt that the Congress intended this concern to be given serious consideration by the entire federal establishment - not just those agencies with wildlife conservation responsibilities.

Three key terms in the preceding are endangered species, threatened species and conservation. All three are specifically defined in the Act as follows:

"The terms 'conserve,' 'conserving,' and 'conservation' mean to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary. Such methods and procedures include, but are not limited to, all activities associated with scientific resources management such as research, census, law enforcement, habitat acquisition and maintenance, propagation, live trapping, and transplantation, and in the extraordinary case where population pressures within a given ecosystem cannot be otherwise relieved, may include regulated taking";

"The term 'threatened species' means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range"; and

"The term 'endangered species' means any species which is in danger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta determined by the Secretary to constitute a pest whose protection under the provisions of this Act would present an overwhelming and overriding risk to man."

The Congress also recognized that biologists - particularly taxonomists - are inclined to quibble over just where a subspecies leaves off and a species begins and took steps to minimize the number of taxonomic debates by defining "species" as follows:

"The term 'species' includes any subspecies of fish or wildlife or plants and any other group of fish or wildlife of the same species or smaller taxa in common spatial arrangement that interbreed when mature."

We interpret the wording "...other group of fish or wildlife in common spatial arrangement that interbreed when mature" to mean what biologists commonly term a population.

Use of the terms fish and wildlife and plants in the definition of species provided a reason to also define those two terms (one sometimes wonders if those who draft legislation and regulations are not really frustrated dictionary authors). Those two terms are defined as follows:

"The term 'fish or wildlife' means any member of the animal kingdom, including without limitation any mammal, fish, bird (including any migratory, non-migratory, or endangered bird for which protection is also afforded by treated or other international agreement), amphibian, reptile, mollusk, crustacean, arthropod or other invertebrate, and includes any part, product, egg, or offspring thereof, or the dead body or parts thereof."

"The term plant means any member of the plant kingdom, including seeds, roots and other parts thereof."

Thus, any species, subspecies or population of animals or any species or subspecies of plant is eligible for consideration under this Act if it is determined to be either threatened with extinction or likely to become so.

When one considers the wide spectrum of life forms involved, their tremendously different degrees of vulnerability, and the general lack of hard data concerning the status of most wild flora and fauna - particularly the plants, the invertebrates and many of the so-called "lower" vertebrates - it becomes apparent that identifying threatened or endangered species is a monumental task. The Congress also recognized that fact and, instead of specifying hard and fast criteria for such species, they identified a number of factors the Secretary was to consider, identified certain reservoirs of knowledge he was to consult, proscribed an extensive public notification and "due process-like" procedure and then directed him, "...on the basis of the best scientific and commercial data available to him..." (emphasis added) to determine whether the species under consideration was threatened or endangered. The factors which must be considered are as follows:

> "(1) the present or threatened destruction, modification, or curtailment of its habitat or range;
>
> (2) overutilization for commercial, sporting, scientific, or educational purposes;
>
> (3) disease or predation;
>
> (4) the inadequacy of existing regulatory mechanisms; or
>
> (5) other natural or manmade factors affecting its continued existence."

It is significant to note that there is no magic number to which the population must decline before a species becomes a subject for consideration under the Act. In fact, the factors lean away from population "guesstimates" and, instead, recognize that man-caused alterations of the environment and/or overutilization are major considerations.

Once a species has been identified as a serious candidate for the Threatened or Endangered Species List, this fact is noted by the publication of Proposed Rules in the Federal Register notifying interested parties that the species is being proposed for addition to the List. A mandatory period of at least 60 days is required (except in certain emergency situations) for public comment. I might note that the Congress recognized that all wisdom does not lie within the federal bureaucracy and, in Section 4(c)(2) they provided the following language:

> "The Secretary shall, upon the petition of an interested person...conduct a review of any listed or unlisted species proposed to be removed from or added to either of the lists...if he makes and publishes a finding that such person has presented substantial evidence which in his judgment warrants such a review."

During this procedure we also review the action pursuant to the National Environmental Policy Act and, where appropriate, prepare Environmental Impact Assessments and Negative Declarations of Environmental Impact Statements. At the end of that time any such public comments will be analyzed and final decisions on the proposal will be made. This will be announced via publication of a Final Rulemaking in the Federal Register.

At this point we have a genuine, official endangered or threatened species. Now what benefits or additional concern accrue to it? This is where Section 7 of the Act enters the picture. That Section, with emphasis placed on certain passages, reads as follows:

> "Sec. 7. The Secretary shall review other programs administered by him and utilize such programs in furtherance of the purposes of this Act. All other Federal departments and agencies shall, in consultation with and with the assistance of the Secretary, utilize their authorities in furtherance of the purposes of this Act by carrying out programs for the conservation of endangered species and threatened species listed pursuant to section 4 of this Act and by taking such action necessary to insure that actions authorized, funded, or carried out by them do not jeopardize the continued existence of such endangered species and threatened species or result in the destruction or modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with the affected States, to be critical."

We interpret this Section as providing three areas of consideration in the effort to conserve threatened or endangered species. First it requires all federal agencies to utilize their authorities in carrying out programs aimed at the conservation of such species, secondly - and perhaps most importantly - it prohibits any federal agency from authorizing, funding or carrying out any action which may jeopardize the continued existence of a threatened or endangered species and, thirdly, it prohibits federal agencies from destroying or modifying habitat which has been determined to be critical habitat.

In order to further define just what was meant by the term critical habitat, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service jointly published a Notice in the April 22, 1975, Federal Register (40 FR 17764) that states, among other things: "Conservation of the earth's resources can maintain ecosystems within which, it is hoped, all species of fauna and flora can coexist and thereby benefit. The role that natural and manmade factors play in affecting interrelationships between fauna and flora and the ecosystems upon which they depend needs to be recognized. For the continued viability of any species, suitable habitat is not only important but essential to life itself. The term 'habitat' could be considered to consist of a spatial environment in which a species lives and all elements of that environment including, but not limited to, land and water areas, physical structure and topography, flora, fauna, climate, human activity, and the quality and chemical content of soil, water, and air.

'Critical habitat' for any endangered or threatened species could be the entire habitat or any portion thereof, if, and only if, any constituent element is necessary to the normal needs or survival of that species. The following vital needs are relevant in determining 'critical habitat' for a given species:

(1) space for normal growth, movements, or territorial behavior;

(2) nutritional requirements, such as food, water, minerals;

(3) sites for breeding, reproduction, or rearing of offspring;

(4) cover or shelter; or

(5) other biological, physical or behavioral requirements."

The procedures for determining critical habitat are nearly identical to those used to determine a threatened or endangered species and involve a formal notice to the affected state governor, the publication of a Proposed Rulemaking in the Federal Register, the provision of at least 60 days for public comment and final decision which is announced via publication of final rules in the Federal Register. Again, the procedure is centered around the gathering of the best information available, the provision of an adequate period for interested persons to provide input and a final decision based upon that accumulated information.

This section of the Act has been tested in the Courts in a suit brought by the Mississippi Wildlife Federation and the National Wildlife Federation against the Department of Transportation. The suit involved construction of a portion of Interstate Highway 10 in Jackson County, Mississippi, which would bisect the last remaining habitat of the endangered Mississippi Sandhill Crane. Judges Simpson, Thornberry and Morgan of the U.S. Court of Appeals, Fifth Circuit, ruled in favor of the Federation and placed the continued existence of "feathered cranes" above the untempered proliferation of "concrete lanes." Those interested in the legal details may read the decision which is cited as National Wildlife Federation versus William T. Coleman, Secretary of Transportation - No. 75-3256.

It now seems apparent that the teeth the Congress put into the law are capable of use by the courts in getting a bit better bite and more control over ecologically irresponsible development.

I don't wish to leave the impression that the determination of a piece of critical habitat is analogous to the designation of a wilderness area or that concern over an endangered orchid will put the timber industry out of business.

While it is true that the determination of critical habitat puts all federal agencies on notice that any action authorized, funded, or carried out by them cannot result in the destruction or adverse modification of critical habitat of endangered or threatened species, this does not necessarily mean that all uses of the area will be prohibited. There may be many kinds of actions which would not be detrimental and could be carried out within the critical habitat of a listed species. This would be the case as long as such actions would not result in a reduction in the numbers or distribution of that species of sufficient magnitude to place the species in further jeopardy or otherwise adversely affect it. If, for example, a power company can meet this requirement in building an electrical power plant on a critical habitat, then nothing in the determination of critical habitat would prevent such construction.

In order to assist federal agencies in their compliance with the mandate of Section 7, the U.S. Fish and Wildlife Service chaired an ad hoc group comprised of representatives of about a dozen federal agencies. That group developed a paper entitled "Guidelines to Assist Federal Agencies in Complying with Section 7 of the Endangered Species Act of 1973." As usually is the case, the guidelines are rather detailed. In fact, the ad hoc group managed to expand the single, rather clearly written paragraph which comprises Section 7 into over 12 pages of single-spaced text. Copies of the guidelines are available from the U.S. Fish and Wildlife Service in Washington, D.C.

A brief summary of those guidelines may be helpful. In addition to describing the scope and requirements of Section 7 and setting forth the procedural aspects of the determination of critical habitat, they also:

--specify that compliance with Section 7 is the responsibility of the agency authorizing, funding or carrying out the action in question and therefore that agency is responsible for screening such activities to determine whether they may be in conflict with Section 7;

--when such is the case, the guidelines spell out a procedure for the agency to enter into consultation with the U.S. Fish and Wildlife Service (or the National Marine Fisheries Service, as appropriate). This consultation will lead to a Biological Determination by the Service as to whether the questionable action would, in fact, either jeopardize the continued existence of the species or destroy or adversely modify critical habitat. Such Biological Determinations will be rendered in writing to the action agency and provision is made for the entry into cooperative actions to prevent any negative impacts upon the species or its habitat. It should be recognized, however, regardless of the conclusions of the Biological Determination, that the final decision on whether to proceed with, modify or terminate a project lies with the action agency. The Act does not give the Secretary of the Interior or Commerce any additional power to halt a project which is authorized, funded or carried out by another agency.

However, in the context, Section 11(g) of the Act is of interest. That Section states, in part:

> "(g) Citizen Suits. - (1) Except as provided in paragraph (2) of this subsection any person may commence a civil suit on his own behalf -
>
> > (a) to enjoin any person, including the United States and any other governmental instrumentality or agency (to the extent permitted by the eleventh amendment to the Constitution), who is alleged to be in violation of any provision of this Act or any regulation issued under the authority thereof..."

I think this focuses even more sharply the significance of the Fifth Circuit Court of Appeals decision in the Mississippi Sandhill Crane case I mentioned earlier.

Our Solicitors have expressed their opinion that, although the critical habitat provisions of Section 7 probably do not apply to threaten or endangered species in countries other than the United States, the requirements for federal agencies to insure that actions they authorize, fund or carry out do not jeopardize the continued existence of such species <u>is</u> applicable wherever in the world such actions are carried out.

Obviously the job ahead of us--the identification and determination of threatened or endangered animals and plants throughout the world as well as the critical habitat of such species--is staggering. Even more significant is the problem of monitoring activities authorized, funded or carried out by federal agencies - again anywhere in the world.

It is with those thoughts in mind that we applaud this Symposium and hope, now that you are a bit more familiar with some of the details of the Endangered Species Act, that suggestions and guidelines for those whose activities may impact upon the natural environment may be developed or modified with those thoughts in mind. In particular we see the process of compliance with the National Environmental Policy Act as one of the more effective means whereby:

-- the welfare of Threatened or Endangered Species present in the potentially affected area must be considered;

-- the impact upon any critical habitat must be fully assessed; and

-- perhaps most importantly, the evaluation of the environmental impact of any given action should include an assessment of whether that action will cause any species of plant or animal to become a threatened or endangered species. It should be borne in mind that a species, for example an endemic mollusk or plant, could be in excellent condition until a project authorized, funded, or carried out by a federal agency comes along. Such a project could, unless it is carried out in an ecologically responsible manner, destroy the habitat upon which the species is dependent and thereby place the species in danger of extinction. This, in turn, would cause the species to be determined to be an endangered species and thereby invoke the provisions of the Act.

Such dilemmas can, must and will be avoided if - or rather when - the impacts of such activities upon the entire ecosystem in which they are to be carried out are assessed.

Those of us in the Fish and Wildlife Service take this responsibility very seriously and are anxious to work with any of you in helping insure the continued survival of the myriad plants and animals with whom we share this planet earth.

EVALUATING IMPACTS ON ENDANGERED AND THREATENED FLORA

Edward S. Ayensu*
Chairman and Director of Endangered Flora Project
Department of Botany, Smithsonian Institution

The National Environmental Policy Act of 1969 came into being several years before the extent to which the United States flora as a whole is endangered had been determined. As a result of a directive in the Endangered Species Act of 1973, we are now in a much better position to provide for the protection of the jeopardized elements in the flora of the United States.

In the Endangered Species Act of 1973, the U.S. Congress requested the Secretary of the Smithsonian Institution to review species of plants which are now or may become endangered or threatened, and to review methods of adequately conserving such species.

In keeping with that request the "Report on Endangered and Threatened Plant Species of the United States" was presented to the Congress in January 1975. In the Report are listed approximately 3,100 species, subspecies and varieties of native vascular plants which it is recommended would qualify, on the basis of the botanical expertise available, for endangered or threatened status pursuant to the Endangered Species Act of 1973.

Of this total, 1,400 taxa (761 from the continental United States plus 539 from Hawaii) are in the endangered category. The numbers of endangered and threatened plants, taken together, represent approximately 10% of the flora of the continental United States (which totals 20,000 species), and nearly 50% of the Hawaiian flora (which totals about 2,200 species). The Report is significant as the first-ever assessment of this country's flora from the standpoint of its degree of endangerment on a national basis. The Report was accepted as a petition for consideration by the Department of the Interior, U.S. Fish and Wildlife Service, which published a notice of review of the status of all the recommended plants in the Federal Register of July 1, 1975.

The lists of plants included in the Smithsonian Report are the result of information and advice which was generously supplied by many expert botanists and taxonomists throughout the country, people who, so to speak, have their "finger on the pulse" of the situation in their states, as well as those who specialize in studying various genera and families. Previously published botanical studies, state and local floras, detailed correspondence, individual state lists of endangered plants, and herbarium specimens were also intensively used as source materials. In 1974, a Workshop on Endangered Plants was convened by the Smithsonian Institution, with staff support from the Office of Endangered Species and International Activities of the Department of the Interior, in order to review and evaluate all plants on a preliminary list which had been prepared under the supervision of Dr. Edward S. Ayensu. The Workshop participants, reflecting a broad spectrum of eminent botanists, represented a wide range of organizations: Council on Environmental Quality, Smithsonian Institution, Department of the Interior, National Science Foundation, major herbaria and arboreta, and state government representatives.

The Report recommended firstly that preservation of endangered and threatened species of plants in their native habitats should be adopted as the best method for ensuring their survival. Transplantation and artificial cultivation should generally be employed only as a last resort.

The Report also recommended that the species of endangered and threatened plants that occur on federal (and state) lands should be mapped and given continued protection, with more specific attention given to preventing the destruction or modification of critical habitats of the plants. The concept of critical habitat, as described by the U.S. Fish and Wildlife Service in the Federal Register, is basically that for any given endangered or threatened species, habitat is considered critical if the destruction, disturbance, modification or subjection to human activity of any constituent element of the habitat might be expected to result in a reduction in the number or distribution of that species, or in a restriction of the potential and reasonable expansion or recovery of that species.

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The term "endangered," we must remember, has two facets. First, plants may become endangered by a wide variety of human and human-induced activities. Secondly, plants known from very limited areas, such as those confined to the type locality only, or from narrowly restricted and tenuously balanced, ecologically fragile habitats, are also usually considered to be endangered.

The modes of direct and indirect human impact on plants and plant habitats in the United States may be summarized as follows.

1. Off-Road Vehicles. Dune buggies; motorcycles; trail bikes; snowmobiles.

2. Mining. Strip mining; shale oil recovery; subsurface mining.

3. Forestry Practices. Clear-cutting; replacing native trees with exotic timber trees.

4. Biocide Spraying. Insecticides; herbicides.

5. Construction and Real Estate Development. Roads; factories; golf courses; power plants; shopping centers; housing tracts; land-clearing; landscaping.

6. Introduction of Competitive Weeds. Chokers of native vegetation.

7. Over-Grazing. By domesticated or feral goats, sheep, cattle, deer, pigs, rabbits, burros, horses.

8. Fire. Destructive fires; preventing natural fires.

9. Agriculture. Fields cleared for monoculture crops.

10. Water Management. Flooding; stream channelization; irrigation; dams; drainage of swamps.

11. Illegal Poaching. On federal, state-owned and private land.

12. Commercial Exploitation. Cacti and carnivorous plants, among many others.

13. Collecting by Private Individuals. For transplanting to gardens.

Many of the plants listed in the Smithsonian Report occur in restricted fragile habitats and others are known from very limited areas, such as from the type locality only. Their occurrence in narrowly confined, critical habitats makes them very vulnerable to human impact. Often they could potentially be exterminated by uninformed human acts before their known or suspected presence on the land has been adequately investigated and the data transmitted to the proper authorities.

Specialized habitats in which endangered and threatened plants are found, with an example of one plant from each, may be categorized as follows. The locations of the types of habitats are not confined to the states from which the plant examples are taken.

1. Serpentine Rock. *Allium hoffmanii* (Liliaceae) in California.

2. Cedar Barrens and Glades. *Lesquerella perforata* (Brassicaceae) in Tennessee.

3. Sandy Pinelands. *Asimina rugelii* (Annonaceae) in Florida.

4. Shale Barrens. *Scutellaria ovata* ssp. *pseudoarguta* (Lamiaceae) in West Virginia.

5. Shorelines. *Micranthemum micranthemoides* (Scrophulariaceae) in several northeastern states.

6. Sand Dunes. *Swallenia alexandrae* (Poaceae) on Eureka Dunes, California.

7. Rocky Cliffsides. *Polygala maravillasensis* (Polygalaceae) in Trans-Pecos Texas.

8. Talus Slopes. *Eriogonum cronquistii* (Polygonaceae) in Utah.

9. Mountain Tops. *Paronychia monticola* (Caryophyllaceae) in Davis Mountains, Texas.

10. Sphagnum Bogs. *Sarracenia oreophila* (Sarraceniaceae) in several southeastern states.

11. Islands. *Pritchardia remota* (Arecaceae) on Nihoa Island, Hawaii.

12. Peninsulas. *Iris lacustris* (Iridaceae) on Door Peninsula, Wisconsin.

13. Hot, Alkaline or Salt Springs. *Eriogonum argophyllum* (Polygonaceae) at Sulphur Hot Springs, Nevada.

14. Canyons. Acer grandidentatum var. sinuosum (Aceraceae) on Edwards Plateau, Texas.

15. Vernal Pools. Neostapfia colusana (Poaceae) in California.

16. Swamps. Roystonea elata (Arecaceae) in Florida.

17. Tidal Estuaries. Cardamine longii (Brassicaceae) in Maine, Maryland, and Virginia.

Those who are involved in making environmental impact statements concerning land usage and alteration should make a detailed vegetational inventory of land proposed for impact. A detailed floristic study would reveal the presence of any recommended or officially listed endangered and threatened plants, their precise location, and the number of individuals. The extent of acreage covered by the plant populations should be mapped and shown in relation to the area slated for disturbance. With this data in hand, alternative areas bypassing the habitats of the plants could then be sensibly considered with a view toward conservation of endangered species.

Endangered and threatened plants are known often to occur in aggregations of several taxonomically diverse species in the same habitat, and often in association with endangered or threatened animals, such as specially adapted pollinators necessary for propagation of the species in nature. Some of these pockets of rarity and endemism are famous, such as the Apalachicola River bluffs in northwestern Florida. Major concentrations of endangered plant species are found in Florida, California, Texas and Hawaii, and other centers are known to be in the Pacific Northwest (particularly Oregon), the Great Basin states of Utah and Nevada, and the southern Appalachians.

In order to help pin-point the exact localities of these aggregations and the consequent critical habitats, I have initiated a computer-mapping program as one of the basic activities of our Endangered Flora Project. As a pilot study we are determining the latitudinal and longitudinal coordinates of the localities of those plants in most dire need of protection under the Endangered Species Act of 1973, that is, the exploited species from among the recommended endangered and threatened lists. The computer draws a map of the state in question, draws the county boundaries, and prints symbols in each county at locations according to the coordinates fed to the machine. Maps of the Venus flytrap (Dionaea muscipula) and the pinkshell azalea (Rhododendron vaseyi) have been drawn in that manner, and available coordinates of all the other commercially and privately exploited species have been computerized.

In time, such locality maps of all taxa in the Report will be superimposed and compared, thus making the habitats where the species are congregated in the various states more identifiable.

It is all the more fortunate that Environmental Impact Statements are required concerning federal lands, because of a connection which may become apparent when all the habitats of the endangered and threatened plants have been plotted. Although approximately 10% of the species in the continental United States flora is endangered or threatened, the affected plants are very likely to occur on much less than 1% of the land surface of the country. It is also possible that, of the plants in the endangered category, perhaps as many as two-thirds of them occur on federal lands and are thereby already under some form of nominal protection. Thus, the more information that is obtained about the plants, the better that federal agencies will be able to comply with Section 7 of the Act by setting up programs to conserve, as it were, a majority of the endangered plants in the nation.

Consideration of endangered and threatened plants in Environmental Impact Statements should be evaluated in overall terms of the potential loss to our environment and society of valuable natural resources from which future generations of people can opt to select and breed new food, medicinal, and industrial-use species from among a diverse gene pool. A number of the species, particularly the cacti and orchids, have known aesthetic and ornamental values which could be perpetuated by growing them from seed or by vegetative techniques. Moreover, the potential loss of elements of our flora could also delay the solution of important and perplexing phytogeographical questions, such as the evolutionary mechanisms in the Hawaiian flora, and put forever out of reach the unraveling of questions regarding disjunct species both within the continental United States and between this country and other regions. All variations in these species must remain intact for such studies to be scientifically all-encompassing and accurate.

Before making decisions to alter the land, the government should know as many facts as possible concerning endangered and threatened plants on its property, and it is to this end that we are endeavoring to assist by updating the lists in the Report in view of the most recent information, by producing computerized information sheets on the species, and by our mapping program.

The Report is serving as an authoritative reference for many people engaged in preparing Environmental Impact Statements at the present time, and we would hope that the use of our more recent publication indicated below will become a standard practice in the future. In that connection, it may be observed that the introduction of common names for plants into the official literature could well cause confusion if not accompanied by the appropriate scientific (Latin) name, particularly in the realm of discussing the various vegetational components of diversified plant communities. The identity of the plants can only be clarified when scientific names are applied, for many plants have several common names (the *Platanthera flava* orchid has five), and in other cases a common name can refer to two or more related or totally unrelated species or genera.

The Director of the U.S. Fish and Wildlife Service has issued a proposed rulemaking which would officially determine approximately 1700 plant species as endangered pursuant to Section 4 of the Endangered Species Act of 1973 (Federal Register 41(117): 24523-24572, June 16, 1976). The names of these species were forwarded by us in advance to the Department of the Interior, and are basically those which appear in our up-dated, sequel publication to the 1975 *Report*, entitled *Endangered and Threatened Plants of the United States*, by E.S. Ayensu and R. A. DeFilipps (1978), published jointly by the World Wildlife Fund, Inc. and Smithsonian Institution. We hope the Department of the Interior will officially give endangered status to the plants as soon as possible, as a positive action toward preventing further deterioration of this nation's irreplaceable flora.

EVALUATING SHORT-AND LONG-TERM EFFECTS OF HERBICIDES ON NON-TARGET FOREST AND RANGE BIOTA

Michael Newton and Logan A. Norris 1/

Herbicides are one of the most ecologically powerful, environmentally gentle tools available to the manager of forests and rangelands in the United States. These chemical tools are used to accomplish a wide variety of management objectives through alteration of density and composition of vegetative communities. Their power suggests that they can be used as substitutes for more destructive practices. This same power, however, dictates the need for thoroughness in the search for harmful effects, both through research and observation of practice.

An adequate biological evaluation of the environmental impact of herbicides in forests and rangelands requires consideration of both short-and long-term effects which are mediated, either directly through toxic impact or indirectly through microsite or habitat modification. The environmental statements required by NEPA are the vehicle with which such evaluations are made on federally managed properties. Environmental statements for vegetation management programs using chemicals have markedly improved as professionals have gained experience with the environmental statement process. However, we find overwhelming attention has been given to consideration of direct toxic impact on non-target animals with little evaluation of the only profound ecological impact of herbicide use: i.e., the alteration of the composition, density, and developmental trajectory of the vegetation. It is apparent that primary producers, and the modification thereof, have a determining role in the lines of all other biota. This paper presents an approach based on that principle for use in the preparation of environmental statements and management plans.

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LAND MANAGEMENT SYSTEMS AND THE ROLE OF HERBICIDES

Forest and rangeland management objectives nearly always revolve around vegetation. Management of vegetation is basic to timber or grass production and wildlife, recreation, or water considerations. Each growing site has some potential for the production of vegetation biomass. Modern land management objectives frequently involve capturing (or recapturing) as much of the site potential as possible in a desirable form of vegetation. The knowledge that ecosystems will respond in certain ways to treatment is basic to the use of these tools to effect certain changes. The ecological basis for vegetation management can be examined by considering the relative biomass trajectories for four major types of vegetation on the grassland ranges and forest tree communities in the United States during the last several hundred years (Figure 1).

Many ranges now dominated by shrubs were largely occupied by grass at the time of European man's entry on the landscape. The tree, shrub, and forb components of the communities were present but less prominent. Ancient man undoubtedly influenced the biomass distribution among these four components to some degree, but his activities were neither intensive nor extensive. Modern man, on the other hand, has gone through a period of resource exploitation in which selective foraging has resulted in a strong shift away from grass and forbs towards unpalatable trees and shrubs.

The recent application of management techniques using selective herbicides has caused a marked shift in allocation of site resources back to grass. Herbicide-sensitive trees and shrubs (the dominant parts of the target systems) are substantially reduced in biomass and the resulting void is soon filled by seeded grasses and forbs and later by native grasses or species adapted to the grazing regime. This practice is almost a reverse of the grazing effect. In the face of selective removal pressure, the resistant species, whether removed by herbicides or animals, become more abundant. Because of their inferior competitive position, under pressure, the sensitive species subsequently have difficulty returning to sites occupied by resistant species without additional disturbance. Therefore, chronic harvesting pressure must be complemented by a weeding program of comparable intensity for maintenance of the harvested species.

Range managers use both weeding and control of harvesting (i.e., vegetation management) to stabilize primary production in preferred species. Such a procedure influences the carrying capacity of the ecosystem for non-target species and cattle. The same set of principles appears to hold in forests as well as rangelands.

MANAGEMENT TECHNIQUES INVOLVING HERBICIDES

Herbicides are used for a variety of specified purposes in both forest and range management. Range applications nearly always involve reduction in the density of shrubs and trees to favor forbs and grasses. This may be type conversion where forbs and grasses are essentially no longer a major part of the present community. In this case seeding or planting operations are also conducted to provide growing stock of desirable species to occupy the site vacated by trees and shrubs. "Release" treatments are used when grasses and forbs are part of the stand but their growth is restricted by deficiencies of light, water, nutrients, and growing space caused by tree and shrub species. In this case, the application of selective chemicals may be augmented by seeding or some other cultural practice to ensure occupation of voids by desirable species.

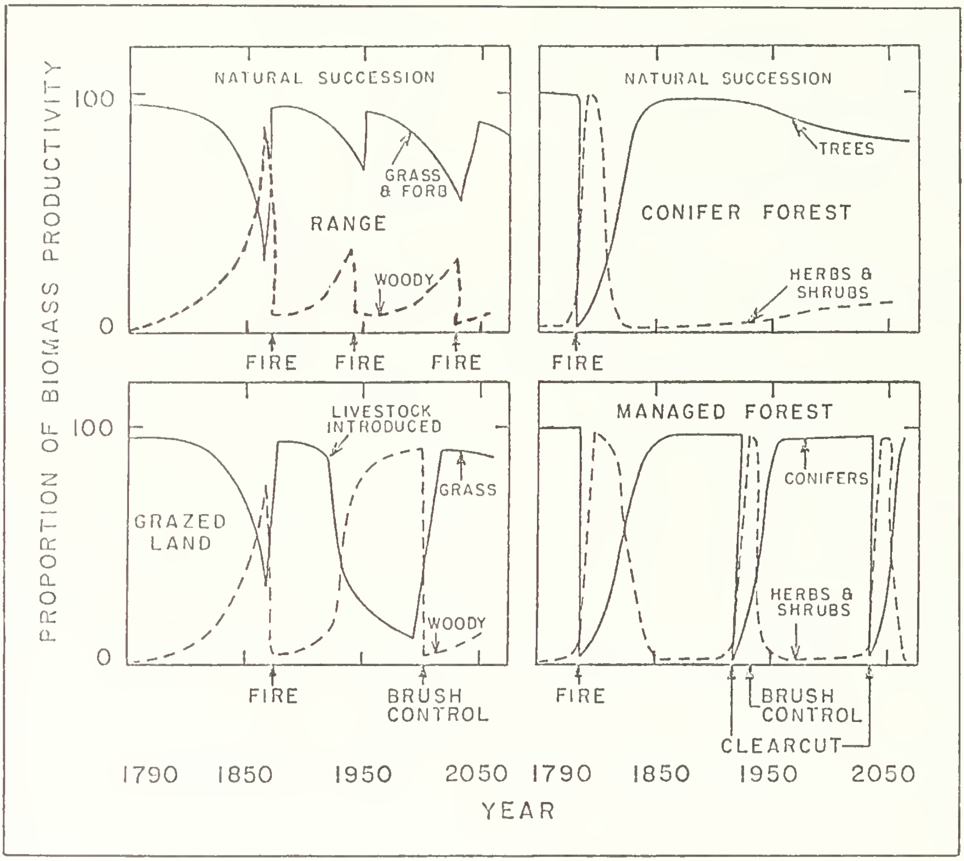

Figure 1. Generalized biomass trajectories for two major types of vegetation in their natural state of periodic disturbance (fire) and under moderate intensity management.

Type conversion and grass release are by far the most extensive patterns of range herbicide use. Contiguous rangeland applications may vary in size from only a few hectares to several square kilometers.

Applications may be made by ground equipment but more frequently by fixed wing aircraft or helicopters. The size of the sprayed unit is important to non-target biota, and the degree of importance is related to species mobility.

Herbicides are used in forestry for purposes which are analogous to those in range management. Reforestation or type conversion, for example, involves a reduction in shrub, grass, or weed tree biomass to permit establishment of desired forest tree species. Fire frequently is used as an adjunct tool. Seeding or planting insures occupation of the site by desirable species. "Release" spraying is used when various weeds (trees, shrubs, forbs, or grasses) prevent established desirable tree species from achieving site dominance because of excessive competition for site resources. In this kind of application, selective herbicide action (achieved through the use of a particular chemical, rate, or season of application) is used to depress the competitors and accelerate the growth of a desirable species.

Reforestation, type conversion, and release treatments account for the vast majority of herbicide applications in forestry. However, the thinning of overstocked stands and cull tree removal with chemicals are increasing in importance as the intensity of forest management increases.

Herbicide application for type conversion, reforestation, and tree release are most frequently accomplished with aircraft, although ground application equipment is used in some locations when vegetation and terrain permit. Contiguous treatment areas are on the average smaller than in rangelands, but there may be a large number of the treated units varying in size from 1 to more than 100 hectares. Larger blocks of land are seldom treated; and the mosaic of treated and untreated sites offers considerable diversity and escape opportunity for wildlife, including species of limited mobility.

Herbicides are used on forest and rangelands for several purposes unrelated to specific land management objectives. These include the control of vegetation on powerline, railroad, and other rights-of-way and phreatophyte control in riparian zones. These are intensive applications but are more limited in scope.

The use of herbicides for modification of wildlife habitat is also a viable management technique for both habitat improvement and for control of damage to forest regeneration. Herbicides are not widely used for these specific purposes at present, but these uses are likely to increase. A great deal of big game habitat improvement results as an incidental benefit from other vegetation management practices involving herbicides.

RELATIONSHIP BETWEEN CHEMICAL BEHAVIOR AND DIRECT EFFECTS ON NON-TARGET SPECIES

Short-and long-term effects of chemicals are dependent on exposure of organisms to a biologically significant dose of herbicide. The initial distribution, movement, persistence, and fate of a herbicide in a particular environment are of paramount importance in determining the probability of organism exposure. Chemical behavior is the result of an interaction between the properties of the chemical and the properties of the environment. This interaction is guided by physical laws to produce the particular pattern of herbicide behavior observed in nature (Figure 2).

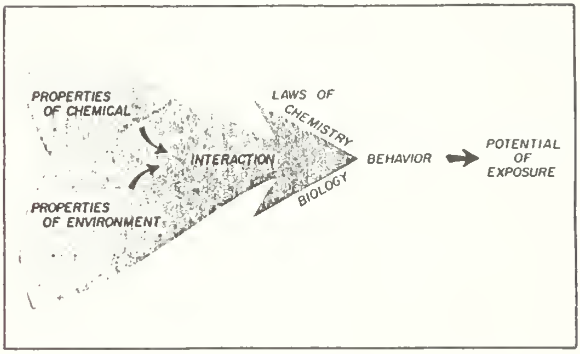

Figure 2. Chemical behavior in the environment determines organism exposure.

Herbicides are, for the most part, short-lived in the environment. Therefore, their direct toxic impacts are largely restricted to the occurrence of an acute lethal dose. Their indirect effects, however, can be long-lasting because they can alter short-term composition and long-term trajectory of the succession of the plant community. Chemical behavior in the environment, while clearly important in determining direct toxic impacts, should also be interpreted in terms of its specificity for certain plants when we analyze effects on vegetation and associated animal community structure.

ANALYSIS OF SHORT-TERM CHEMICAL EFFECTS - DIRECT TOXICITY

The time span in our definition of "short-term" is arbitrary. We have selected the year of application or the duration of biologically significant herbicide residues, whichever is longer. With the possible exception of picloram, short-term effects will be restricted to the year of application; most will be a matter of days or weeks. None of the herbicides used in rangelands or forests have been shown to accumulate substantially in animal tissues. The short-term of persistence eliminates chronic intoxication as a possible effect.

A direct toxic effect of an herbicide requires organism exposure to a significant dose. Toxicity to a given organism is an inherent chemical property. Organism response to exposure is produced by a combination of magnitude and duration of exposure with absolute toxicity.

The nature of the dose-response relationship varies with both the chemical and the organism. The pattern of dosage and potential responses of forest pesticides has been summarized by Newton and Norgren (1977). Variation within species (Figure 3) is indicative of the range of dosages producing some effect on a species. Exposure has no effect on the population up to a threshold level, then effects become progressively greater until nearly all organisms have responded. The data for <u>acute</u> toxicity usually shows a deviation from the normal distribution. There is typically a "no-effect" level and a "100-percent" response level (these extremes would be absent if the effects followed the normal distribution). It is <u>only</u> between these extremes that a herbicide has an effect on a given population. When comparing among populations, however, an array of population effects may be used to examine the differences in sensitivity among different classes of organisms.

The dose-response relationships for a herbicide to several organism groups, are compared in field and laboratory exposures in Figure 4. These examples show that broadleaf higher plants are consistently the most sensitive organisms to the herbicide 2,4-D, and that low sensitivity and low exposure both contribute to the safety of animals. This is the basis for its use for selective control of vegetation, and is the basis for using water quality criteria for protection of aquatic organisms. Most pesticides are registered for use to control only the organisms which are highly sensitive. Thus, a selective chemical effect is achieved through the

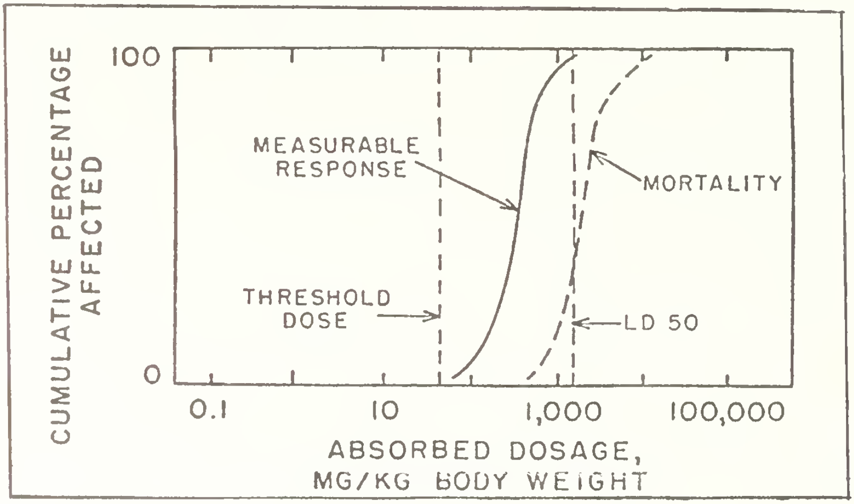

Figure 3. Typical dosage - response curve for an animal population fed a toxic substance. Note that dosage is based on units of toxicant per unit of body weight. Threshold (no effect level) is the dosage below which organisms detoxify chemical as fast as it is absorbed. These curves are transformed normal distributions. In laboratory tests, slopes of curves vary among species (Muirhead-Thomson 1971).

economic as well as biological screening process.

The probability for toxic impacts on non-target organisms is significant where dose-response curves for target and non-target organisms overlap to a significant degree. The herbicides used in forest and range management are not known to produce direct acute or chronic effects on organisms other than higher plants when used at registered rates of application.

EFFECTS OF HERBICIDES ON ANIMALS

Figure 4 illustrates a large margin between the dosage of herbicide required for maximum effect on higher plants and the level required for threshold response in animals of all kinds. Norris (1971) and House et al. (1967) have summarized a substantial amount of data on herbicide residues and persistence in vegetation, soil, and water, and (Newton and Norgren 1977) have summarized the impacts of such residues on a variety of species in the forestry context. In general these authors indicate that for a 2-kg/ha application, initial herbicide residue levels would (1) generally be less than 100 ppm in vegetation, (2) be less than 3 ppm in the surface 2.5 cm of soil and (3) be less than 0.05 ppm in streams, unless extensive direct application is made to surface water. These initial residue levels will vary somewhat with conditions of application and vegetation composition and density. Their quantities produce effects on sensitive plant species but not animals exposed to the same applications.

Animal exposure occurs dermally during and immediately after application. Dermal toxicity of herbicides is typically low enough to be of academic importance, as attested by research data and years of actuarial data for spraymen daily exposed to the concentrates. Oral ingestion, however, may be significant. Given the maximum level of 100 ppm of herbicide in treated herbage, in 1 day, an animal consuming 5 percent of its weight per day ingests a maximum of 5 mg/kg/day for each kg/ha applied, assuming all of its feed has a maximum concentration of herbicide. Animals appear to take in less than the maximum, however. Newton and Norris (1968) reported intake of atrazine[2/] and 2,4,5-T by deer amounting to about 1 percent of the theoretical maximum, or less. Furthermore, deterioration of both the herbicide and the treated vegetation limits exposure to a relatively short period, and herbicides usually pass through the digestive system with little or no retention

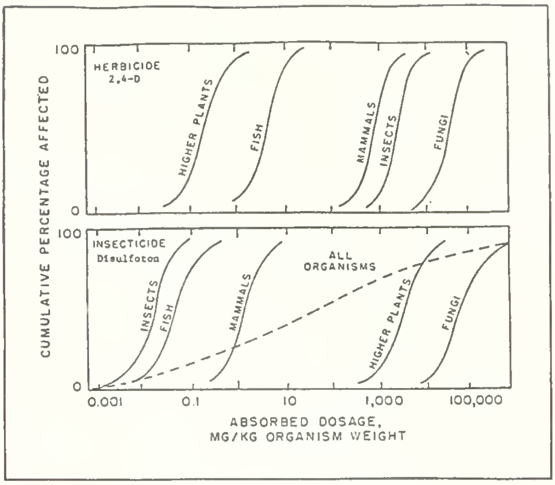

Figure 4. Typical dosage-response spectra for an insecticide and a herbicide for five classes of organisms. Mid-points for each group are estimates; those affected only in the range of 500 mg/kg or greater are not as precisely defined as those in the more sensitive groups.

or accumulation. More recently, Newton and Snyder (1978) have produced detailed evidence of negligible residues of the TCDD contaminant of 2,4,5-T in forest wildlife.

Herbicide movement and persistence are difficult to generalize in reference to precise levels of exposure to consumer and aquatic organisms. Norris (1971) and House et al. (1967) again offer reasonable summaries for persistence characteristics in vegetation and water. In vegetation, herbicide half-lives vary from 1 to 30 days. The half-life in stream water varies from less than 0.5 to 24 hours, when herbicide input is restricted to the time of application. Rapid herbicide

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[2/]This publication reports research involving pesticides. It does not contain recommendations for their use nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state and/or federal agencies before they can be recommended.

dilution with downstream movement tends to protect aquatic organisms, and the recurrence of contamination by movement of soil water is unlikely (Norris and Moore 1971). Kearney et al. (1969) and Harris (1968) report in detail on the mobility and persistence of herbicides in soil, Figure 5.

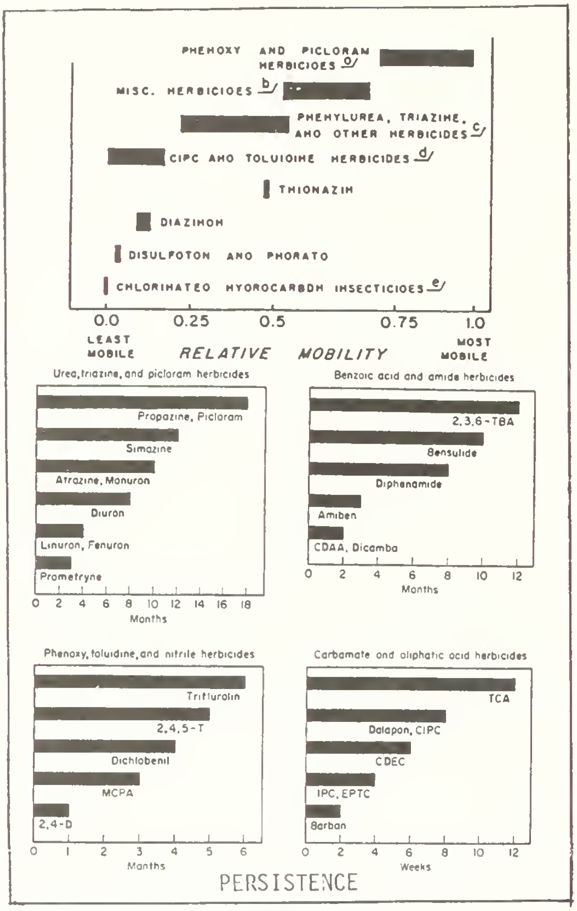

Figure 5. Generalized mobility and persistence characteristics of herbicides in soil (Harris 1968 and Kearney et al. 1969).

The data on residue and persistence characteristics of a herbicide in a specific environment can be used to determine both the magnitude and duration of non-target organism exposure. Exposure data can then be evaluated in terms of established dose-response relationships for the chemical and the specific organism or a closely related species for which test data are available. If the magnitude and duration of exposure are less than the threshold response level, direct toxic effects are precluded. This kind of an analysis consistently shows that those herbicides and patterns of use registered by the Environmental Protection Agency for use on forest and rangelands will not normally result in direct toxic effects on non-target animals. Strong evidence indicates that there is a large margin of safety in this regard even in the event of accident or other mishap.

EFFECTS OF HERBICIDES ON PLANTS

Herbicides are the pesticides to which plants are most sensitive. It is the intent of forest weed control to initiate a change of vegetation type, and the herbicide practices in use today are generally very effective.

For practical purposes, the herbicides in use in forest management may be grouped according to the spectrum of species they control. Table 1 lists the herbicides presently registered for forestry use and gives the principal group of plants affected, the important resistant species (commercial and non-commercial), and the persistence of biologically active residues in the forest environment.

The array of effects of herbicides listed in Table 1 suggests that most forest sites carry considerable vegetation that will survive virtually any herbicide applied at registered rates, even though plants are "sensitive." The target species are usually not killed completely by such applications, but are injured so as to decrease their competitive ability. The principal immediate effect of applying a herbicide may be expressed in terms of the model illustrated in Figure 6, which diagrams a forest ecosystem in terms of its principal structural components. Referring back to Table 1, it is possible to visualize at what point a forest ecosystem is affected directly by the herbicide and for how long the direct effect influences ecosystem function.

There are specific effects worthy of mention within each part of an ecosystem. These differ with the specific nature of the herbicide, the problem for which it is used, and the distribution of the herbicide in the forest. Triazines, glyphosate, dalapon, and occasionally pronamide or amitrole are used for herb control in reforestation areas where moisture is limiting to survival of conifers. The rates of use generally preclude the survival of large amounts of grass. These herbicides are broadcast in ecosystems in which seedling trees are to be planted. During a brief interval following application, there is a substantial reduction in primary production, a decrease in demand on water and nutrients, and a considerable decrease in

Table 1. Herbicides Registered for Use in Forest Management, Duration of Direct Effect, Sensitive Groups of Species and Resistant Groups of Species.

	Months of Activity in Plants	Soil Half-life Months	Target and Sensitive Spp.	Resistant Species: Commercial	Resistant Species: Non-Commercial
Amitrole	1/2 - 6	1/2 - 1	Shrubs, herbs	Coastal conifer	Hardwoods, shrubs
Asulam	12	1/2 - 1	Bracken only	All conifers, hardwoods	All woody
Atrazine	3	1 - 4	Annuals, Deciduous	Most woody	Woody, ferns
Ammonium ethyl carbamoyl phosphonate	24	<1	Shrubs, hardwoods	Conifers	Herbs, evergreen woody
Arsenicals, organic 1/	3	1 - 6	Conifers, hardwoods	Few	Few woody, many herbs
Dalapon	1	1/4 - 1	Grasses	Trees	Trees, shrubs, forbs
Dicamba	3 - 12	2 - 12	Shrubs, hardwoods	Few	Some shrubs, ferns
Dinoseb	1/4	<1/2	All green vegetation	None	None
Glyphosate	24	<1/2	Most herbs, deciduous woody plants	Conifers	Evergreen woody, dormant herbs
Picloram	3 - 24	2 - 12	Trees, shrubs	None	Few woody evergreen shrubs, grasses, ferns
Pronamide	2 - 4	3 - 6	Grasses	All woody	All woody, forbs
Silvex 2/	3 - 6	1 - 2	Shrubs, trees	Conifers	Some trees, shrubs, grasses, ferns
Simazine	3 - 6	4 - 8	Grasses, forbs	Trees	Trees shrubs, ferns some herbs
2,4-D	1/2 - 1	1/4 - 1/2	Some shrubs, forbs	Conifers	Hardwoods, shrubs grasses, ferns
2,4,5-T 2/	3 - 6	3/4 - 1 1/2	Shrubs, hardwoods	Conifers	Some hardwoods, ferns, grass

1/Applied by injection only; effect limited to treated stem.

2/Registered uses of Silvex and 2,4,5-T on forest land were suspended by EPA on March 1, 1979.

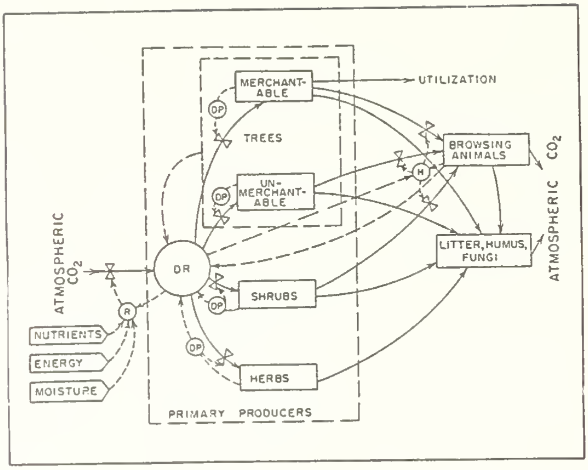

Figure 6. Simplified forest ecosystem model illustrating the allocation of site resources to various vegetation groups, and thence to various consumers. Rectangular symbols represent organisms capable of storing carbon; pentagonal symbols are site factors, or resources; "bowties" are internal controls; dashed lines are feed-back. DR, dominance ratio; DP dominance potential; H, habitat; R resources (from Newton, 1973b).

carrying capacity for herbivores totally dependent on grasses, especially those of limited geographic feeding range. Warm summer rains can move nutrients toward a leaching sink if devegetation is continued year after year, but areas with dry summers and those with the usual incomplete vegetation control do not sustain measurable losses (Miller 1974). These treatments are usually applied no more than once or twice at the time of reforestation, and their impacts are brief, leading to establishment of a forest cover.

The brushkillers (i.e., the phenoxys, picloram, amitrole, dicamba, glyphosate and ammonium ethyl carbamoyl phosphonate), are usually used either in forest site preparation or in range or forest release operations involving application of broadcast sprays to complex mixed seral communities. These sprays damage target woody vegetation considerably but generally leave most of the herbs and some resistant trees and shrubs. While the herbicide is still active in sensitive woody cover, primary production decreases briefly and herbaceous cover increases rapidly. Growth of resistant woody and herbaceous vegetation increases shortly after application. Structure of the treated ecosystem changes substantially in terms of the dominance ratio of component species (Newton 1973a). Increased growth of herbs and sprouts often increases carrying capacity for herbivores. Resistant trees and shrubs increase in dominance, eventually resuppressing the ground cover.

Herbicides are used in combination with fire to an increasing degree. They permit controlled burning when surrounding areas are unlikely to be flammable. In this procedure, the herbicides may be used for sprout control, fuel desiccation, or both. The herbicides have a substantial effect on vegetation, but the resulting fire has an overriding effect on every species present. The immediate effect of the fire is to empty every "box" in the forest ecosystem. The interval before "green-up" has been described as very brief (Roberts 1975), but the total temporary effect on ecosystem composition and structure is very great. It is worth pointing out that this treatment is usually very costly and is reserved for forest rehabilitation operations on very productive land supporting highly stable subclimax communities from which past management has excluded conifers. In such circumstances, the practice totally removes the woody component from dominance, followed within weeks by development of a dense herb cover in which sprouts begin to develop. This change is not a consequence of toxic action but of the physical event of fire.

INTERACTION BETWEEN PLANTS AND ANIMALS

We have thus far considered the direct action of herbicides on animals and plants and have found herbicides to be directly effective largely on plants. Figure 6 illustrates, however, that herbivores are directly dependent on the plant community for food and cover and the other animals are dependent on herbivores and cover.

Changes in primary producers clearly have a major influence on the animal community, independent of the direct effects of the herbicide. Numerous effects have been documented. Phenoxy herbicides were studied two decades ago for their potential use in improving big game habitat. The action of the herbicides in reducing the level of dominant canopy, and also of stimulating sprouting, was beneficial for the winter range condition of deer (Krefting et al. 1960; Mueggler 1966). Keith et al. (1959) observed that the composition of the herb community in a part of the Rockies had an important effect on the populations dynamics of the pocket gopher. More recently Borrecco (1973) and Borrecco et al. (1972) demonstrated that several species of large and small mammals were responsive to management of herbaceous cover with herbicides. Their findings support the generalization that herbicides do not have an immediate effect on animals, but as vegetation responds, the animal community appears to follow a successional pattern in accord with the changes in habitat (Newton 1973a). Vegetation management is now regarded as a potential tool for regulating animal damage to forest plantations in the Pacific Northwest.

ANALYSIS OF LONG-TERM EFFECTS

There are clear patterns of short-term effects of herbicides on forest and range communities. In rangelands, the usual pattern after treatment is an increase in herb cover. In forest lands with substantial shrub and crop-tree component there is an increase in herbs after brush control and an increase in woody cover after herb control. These short-term effects are the initial phases in long-term pathway of ecosystem development. This may be termed succession in the classical sense, except that the initial inhabitants are there by design. Furthermore, the dominance ratio (Newton 1973b) is managed by repeat applications if the plant communities show signs of wavering off a planned path.

Ecosystem development under forest management can be very similar to natural forest succession. It is very different from succession in forests from which the dominant high-valued species are chronically subjected to utilization pressure. Figure 6 indicates that the removal of any component of a forest ecosystem will merely focus productivity among the remaining vegetation. Plants or trees in a dominant position after some harvesting tend to remain dominant. The cause-effect patterns is precisely the same when comparing the effects of removing high-quality timber by harvest or by suppressing the low-quality material with herbicides and the development of undamaged parts of the system is accelerated. This is one of the fundamental silvicultural or agronomic concepts, and is the basis for all weeding.

The course of forest ecosystem development after application of the herbicide is controlled by three principal factors other than soil and climate. The first, and most important factor, is the population of rapidly growing tree species after herbicide residues become inactive. Trees with high dominance potential will dominate the site continuously if they are present and dominate immediately after treatment (Newton 1973b). If no such species are present, the introduction of trees by planting has a major influence on the long-term direction of ecosystem development after herbicide application Figure 7. Because the usual purpose of treatment is to promote the

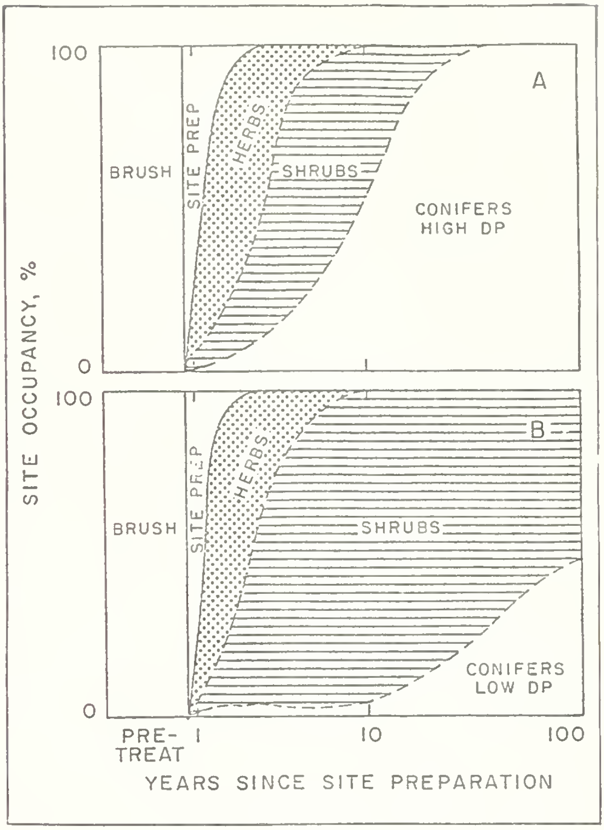

Figure 7. Development of plant groups after a disturbance to a forest. Components are analogous to compartments in Figure 6. Note that when conifers of high dominance potential are planted, as in A, succession is dominated by conifers and ground vegetation becomes sparse. In B, however, the diagram reflects low conifer stocking or vigor, and the low-stature woody vegetation remains dominant for much longer. The conifers are causal, but non-target species will be affected.

growth of trees, the shift to tree dominance is the most common long-term effect of herbicide use on the general structure of forest ecosystems. Development of the dominant tree layer has a very great impact on all non-target biota, because if affects

Table 2. Comparative Magnitude and Duration of Environmental Impacts of Forest Practices[1/]

Practice	Timber Values	Water Quality	Water Yield	Big Game	Small Mammals
Tree planting[2/]	Great(+) (if successful) Long	Small(+) Long	Small(-) Long	Great(-) Long	Variable Long
Vegetation Control:					
Chemical:[3/] Herbs	Great(+) Long	Small(-) Short	Small(+) Short	Moderate Short(-) Long(+)	Moderate(-) Short and Long
Brush	Great(+) Long	Small(-) Short	Moderate(+) Short	Moderate to great(+) Short	Variable Long
Weed trees	Great(+) Long	Small(-) Short	Moderate(+) Short	Moderate to great(+) Short-long	Small(+) Short
Mechanical: Herbs	Moderate(+) Long	Moderate to great(-) Short	Moderate(+) Short	Great(+) Short	Variable to great(-) Short
Brush	Great(+) Long	Moderate to great(-) Short	Moderate(+) Short	Variable (+ and -) Short	Great(+-) Short
Weed trees	Great(+) Long	Great(-) Short	Small Short	Moderate(+) Short	Small(+ and -) Short

1/ Plus or minus relates to a presumed value change relating to a specific resource.

2/ Impact of planting depends on success, which in turn may be determined by the effectiveness of cultural measures.

3/ Selectivity range of the particular herbicide will determine whether residual vegetation is more or less favorable habitat.

all subordinate vegetation. When the dominant tree species are natives, this effect approaches the natural balance of some sort of subclimax vegetation. In rangelands, the promotion of herb cover at the expense of trees is likely to result in the slow re-invasion of trees because of their higher dominance potential. Pressure from livestock on the grass will accelerate the upswing in woody vegetation in the absence of fire. In all situations, the long-term impact of the management practice is largely determined by the subsequent character of the new woody plant dominants in the community.

Most forests are managed in a mosaic of small management units. Herbicides used in an even-age management system are used infrequently, and in a pattern of adjacent vegetation that offers diversity and escape opportunity for wildlife subjected to temporary shortages of cover or forage. These patterns have been described as favorable for many species of wildlife, even with more frequent applications than those used in forestry (Bramble and Byrnes 1972). The scale of range treatments reduces escape opportunity under some circumstances, and local changes in plant community structure can have effects on herbivores whose preferred forage has been removed.

Any evaluation of the effects of herbicides on non-target species and non-timber values must take into account the comparative effects of alternative practices for achieving the same goals. Table 2 lists an array of relative impacts of herbicides and bulldozers on various non-target species, including aquatic species and their habitats. Fire is intermediate in effects on most groups between chemical and mechanical methods. Insufficient data has been recorded for manual methods to evaluate their silvicultural or range benefits or impacts.

CONCLUSIONS

We have outlined our interpretations of effects of several kinds of disturbances in the management of range and forest lands. Herbicides constitute one special type of disturbance, unique in substituting certain biochemical properties for physical impact. In an evaluation of their effects on non-target forest and range biota, the following conclusions are germane to impact analysis in Environmental Statements:

1. Environment impact of herbicides on forests and ranges must be evaluated in the framework of management systems that have already had an effect, and whose effects will become more severe with no maintenance, to the detriment of major renewable resources.

2. The non-target species in ecosystems previously disturbed by management are already off natural baselines, including populations that are above and below natural levels.

3. Direct toxic hazards of herbicides on non-target species are a matter of public concern. They therefore need to be mentioned. However, the likelihood of direct effect of herbicides is low and such effects need to be examined in terms of the consequences and hazard of using alternative methods, including non-treatment, to achieve the same resource management goal. The infrequent use of herbicides and their short lives and non-cumulative effect are documented; they reduce the risk of surprise adverse effects.

4. Short-term effects of vegetation management are determined by physical impact and ecosystem resiliency. In decreasing order, the environmental impacts of alternative practices are: mechanical scarification, burning, and herbicides. On the basis of limited evidence and adaptation to the criteria by which other methods are judged, hand clearing probably falls between burning and chemical methods. Projected development of surviving plant species groups are useful for comparing and evaluating habitat change, regardless of method. Impacts on animals can be expressed in terms of habitat suitability and stability.

5. Long-term effects of herbicides are totally confounded by the management system in which they are used. In general, the goal of such management is maintenance in perpetuity of forest or range communities in a condition where non-target range and forest species have good opportunity to thrive, regardless of tools used.

6. Herbicides are unique in being able to reverse past management impacts

without causing physical impact on soils and watersheds, or loss of ecosystem productivity.

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INTEGRATING AND CONTROL MECHANISMS IN ARID AND SEMIARID ECOSYSTEMS -- CONSIDERATIONS FOR IMPACT ASSESSMENT

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INTRODUCTION

In terms of total area affected, cultivated agriculture and livestock grazing are, of course, the major human uses of, and impacts on, arid and semiarid areas. The paucity of research from an ecosystem perspective, and the strong ecological focus of this symposium, would seem to be adequate reason for excluding the former from this review.

However, that exclusion does not narrow the field of concern materially, as a huge literature reports the vast amount of research over the past 20 to 40 years on the basic ecology of arid and semiarid systems, and the effects of grazing on those systems. I would like, in this review, to touch on three aspects of this now immense subject: (1) consideration of some characteristics of the moisture constraint and its impact implications; (2) some patterns of biotic interactions within the plant community that are involved in community change; and (3) some implications of those patterns for impact prediction.

Simulation modellers of ecological systems commonly characterize their subject in three entities: components of the system, processes by which the components interact and change, and constraints on the processes which affect the rates at which the latter proceed. Discussions of ecosystems can focus on each of these entities: structure, functions, and controls. I have chosen the third for the subject of this review.

THE MOISTURE CONSTRAINT AND ASSOCIATED BIOTIC VARIATION

The structural and functional characteristics of arid and semiarid vegetation which have received the greatest notice are the low standing-crop biomass and primary production, relative to those of other vegetation types. Far less often discussed, and yet equally as characteristic, is the high year-to-year variation in function. This is a characteristic that has profound implications for environmental impact assessment.

The high variability appears to stem from two, main causes: the high, relative variation of precipitation in arid and semiarid areas; and the responsiveness of the vegetation to that variation as a result of the extreme moisture constraint under which it exists. I would like now to explore these two causal patterns.

ABSOLUTE VERSUS RELATIVE MOISTURE VARIATION

Although it appears to have escaped mention in much of the ecological literature, climatologists have recognized for some time that the degree of year-to-year variation in precipitation is correlated with precipitation gradients. However, the correlations differ, depending on whether the variations are expressed in absolute or relative terms. Thus the range of annual values and standard deviation of the mean increase as the mean annual precipitation increases. But the coefficient of variation decreases as the mean annual value increases. This pattern has been reported for different stations within the state of Arizona by Hastings and Turner (1965), within the province of British Columbia by Longley (1952), and more generally over the world by Conrad (1941).

I have illustrated this pattern (Fig. 1) by summarizing annual precipitation data for three stations in the U.S.: (1) 13 years of annual precipitation totals measured at the U.S. Forest Service's Desert Experimental Range near Milford, Utah (Hutchings and Stewart 1953): (2) 24 years of annual precipitation values for a short-grass prairie area near Hays, Kansas (Hulett and Tomanek 1969); and (3) 10 years of data kindly provided me by Robert L. Burgess for a deciduous forest area near Oak Ridge, Tennessee.

Most of the annual values for the desert area fall within a 13 cm (ca 5 in) range, those for the grassland area within a 40 cm (ca 16 in) range, and those for the forest area within a 100 cm (ca 39 in) range. Vegetation in the forest area thus experiences eight times the range of variation in annual precipitation as the desert area. Yet in a relative sense, the coefficients of variation indicate that the standard deviation for the desert area is nearly a third of the mean while that for the forested area is about half that fraction, or 17 percent of the mean.

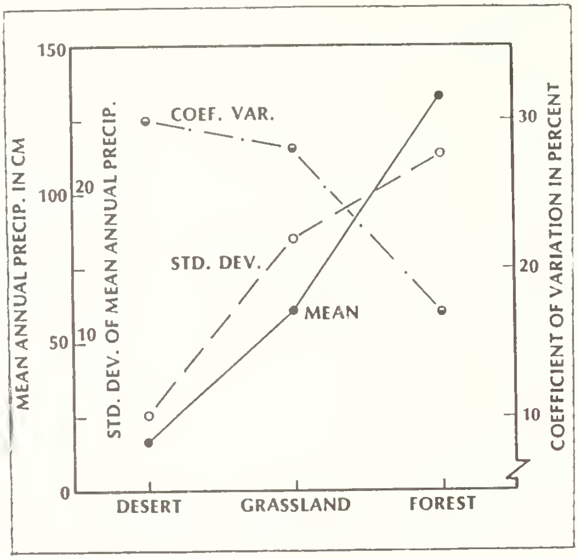

Figure 1. Relationships between mean, annual precipitation, and measures of absolute (standard deviations of the means) and relative (coefficients of variation) variation in the means at the U.S. Forest Service's Desert Experimental Range, Utah (Hutchings and Stewart, 1953), a short-grass prairie near Hays, Kansas (Hulett and Tomanek, 1969), and a tulip poplar *(Liriodendron)* forest near Oak Ridge, Tennessee (Robert L. Burgess, Personal Communication).

ANNUAL VARIATIONS IN PRIMARY PRODUCTION AND THEIR IMPACT IMPLICATIONS

Estimates for net, annual, above-ground primary production are available for each of the above three stations. I have plotted each of these three sets of estimates as functions of the total, annual precipitation, and fit least-squares regression lines to each of the three plots (Fig. 2).

The values for the tulip poplar *(Liriodendron tulipifera)* forest were kindly provided by W. Frank Harris and Robert L. Burgess. The data originally provided were estimates of branch and bole production. I arbitrarily added 10 percent to each annual value for leaf production and 10 percent for understory production -- values which Dr. Burgess suggested as reasonably approximating the magnitude of these elements of production.

Annual precipitation, totaled for a calendar year, is not a wholly satisfactory means for characterizing the moisture environment of the vegetation. Temperature modifies the effectiveness of the precipitation. Season of precipitation is important, determining whether the moisture falls during the growing season or not. Variations in relative humidity, such as might occur with proximity to a coastal area, undoubtedly play a part as do soils of different texture and moisture-holding characteristics. As one alternate parameter, Rosenzweig (1968) used actual evapotranspiration in plotting primary production as a function of the moisture environment.

However, the purpose here is not to develop precise functional relationships between moisture parameters and production with which the latter could be simulated with great precision. Rather, the purpose is to infer some more general aspects of the moisture constraint; and total annual precipitation appears adequate for this purpose.

The first point to note in Fig. 2 is the slopes of the three regression lines. They are obviously steeper at the arid end of the scale and flatten at the moist end. Desert vegetation is far more responsive to moisture variation, its production varying over a greater relative range than that of grassland or forest. The highest production value measured for the Desert Experimental Range (DER) exceeded the lowest by a factor of nearly 4. This is a common range of variation for perennial vegetation in arid and semiarid areas. Cable and Martin (1975) measured 3- to 5-fold variations in perennial grass production over a 10-year period of the Forest Service's Santa Rita Experimental Range in southern Arizona. Paulsen and Ares (1962) reported 6-fold variations in perennial grass production over a 15-year period on the Agricultural Research Service's Jornada Experimental Range in southern New Mexico.

In fact, these factors may be conservative estimates of the full-range over which desert production varies. The DER values are for perennial shrubs, as the Santa Rita and Jornada values are for perennial grasses. Annual plants are uniquely important in deserts, their production in high-precipitation years often approaching that of perennials (Norton 1974; Novikoff 1975). But in dry years they may not produce, and hence their production is

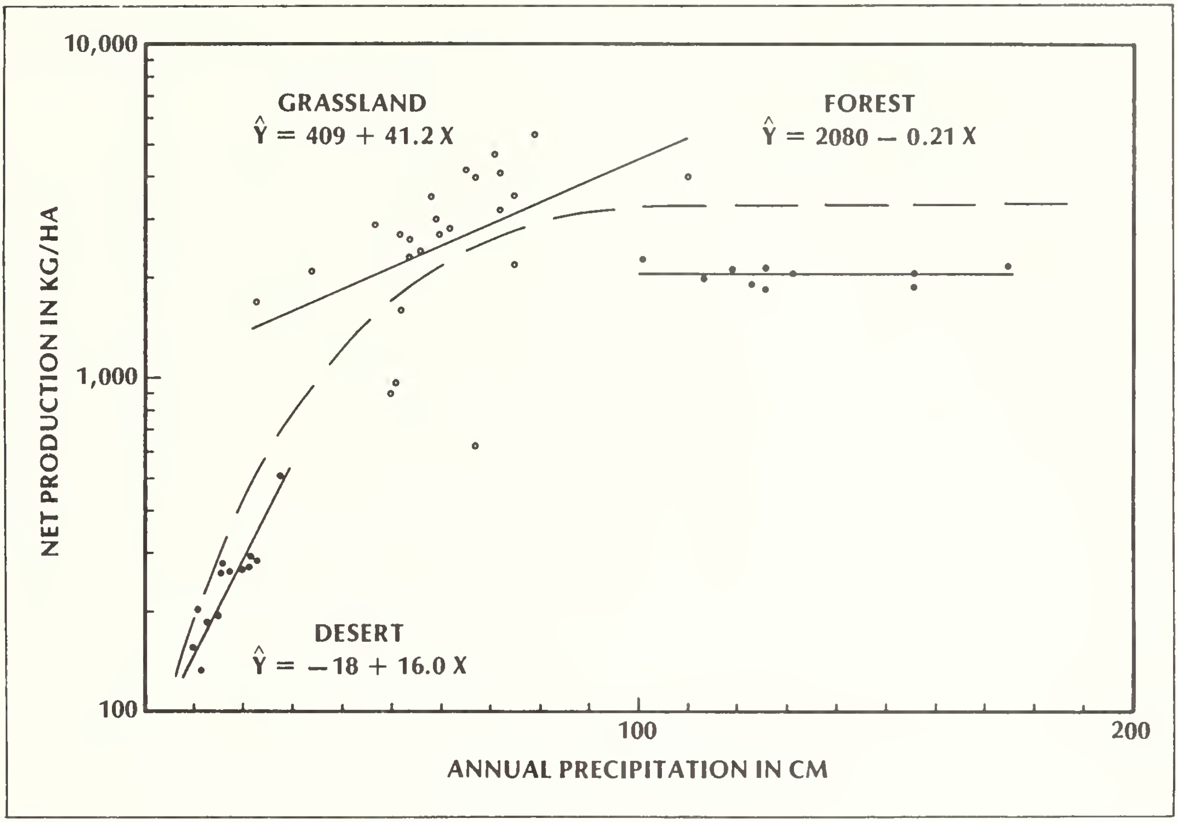

Figure 2. Regressions of net, annual, above-ground primary production on mean, annual precipitation for the sites described in Figure 1. The unpublished tulip poplar forest production data were provided by W. Frank Harris.

more variable than that of the perennials. Thus a factor of 6 to 8 is not an excessive expression of the range over which the entire primary production may vary.

In contrast, the lower slopes of the grassland and forest plots imply less moisture-related variation over comparable moisture ranges. The extreme forest values vary by no more than 20 percent.

The high year-to-year variations in production of arid and semiarid systems renders environmental impact both difficult to predict and equally variable. Management of grazing systems is in a particularly difficult plight under this climatic regime.

Forage production for livestock can be expected to vary between years by factors of 6 to 8. If the same fraction of vegetation could be grazed in a dry year as in a wet year without differential effect on the plants, livestock managers should be prepared to change the numbers of their animals by factors of 6 to 8 from one year to the next. Since there is some evidence to be discussed below that plants in drought periods cannot sustain as much grazing pressure as those in moister times, grazing systems in arid and semiarid areas would seem to need even more flexibility than the factors of 6 to 8.

Over evolutionary time, the wild animals and human pastoral cultures of arid areas developed this flexibility through nomadism. Continuous movement to areas receiving precipitation assured a rest for those areas struck by drought. Such a pattern also implies extensive areas of pasture land without political or social restraint to free movement; or at least land held in common by a given social group over which its members are free to move.

In technologically advanced cultures, this flexibility is more difficult to achieve. Where the land is divided into privately-owned tracts, movement is virtually impossible. Where there are large areas of publicly-owned land, as in western U.S., the potential for a nomadic analog may have existed at one time.

But in fact, public land is divided first by state lines, and then within states by agency-administered land units (e.g., national forests), and ultimately into grazing units. The latter tend to be leased for periods of a generation or more by individuals and families, and the result approaches the sedentary characteristics of private ownership.

On the experimental grazing areas, some degree of year-to-year flexibility is achieved in a variety of ways. The different kinds of rotation systems afford some variation in grazing pressure (cf. Herbel et al. 1974; Martin and Cable 1974; Merrill, n.d.). Herbel et al. (1974) advocate flexible herd management: managing herds with a high proportion of easily marketed or purchased young animals to adjust for dry or moist period.

The degree to which these practices have been adopted on both private and public rangelands has not been complete, however. A more common practice is to stock on a relatively stable basis with numbers or animals set to the average precipitation year. The lesser pressure imposed on the vegetation in the moist year is assumed to compensate for the excessive pressure of the dry year.

THE PRODUCTION-MOISTURE GRADIENT IN BROADER PERSPECTIVE

The second inference I would like to draw from Fig. 2 is a more abstract one about the form of the general relationship between moisture and vegetative production. Net primary production is, of course, subject to numerous variables besides water: nutrients, temperature, and light. The life form of the dominant plants plays a role that may be evident in Fig. 2. A forest may fix more carbon than a grassland, but it must budget a large portion of that carbon to the respiratory demand of the extensive woody tissue. Hence the net production may be less than that of grassland. Consequently, the addition of numerous, diverse systems to Fig. 2 would induce somewhat more vertical scatter than is implied by the three sets of data shown.

However, if all of the variables affecting primary production but water could somehow be held constant, the relationship between primary production and moisture over the full moisture range which plant communities experience could perhaps be represented by the dashed line in Fig. 2. This curve is primary production estimates of different world ecosystems plotted as function of precipitation. The steep slope at the dry end of the scale in Fig. 2 would be expected to express the extreme constraint at that part of the continuum. As moisture is increased, it would be less limiting until at some point -- perhaps the 80-100 cm region in Fig. 2 -- it would no longer be limiting and the relationship would become asymptotic.

This may seem to be belaboring the obvious and superficial, but Rosenzweig (1968) in a widely cited paper has represented this relationship as a straight line on a log-log plot. I have not reanalyzed Rosenzweig's data to learn the basis for our discrepancy. My plot is semi-log, and a log-log plot does tend to contract the right-hand portion of the horizontal scale. My deciduous forest points are clumped more closely against a straight line that can most nearly represent the desert and grassland observations on a log-log scale. But a straight line is not a good representation of a log-log plot for the data in Fig. 2 in which the deciduous forest points have essentially no slope.

More germane to the subject at hand, however, is the implication of the curve in Fig. 2 regarding the moisture-stress status of vegetation along the curve. Although much has been written about the adaptations of desert vegetation for aridity, the fact remains that production is enhanced by increased moisture throughout the range it experiences. Hence, desert vegetation is apparently under some moisture stress throughout the moisture range it experiences, and more generally vegetation along the curve is under some stress until the asymptote is reached.

As a corollary, the degree of stress at any point along the curve would appear to be a function of the slope at that point. Consequently, desert vegetation is under more stress than more mesic types, notwithstanding its adaptations.

Consequently, any impact which tended to reduce the moisture of a site would tend to move the system down the moisture gradient and change it toward the type characteristic of the new point on the scale. The range management literature is replete with examples (cf. Ellison 1960 for lengthy review). Where grazing of grassland alters soil temperature, evaporation, and infiltration and run-off patterns by reducing mulch and compacting the soil, grasslands may move from tall- to mid-grass types, or mid-grass to short-grass types.

Some of the most dramatic changes have been those cases where grassland is delicately balanced above the desert type on the scale. Gardner (1951), Humphrey (1968), Hastings and Turner (1965), York and Dick-Peddie (1968) and others have described the change from desert grassland in Texas, New Mexico and Arizona to shrub-dominated desert types.

Consideration need not be confined to grazing effects. Any climatic change, air-borne contaminant or mechanical disturbance resulting from recreational use which changed the moisture regime of a site would change its position in the gradient.

A second consequence is more hypothetical, and that is the question of whether a plant existing at a relatively arid point on the moisture gradient (and under more moisture stress) is more sensitive to a given perturbation than one occupying a more mesic point (and under less stress). In a sense this is asking the question of whether the arid system is more fragile than the more mesic one if we define "fragile" as the degree of response to a measured perturbation.

The same vegetation is more sensitive to grazing during drought than during moister periods (Savage 1937; Albertson *et al.* 1975; Box 1976). One of the mechanisms seems to lie in the plant's growth responses to moisture stress on the one hand and grazing on the other. Under moisture stress, photosynthesis may continue but vegetative growth tends to be suppressed in favor of root growth (Hsiao and Acevedo 1974). This is presumably an adaptation for extracting moisture from a larger volume of soil. Grazing commonly produces a *reduction* in root tissue (Box 1976), perhaps because a lesser photosynthetic input from a reduced foliar area cannot supply the respiratory demands of the entire root system. In a drought period, the effect would be to magnify the plant's already difficult moisture plight.

The same generalizations have not definitely been shown to apply across a gradient of plant communities: i.e., that arid-land vegetations are more sensitive to grazing than more mesic ones. But the reciprocal of this question is rather widely agreed upon by range specialists: that vegetation in arid areas requires a longer period for recovery from damage than more mesic vegetation (Box *et al.* 1976). The question surely needs study in view of the tendency for range managers to apply the same "take half, leave half" philosophy to most vegetation types.

This section should not be taken as a condemnation of livestock grazing. Vegetation has evolved to withstand herbivorous removal; and there is considerable evidence that, under some circumstances, primary production is *enhanced* by light to moderate grazing (Ellison 1960). Range will improve under proper grazing management (cf. Homgren and Hutchings 1972; Martin 1975), and will exist in health under proper use. In a world with inadequate food, livestock grazing is socially desirable and can be ecologically sound.

But a major fraction of U.S. grazing lands are degraded and producing at less than their potential. Perhaps the most difficult task facing range management today is the rehabilitation of those ranges to something approaching their potential. Since much of the degradation has in essence been a change from more mesic to more arid conditions and vegetation types -- in effect, desertification -- rehabilitation will of necessity involve an understanding of, and correct response to, the moisture constraint.

BIOTIC INTERACTIONS AND PREDICTION OF DESERT PLANT COMMUNITY CHANGE

Increasingly, ecology aspires to reach the point of predicting the effects of perturbation on ecosystem structure and function. These aspirations have obviously been given impetus by passage of the National Environmental Policy Act.

The production-precipitation functions I presented in the last section are examples of how the science has arrived at the point of predicting year-to-year variations, particularly those associated with year-to-year variations in the physical environment. But we are equally, if not more concerned with predicting the effects of perturbation on long-term changes in community structure and function. Such predictions are, to a considerable degree, still over the horizon.

Since community structure may be substantially a function of biotic interactions, and changes in structure often a function of these interactions I would like now to consider two aspects of this subject in a somewhat speculative vein, and then return to the question of prediction.

STATUS OF ANNUALS IN HOT VS. COLD DESERTS

The singular importance of annual plants in desert vegetation has captured the interest of ecologists for many years. Unlike any other major vegetation type, their production may approach or equal that of perennials, often on the same site (Table 1); and their number of species exceeds that of perennials

Table 1. Range of Values for Annual, Above-ground Net Primary Production in Desert Perennial and Annual Vegetation.

Location	Year Observed	Prod. in Kg/Ha Perennials	Prod. in Kg/Ha Annuals	Source
Desert Experimental Range, Utah	13	134-504	-	Hutchings and Stewart, 1953
Nevada Test Site[1]	3	-	0-616	Beatley, 1969
Rock Valley I.B.P. Site, Nevada	2	180-600	4-450	Norton, 1974
Curlew Valley I.B.P. Site, Utah	2	600-1,800	650-1,300	Norton, 1974
Southeastern Arizona	1	1,000[2]		Chew and Chew, 1965

[1]Undisturbed sites only.
[2]Larrea tridentata, which made up 74 percent of the total production only.

(Kassas 1966), often by a large margin. Thus the number of winter annual species regularly occurring on the US/IBP Desert Biome Site in Rock Valley, Nevada has been 41, the number of perennials 10. The same comparison for the Biome Silverbell Site in southern Arizona is 48 and 8. Beatley (1966) reports 140 species of winter annuals on the Nevada Test Site in the Mohave Desert.

However, the status of annuals in the southern or "hot" deserts of North America differs from that in the northern or "cold" deserts. The large number of species in the southern deserts are predominantly native (Went 1948; Beatley 1966), and coexist with the perennial vegetation. Two schools of thought have developed regarding the nature of that coexistence.

The first is that of Beatley (1969) who concluded that the distribution and production of the annual flora is largely independent of the species and distribution of shrubby perennials, at least those of the Mohave Desert. Except for burned areas where the exotic Bromus rubens atypically increased production, her observations showed annual production unaffected by the kinds or numbers of Mohave shrubs, or by mechanical disturbance. The impression is one of a separate and independent component of the vegetation.

The second school of thought holds that some components of the annual flora are favorably influenced by the shrub component because some annual species characteristically grow under and through the shrub canopy. Thus Halvorson and Patten (1975) observed an increase in annual species along with increasing numbers of perennials as they ascended the lower mountain slopes in the Sonoran Desert of Arizona. Growth rates of annuals under shrub canopies were twice those of annuals in the interplant spaces, and total primary production was higher under the canopies.

(Muller and Muller 1956; Muller 1953) attributed this favorable influence to an improvement of the soil environment through entrapment of windblown organic matter by the shrub. But Went (1942) intimated that certain unidentified chemical exudates of the shrubs were beneficial in some way to the forbs.

Whichever view is correct, the annual flora of the southern deserts has evolved into a rich array of species. It coexists with the perennials, at the least functioning autonomously, and possibly existing in part as commensals with the shrubs.

The pattern in the cold deserts is quite different. Native annuals are few and inconspicuous, the common ones being exotics.

The Curlew Valley Desert Biome Site in the Great Basin sagebrush (*Artemisia tridentata)* vegetation contains only eight species, all of them exotics. Only three -- *Halogeton glomeratus, bassia hyssopifolia,* and *Descurainia pinnata* -- are at all abundant.

Furthermore, the cold-desert annuals do not coexist successfully with the perennials. In healthy shrub stands, annual production is inconsequential. On the Nevada Test Site, where elevational differences place part of the area in Mohave and part in Great Basin Desert, annual production is markedly lower in the Great Basin zone than in the Mohave (Rickard and Beatley 1965; Beatley 1969). Only in disturbed situations, particularly where shrubs have been killed, is there a flush of annual growth. Thus, on the Curlew Valley Biome Site, annual production is low in healthy shrub stands, but reaches the high levels shown in Table 1 in a 40 hectare portion of the area where shrubs have been killed (Shinn 1974).

The mechanisms underlying the different evolutionary history and functional status of annuals in the two desert types is not known, but I suggest differing perennial root strategies as one hypothesis. In the southern deserts, root biomass is characteristically about half or less of total, perennial biomass (cf. Barbour 1973; Wallace et al. 1974) while in the Great Basin this percentage may rise to 87 percent of the perennial standing crop (Norton 1974; Caldwell 1974). In terms of actual weight, I have calculated live-root biomass for the Silverbell, Arizona site from data reported by Thames (1974) and MacMahon (1976) at 10,929 kg/ha; that for the Curlew Valley, Utah site from data reported by Shinn (1974) at 27,499 kg/ha.

Furthermore, the vertical distribution (Fig. 3) of the root mass differs. Nearly half of the greater root mass in Curlew Valley is in the upper 20 cm, while only a fourth of the lesser root mass in Silverbell is in this layer. Maximum root mass in the latter area is in the 20-40 cm depths.

These differing strategies may relate to the different precipitation patterns in the two regions. In the south, precipitation is lower, spatially and temporally more variable, and occurs entirely as rain. Woody lateral roots may extend for considerable distances (Kassas 1966), often to arroyos to intercept runoff. In the north, much of the precipitation is fall-to-spring frontal moisture, with a large fraction occurring as snow. In spring, after snowmelt and ground thaw, the soil may approach field capacity for a short period. The extensive, more fibrous root system of the Great Basin shrubs may more effectively exploit this seasonal moisture resource during its period of availability.

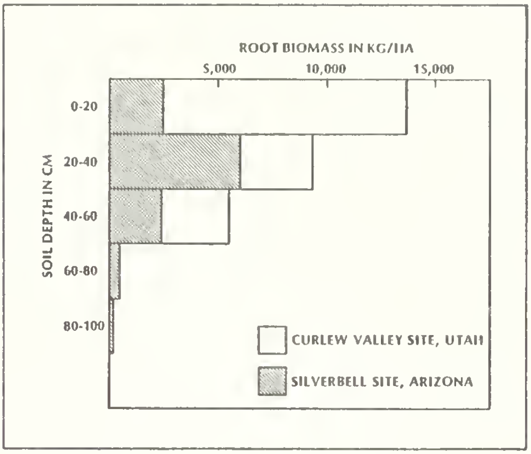

Figure 3. Distribution of root biomass by soil depth on the US/IBP Desert Biome Silverbell (Arizona) and Curlew Valley (Utah) research sites. Silverbell data from Thames (1974) and MacMahon (1976), Curlew Valley data from Shinn (1974).

Whatever the strategy, the surface 20 cm of soil in the southern desert appears to offer a niche into which an abundant flora has evolved. In the northern deserts, this soil zone is permeated by fine, actively growing roots of shrubs which may have blocked the evolution of an ephemeral flora.

The impact implications are rather clear. Any disturbance which damages or destroys perennial vegetation in the northern deserts will produce a luxurient growth of exotic annuals. We have sufficient measures of the production and distribution of these species that we can predict with reasonable confidence the species that will appear and their production, given soil and precipitation characteristics.

In the south, the effects of perennial disturbance cannot yet be predicted fully. If Beatley's (1969) independence hypothesis is correct, the annual flora might not be seriously affected by disturbance or removal of perennials. But if the commensal hypothesis is valid, reduction of perennials could lead to a reduction in the annual flora, at least the natives. At the same time, some exotic annuals have invaded the southern deserts. These forms could conceivably increase in place of the natives, a possibility for which there is some evidence (Beatley 1966a).

Any long-term environmental influence which gradually eliminated perennials and converted the vegetation increasingly to a desert of annual plants would progressively increase the variability of the system because of the greater variation in annual production. This effect can be seen in the Middle East and North Africa where the vegetation has been subjected to millenia of heavy grazing, and removal of woody perennials for fuel and building material. Thus, annuals contribute 60-80 percent of the primary production in parts of Israel (Immanual Noy-Meir, Personal Communication) and up to 100 percent in parts of Egypt and Sudan.

COMPETITION AND THE PERENNIAL COMMUNITY STRUCTURE

The question of whether desert vegetation undergoes succession has had a contentious history of more than a half century duration. Shreve (1942) asserted that succession in the traditional, autogenic sense of successive environmental modification does not occur because the vegetation has no significant influence on the physical environment. Muller (1940) denied that any successional sequence occurs in the *Larrea-Flourensia* vegetation of west Texas.

Yet Shreve (Shreve and Hinckley 1937) had earlier documented marked increases in plant populations during 30 years of protection at the Desert Laboratory near Tucson, Arizona. And as early as 1924 Shantz and Piemeisel (1924) had generalized the successional status of a number of species in southern California, Nevada, and Arizona. Kassas (1966) questioned Shreve's assertion that the vegetation does not modify the physical environment, pointing out that desert shrubs entrap windblown soil and organic matter, intercept moisture, and retard runoff. In his view, successional sequences do occur.

This latter view now seems to prevail, and several successional sequences have been described. Gardner (1950, 1951) described the pattern and rate of perennial grass recovery in the degraded, desert grasslands of southern New Mexico. Shields et al. (1963) described a 4-year sequence following a nuclear blast on the Nevada Test Site.

Wells (1961) compared vegetation on the streets of a Nevada ghost town, which had been abandoned for 33 years, with that on nearby undisturbed areas. Certain species in the succeeding vegetation were those characteristically found along the margins of washes. Traditionally they had been thought to occur there because of more demanding water requirements, but Wells now suggests that their presence in these sites could be associated with the disturbance provided by seasonal runoff and scouring.

Hence, desert vegetation, freed of disturbance, will undergo changes in structure over a period of time. Whether this change entails the autogenic changes prescribed by Shreve, and whether it should be called succession, is perhaps a semantic question.

The time scale involved seems to number in the decades. Thus, Shields et al. (1963) predicted that post-blast recovery would require more than 33 years, while Wells (1961) observed that 33 years protection had not been sufficient for the return of the undisturbed vegetation. Kassas (1966) suggested that 100 years may typically be required to reach a climax state in deserts. Chew and Chew (1965) predicted that production of the developing *Larrea* community they studied would level off at 65-70 years, standing biomass at 80-90.

What the nature of the climax might be in terms of its persistence over time, or whether cyclic changes might occur, is to my knowledge largely unexplored. Clark Martin (Personal Communication) has described cyclic or wave patterns in some plant species of the desert grasslands of southern Arizona.

The existence and nature of competitive interactions, which might in part organize the desert plant-community structure and mediate change, has also been a contentious question. Although West and Tueller (1972) have questioned the existence of competition at the extremes of aridity, and Barbour (1973) has questioned the adequacy of evidence to support a competition hypothesis, most investigators postulate some form of competition. The disagreement largely surrounds the mechanism.

Numerous authors have recorded a positive correlation between precipitation levels and shrub density (Went 1955; Hastings and Turner 1965; Woodell et al. 1969; Beatley 1974), dispersion (Barbour 1969; Woodell et al. 1969; King and Woodell 1973), and diversity (Shreve 1942). Yang and Lowe (1956) point out that their correlation between soil texture and diversity is also a correlation between moisture availability and diversity. Several authors take these correlations to imply competition for moisture, especially root competition (Shreve 1942; Kassas 1966; Woodell et al. 1969) although Barbour (1973) questions the evidence for root competition.

If competition exists which limits vegetation density, it should have its effect through density-dependent patterns in plant demography, either in reproductive or survival rates, or both. That implication of the competition hypothesis has been somewhat difficult to reconcile with the observation that germination tends to be a highly episodic phenomenon correlated with above-average rainfall years (Went 1948, 1955), and by implication recruitment of new plants into the vegetation is similarly episodic. Based on reasoning which I do not quite follow, Barbour (1969) has inferred episodic recruitment from non-normal height-frequency distributions in *Larrea divaricata*.

Reconciliation might lie in making a firm distinction between germination and seedling survival to about 2 or 3 years of age when a plant can be considered a recruit into the population. The evidence for the episodic nature of germination does appear convincing. But numerous authors describe high mortality rates of seedlings (Shreve 1942; Went 1948, 1955; Knipe and Herbel 1966). Shreve (1942) observed that the ratio of older *Larrea* plants to young ones may be about 400:1. Went (1948, 1955) concluded that shrub stands are closed and seedlings can only recruit into them when an older plant dies.

Recently, Rae (1976) has summarized the age distribution of perennial plants in paddocks which have been under study at the Dubois Sheep Station in southern Idaho for several decades. These distributions show a smooth decay curve intermediate in form between log-normal and log-log distributions. Beyond 3 years of age, there are no abrupt year classes in the population which would suggest episodic recruitment.

Additional inferences of competition can be drawn from the long-term grazing studies. Research on the Desert Experimental Range provides a classical example (Homgren and Hutchings 1972). The salt desert shrub type of the Great Basin Desert, in which the DER is located, is used for winter sheep grazing. In 1931, the Forest Service began studies on the effects of different intensities and seasons of grazing use in vegetation which had been grazed for a half century or more. The DER was subdivided into experimental pastures, and each was subjected to a yearly grazing treatment with periodic measurements of vegetation.

The vegetation over much of the area is a relatively simple one with three species of shrubs -- *Atriplex confertifolia, Eurotia* (now *Ceratoides) lanta, and Artemisia spinescens* -- dominating. The latter two species are preferred by sheep, the former is low in preference but taken in light or moderate amounts when the others are no longer available.

Over the period 1935 to 1967, vegetation changed under the different grazing treatments (Figs. 4 and 5). Under heavy grazing in late

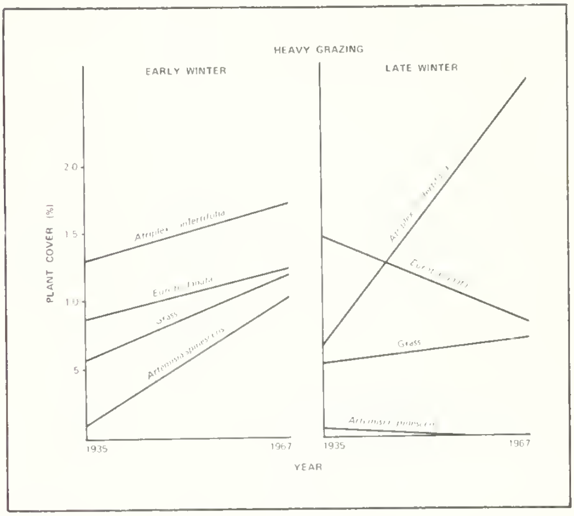

Figure 4. Vegetation changes under heavy early- and late-winter sheep grazing on the Desert Experimental Range, southwestern Utah (after Homgren and Hutchings 1972).

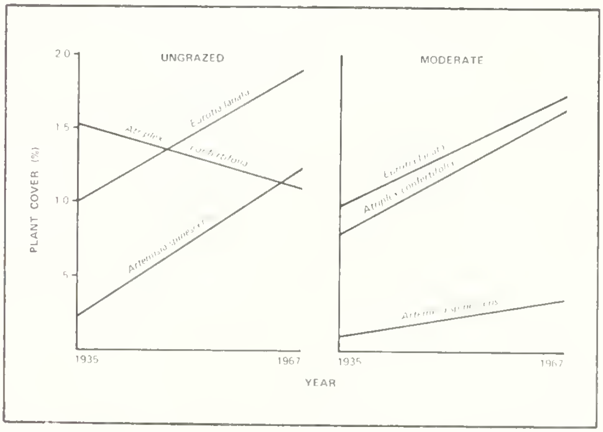

Figure 5. Vegetation changes under moderate, winter sheep grazing, and under protection from grazing, on the Desert Experimental Range, southwestern Utah (after Homgren and Hutchings, 1972).

winter, when the shrubs were breaking dormancy, *Atriplex* increased markedly while the other two declined. In addition, perennial grasses increased. Under moderate, and heavy early-winter grazing, all species increased between 1935 and 1967. Under complete protection from grazing, *Atriplex* declined while the others increased.

One may interpret these results on the basis that all species are in competitive tension. Any impact which affects one more severely than others, will place it at a competitive disadvantage. The others may then increase at its expense. Under heavy late-winter grazing, the most heavily grazed species declined while the less palatable *Atriplex* increased. Perennial grass, inactive in winter and often covered by a snow mantle, also increased. Under the less severe treatments, none of the species were at such a severe disadvantage that they were forced to yield dominance to others. All were able to increase between 1935 and 1967, presumably from a degraded state which preceded establishment of the area.

Under protection, grazing played no part in the competition-induced change. According to Homgren and Hutchings (1972) *Atriplex* is less drought tolerant than the other species. Hence, it is periodic drought periods which provide the preferential impact, and *Eurotia* and *Artemisia* increase to fill the competitive void.

Perhaps the most controversial topic in this entire subject has been that of allelopathy. Went (1955) stimulated investigation early with his suggestion that desert plants secrete inhibitory substances from their roots. This has been challenged by Barbour (1969, 1973), King and Woodell (1973) and by Knipe and Herbel (1973) who were unable to find experimental evidence of the phenomenon.

However, Gray and Bonner (1948), Muller and Muller (1956), and Muller (1953) have experimented with water-soluble foliage extracts with varying degrees of positive evidence, depending on the experimental plants used. Knipe and Herbel (1973) clearly obtained inhibition of radicle and plumule growth in perennial grass seedling with foliar and stem extracts from *Larrea tridentata*. The extracts did not affect *Larrea* seedlings, however. Hence, there is experimental evidence of the existence of allelopathy in desert vegetation, and Muller (1966) makes a strong case for including it in any model of plant community dynamics. But the extent to which it operates is unknown.

It seems to me these varied lines of evidence permit one to view the desert plant community as existing in a matrix of biotic interactions, particularly competitive (Fig. 6). The pattern extant in a given area at any point in time is a function of its past history and of those interactions to date. It may be changing toward some other state, or it may have arrived at some equilibrium.

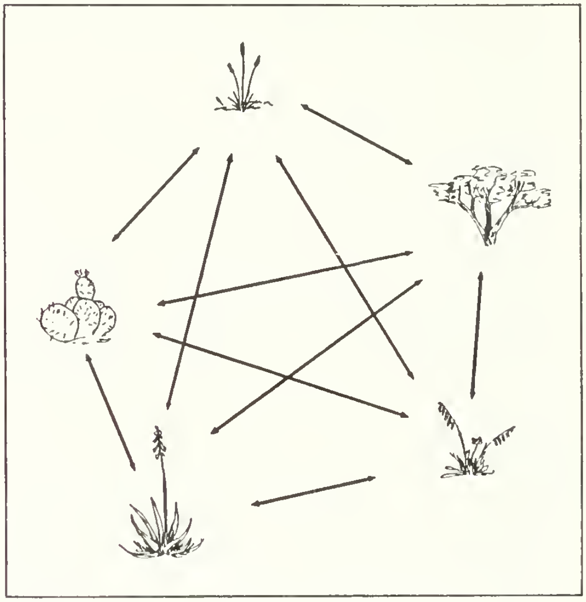

Figure 6. In a desert vegetation, shrubs, forbs, grasses, and succulents exist in competitive tension for water, and perhaps for light, space, and nutrients. This tension importantly affects the composition of the vegetation at any point in time.

This is no new concept of the plant community. But desert specialists have been somewhat slow to adopt it. I have explored it at some length here because the adoption of some such conceptual framework is a first step in developing the predictive capability we need for desert systems.

Any impact which affects some part of the community more strongly than others -- whether it is grazing, climatic change that favors some species more than others, or airborne contaminants such as might be emitted by a coal-fired power plant (Gordon 1975) and to which some plant species were more sensitive than others -- would alter the competitive balance.

THE PROBLEM OF PREDICTION

The scientists who committed so many years to the research at the Desert Experimental Range can now predict, with a high probability of being correct, the community changes one could expect under certain circumstances. That prediction will be largely empirical and based on the observations they have made on the DER vegetation in the past. Conseqently, their predictions will be most accurate for a system with the same vegetation starting points, the same grazing patterns, and the same weather inputs over time which they observed.

There is a great deal of this kind of empirical knowledge in the range management field today. It is the basis for the considerable level of competence which the professional has achieved.

But the probability of correctly predicting community changes on the basis of the DER research base declines as vegetation composition grades away from that in the DER paddocks, as new grazing patterns and classes of livestock are placed on that vegetation, and as weather patterns differ from those observed. An empirical model based on the DER research findings (cf. Wilkin and Norton 1974) may be able to predict the outcome of certain unstudied conditions to a limited degree, but it will ultimately be limited by the range of observations made during the period of study.

The superb, long-term grazing studies like those of the DER, Santa Rita, Jornada, and Sonora, Texas stations were established in major vegetation types. But many other major types have not had similar studies, and numerous variations of the vegetation types on the stations can be found. Hence, our predictive capability is still limited.

The needed approach to the problem is, in my opinion, to work toward development of models which predict community change on the basis of physiological and morphological mechanisms involved in that change. If, for example, we know the morphology of the root systems of plants in a community, the patterns of moisture uptake by those systems, and the effects of different perturbations on root function, we have some basis for predicting the changes to be expected from those perturbations. If root morphology and function fall into generalizable patterns, we begin to have some basis for prediction in any community, given the root characteristics of the species in it. Cable (1969) reports precisely the kind of research we need to approach this goal.

Additionally, our modeling approaches need to evolve further. The heavy emphasis on modeling in the past 6-8 years has produced some sophisticated models incorporating a high degree of mechanism. These models can simulate the short-term (a few years) dynamics of essentially unchanging systems, but most cannot yet predict long-term change in system structure and function. This inability does not stem from any inadequacy in the modeling art, but from inadequate biological data of the sort I have been discussing in this section on biotic interactions.

Although we have not moved in this direction in the arid and semiarid regions, some first steps in the direction of modeling community change mechanistically have been taken in forest areas (Botkin _et al_. 1972). Similarly, Horn (1974, 1975) has used Markov chains as models of forest succession, and predicted change on this basis. However, the assignment of probabilities to each step in the chain must come in part from a knowledge of the mechanisms which determine those probabilities. Hence, the need for elucidating those mechanisms remains.

In my view, the next research cycle should involve interdisciplinary teams directing their efforts to the data needs of mechanistic models designed to predict community change. These efforts should concentrate on entire communities, and research efforts should give special attention to biotic interactions. In the arid and semiarid regions, the long-term grazing research stations would be excellent sites on which to focus some projects of this sort because of the extensive knowledge of the biota, like Cable's (1969), which already exist.

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EVALUATING IMPACTS ON CONTINENTAL SHELF ENVIRONMENTS CONCEPTS AND PROSPECTS[1/]

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INTRODUCTION

New and expanding activities on the continental shelf including disposal of wastes and dredged material, deepwater ports, floating nuclear power plants, mining, and oil and gas exploitation, have spawned increased interest in the ecology of continental shelf ecosystems and the environmental effects of these activities. Changing patterns of historical uses of the shelf environment, i.e., fishing and transportation, and as yet hypothetical new uses, such as tapping energy from the ocean's currents and gradients, will undoubtedly further increase our concern for the coastal oceans.

In response to the increasing demand for use of the continental shelf and driven by increased awareness of environmental problems, many government agencies (most of them federal) and private corporations have greatly expanded environmental impact research on the continental shelves of United States. The adequacy, aims and approaches of these investigations often differ substantially from each other. This has been a cause of criticism by the scientific community, government officials and the public. In this paper I outline the nature and extent of activities potentially impacting continental shelf ecosystems, review past experiences and ongoing programs concerning impact evaluation, point out features of continental shelf ecosystems which should influence how we study them, and attempt to develop a conceptual framework for future investigations related to environmental impacts.

CONTINENTAL SHELF ACTIVITIES

Many of the new and expanding activities can be considered offshore extensions of typically land-based activities (such as waste disposal) for the purpose of reducing environmental risks to the coastal zone.

Ocean dumping is practiced for the disposal of chemicals, dredged materials, sewage sludge and other refuse. Ocean disposal is regulated by the Environmental Protection Agency (EPA) under authority of the Marine Protection, Research and Sanctuaries Act of 1972 (P.L. 92-532 as amended by P.L. 93-254). Permits are issued by EPA, or by the Corps of Engineers in the case of dredged material, for ocean disposal at specified dump sites (Fig. 1). Environmental criteria for permitting ocean dumping (EPA 1973) rely heavily on chemical analyses of the waste or bioassays, although field monitoring is sometimes required. Generally speaking, however, ocean dumping of wastes on the continental shelf is disfavored by EPA in favor of alternate disposal methods (e.g. land-based disposal, disposal farther offshore and incineration) or recycling. However, pressures continue to mount for increased shelf disposal of dredged material since disposal in and around coastal waters has become increasingly restricted.

Ocean outfalls for the discharge of sewage and sewage sludge loom attractive to localities under pressure to reduce inputs to bays and estuaries. Large population centers in Southern California and South Florida already rely on direct disposal of sewage into continental shelf waters. Many smaller coastal cities and towns are finding ocean outfalls an attractive alternative to current disposal practices.

Another waste product for which ocean disposal is proposed is heat from electric generating plants. Nuclear power plants are in operation or under construction on the ocean shore in California and plans have been developed for the construction and operation of floating nuclear power plants. Although the tremendous heat capacity of the ocean practically eliminates any threat of thermal pollution by offshore power plants, entrainment effects are potentially significant with regard to species with localized distributions and planktonic larvae.

Economic and environmental considerations argue for the location of some traditionally land-based activities offshore. Offshore oil ports allow the use of the more economical, very large crude oil carriers and reduce the hazards to the coastal zone. Two large volume offshore ports, one off Louisiana and another off Texas, are being planned and others

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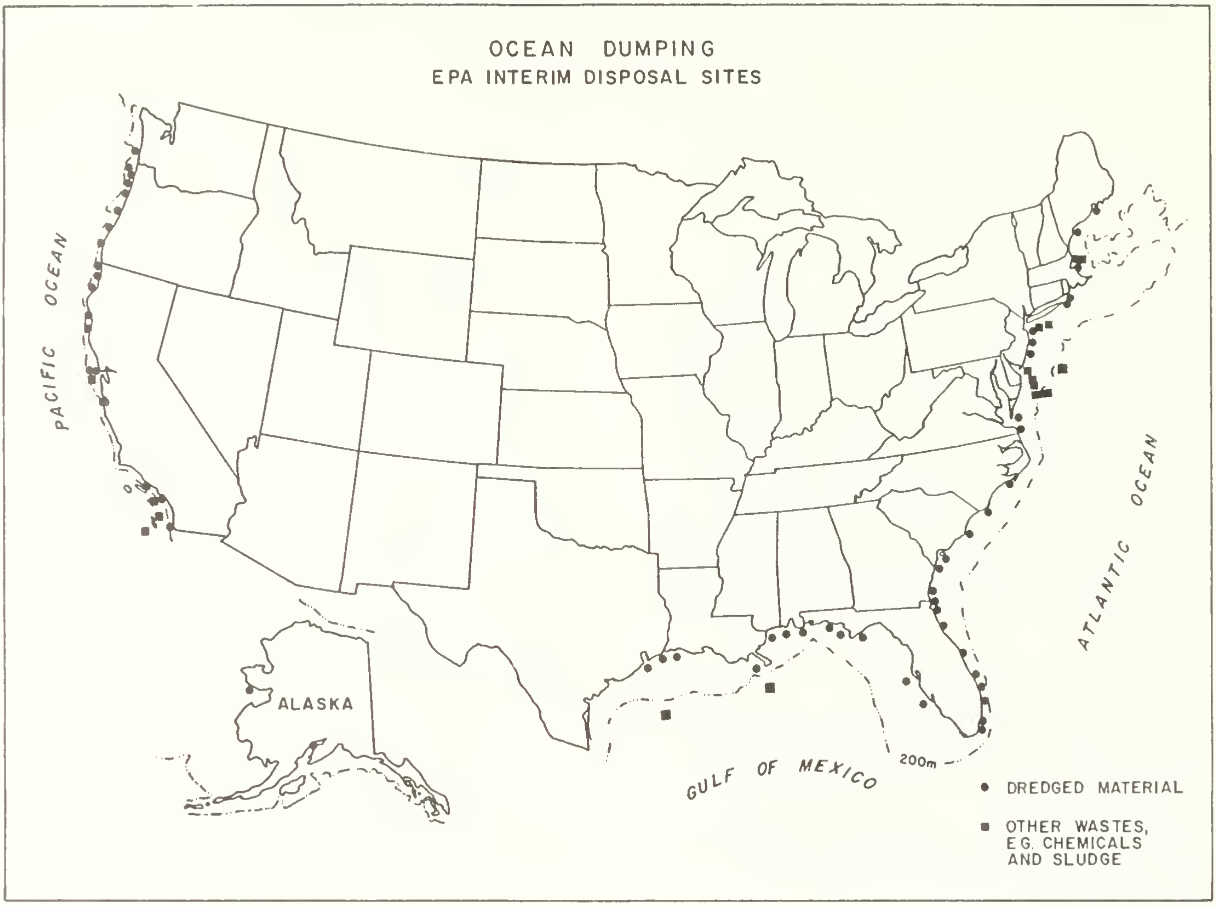

Figure 1. Interim ocean disposal sites on or near the continental shelf of the United States.

have been suggested for off Middle Atlantic and South Atlantic states. Offshore islands, possibly constructed from waste dredged material, have also been suggested to accommodate industry which may be incompatible with conservation of the coastal zone.

Mineral resource extraction is now becoming a widespread activity on the world's continental shelves. This includes extraction of surface minerals, chiefly sand and gravel for building materials, as well as subsurface resources, including oil, gas and sulfur. The continental shelf activity presently drawing by far the most attention is oil and gas development. This is due to the expansion of activities, heretofore concentrated mainly off Louisiana and Texas and parts of Southern California, to Atlantic and Pacific coasts and vast areas of the Alaskan continental shelf. The leasing and development of these outer continental shelf (OCS) tracts is under control of the Department of the Interior, specifically the Bureau of Land Management (BLM) which leases OCS lands thereby effectively permitting the right to exploit oil and gas resources, and the U.S. Geological Survey (USGS), which regulates development.

In additon to widespread concern regarding the onshore impacts of extensive development of frontier OCS areas, questions have been raised about the environmental impacts of offshore petroleum development on continental shelf ecosystems. In particular there are threats of acute and chronic contamination of the ecosystem by petroleum hydrocarbons, the introduction of trace metals, sedimentation by drill cuttings and drilling muds, and effects resulting from the installation of pipelines. These concerns have prompted the extensive environmental studies of frontier areas sponsored by BLM, which will be addressed in more detail below.

The environmental ramifications of living resource extraction on the continental shelf will undoubtedly receive increased attention in the near future. A large portion of the national fishery is already based on the continental shelf, but with the 200-mile fishery jurisdiction virtually new resources have become available to segments of the U.S. fishing industry. The unprecedented prospects for managing these resources will hopefully be realized by management schemes which take into account the environmental effects of alternate fishing methodologies.

In the case of many of the continental shelf activities mentioned above, it is important to point out that key issues regarding severity of impact revolve around scientific questions which have scarcely been addressed. There is much legitimate scientific controversy -- for example about the effects of chronic low-level contamination by petroleum hydrocarbons -- at the heart of the environmental impact assessments on which decisions regarding these activities are based. Thus at times decisions are made involving massive commitment of resources and potentially long-term environmental effects on frightfully little firm evidence. From this point of view, one can argue that the high costs of pertinent environmental research on the shelf are clearly cost justifiable if they affect decision-making.

PREVIOUS STUDIES

Few intensive impact evaluations have been conducted on continental shelf environments. Perhaps the most intensively studied activity has been ocean dumping in the New York Bight apex, where large quantities of sewage sludge, dredged material, construction debris and acid-iron wastes have been discharged in a rather confined area off northern New Jersey. The impacts of these activities have been studied by or for the Corps of Engineers, the National Oceanic and Atmospheric Administration (NOAA) and EPA, and are the focus of the ongoing Marine Ecosystems Analysis (MESA) program of NOAA. Early results emphasizing the effects of sludge disposal were summarized by Pararas-Carayannis (1973) and the National Marine Fisheries Service. Reports on the effects of acid-iron disposal were published by Vacaro et al. (1972) and Wiebe et al. (1973). An overview of these studies is presented in these proceedings by O'Connor, and more detailed findings have been published in proceedings of a symposium held on this subject in November 1975 (Gross 1976).

The New York Bight experience is a case study in the difficulties of conclusively demonstrating impacts in the real world, where natural and anthropogenic factors other than ocean dumping of wastes may exert overwhelming influence on ecosystems. For example, dump sites are located at the head of the Hudson Shelf Valley which forms a unique and discrete habitat for which no suitable unaffected control habitats exist. Also, for many pollutants, direct input by dumping pales by comparison to the inputs from the Hudson River and New York Harbor. As a result, although contamination of the environment and impacts to some segments of the biota have been demonstrated, the composite evidence has failed to unequivocally demonstrate serious effects on the marine resources of the region.

In much more limited studies of the impact of ocean dumping Lear et al. (1977) conclude that dumping of Philadelphia sewage sludge has resulted in trace metals contamination of bottom sediments and localized impacts on benthic organisms.

The environmental impact of waste discharges by ocean outfalls into the Southern California Bight have received substantial recent investigation, chiefly by the Southern California Coastal Water Research Project (SCCWRP). Each year approximately 1.4×10^9 m^3 (1,000 mgd) of municipal wastewater and 0.25×10^9 m^3 (180 mgd) of discrete industrial wastes are discharged into the Bight (SCCWRP, 1973). Municipal wastes include treated sewage effluent and sludge discharged via ocean outfalls at depths of 6-100 m. Significant contamination of shelf and basin environments by trace metals and chlorinated hydrocarbons was demonstrated by the SCCWRP studies. Localized effects on the benthos and fishes near outfalls were also found. Nonetheless, the conclusion was reached that "there is no evidence to document that present wastewater disposal practices have had any substantial adverse or irreversible effects on the general ecological characterics or environmental quality of the Bight" (SCCWRP 1973).

The impacts of oil and gas development on continental shelf ecosystems have received much less attention than the New York Bight or Southern California Bight situations. The effects of large oil spills from offshore platforms in the Santa Barbara Channel in 1969 and east of the Mississippi River Delta in 1970 (Chevron spill) received some investigation.

Studies of the Santa Barbara blowout were concentrated on the intertidal biota, marine mammals and birds (Allan Hancock Foundation 1971). Much less attention was directed at assessing effects on offshore communities even though it was known that substantial quantities of oil did reach the seabed. Continental shelf benthos was resampled at several "baseline" stations sampled a decade earlier and changes in the biota were noted. However, it was surmised that these changes could have been due to heavy rainfall around the time of the spill, the effects of drilling and spills in the channel, the increasing pressure of land-derived pollutants, or even natural fluctuations in population levels.

Environmental contamination by petroleum hydrocarbons and effects on benthos and nekton were investigated following the 1970 Chevron spill. Results were summarized by McAuliffe, et al. (1975) although the particulars are as yet unreported, and thus have not been subject to scientific scrutiny. These studies showed that petroleum hydrocarbons did contaminate sediments within a 5-10 mile radius of the platform, but the authors were unable to demonstrate any biological effects.

Finally, only one extensive environmental study of offshore oil fields has been conducted -- this a study off Timbalier Bay, Louisiana, by the Gulf University Research Consortium, sponsored by a group of offshore operations companies. Results are as yet unpublished, but overview summaries suggest a lack of significant effects on the offshore environment. Unfortunately, many of the unpublished reports reveal incomplete data, a lack of suitable controls or poor sampling design, as well as often being inconclusive.

The purpose of the foregoing review is to demonstrate that even the most extensive and intensive impact assessments on the continental shelf environment have been inconclusive or have produced equivocal or debatable conclusions. There seem to be several general explanations for this failure to come to grips with the problem: (1) large, open, dynamic shelf ecosystems are more difficult to study than smaller freshwater and coastal systems; (2) research was often of insufficient quality or completeness, principally because of inadequate support; (3) the natural causes of spatial and temporal variation were unknown; (4) baselines and controls were not, or could not be, effectively used; and (5) impacts on specific biotic components have been difficult to relate to resource values or to total ecosystem "health."

CURRENT STUDIES

A host of government agencies have interests concerning environmental impacts on the continental shelf and several are sponsoring or conducting monitoring studies, baseline studies or basic research on shelf ecosystems in order to enhance our ability to detect, understand, or predict environmental impacts. MESA studies of the New York Bight and SCCWRP studies of the Southern California Bight are examples of continuing programs.

The EPA mandate concerning environmental impacts is understandably broad and encompasses many activities but the agency has special responsibilities concerning ocean dumping. The EPA is conducting baseline and impact assessment research at some dump sites, for example off Delaware Bay. The Agency also has a major responsibility for experimental work on the lethal and sublethal effects of contaminants on shelf organisms and communities. NOAA is, of course, responsible for MESA investigations and for impact assessments related to fishery resources. This agency is also heavily involved in managing and conducting some of the BLM environmental studies of frontier oil and gas areas described below.

The Army Corps of Engineers, principally through its Dredged Material Research Program (DMRP), is concerned with ocean dumping of dredged material (Boyd et at. 1972). The DMRP has conducted field studies involving the closely monitored dumping of dredged material at several sites around the nation. Two of these sites were located on the shallow continental shelf off Galveston, Texas, and off the mouth of the Columbia River. The DMRP has also sponsored experimental research on such topics as the bioavailability of toxic contaminants of dredged material and the effects of burial on benthic communities.

The Department of Energy is sponsoring rather basic research on continental shelf processes. Studies on the Atlantic coast are directed toward processes which may relate to environmental impacts associated with coastal nuclear power plants. The Coast Guard has responsibility for regulating offshore ports and is supervising baseline sampling at Gulf of Mexico deepwater ports sites. The National Science Foundation funds basic research on continental shelf ecosystems not necessarily related to impact assessments, but which may indirectly contribute to a better understanding of impacts of man's activities. The NSF has also through its International Decade of Ocean Exploration sponsored research on the fate and effects of trace pollutants in the ocean environment.

The Outer Continental Shelf Environmental Studies Program of the Bureau of Land Management has attracted considerable attention because of the size of the program (over $44 million in FY 1978) the geographical scope and particular emphases of the studies, its role in decision-making concerning oil and gas development and the new entry of BLM into environmental research. BLM OCS baseline studies were conducted on the eastern Gulf of Mexico shelf (MAFLA region), the South Texas shelf, the Southern California Bight, the Middle Atlantic shelf (Baltimore Canyon Trough), the Southeast Georgia Embayment, Georges Bank, and extensive portions of the vast continental shelf of Alaska. Other environmental assessments of drilling and production activities have begun or are planned.

The BLM Environmental Studies Program has expanded explosively since 1974 and the study design had to be quickly developed and implemented. The scope of studies as recently perceived by BLM is outlined in Table 1. Basically, studies are classed as Reconnaissance Studies, Benchmark Studies and Fate and Effects Studies. The greatest emphasis in terms of biological studies is on the so-called benchmark studies which are broad, multi-year survey programs intended to provide a statistically sound characterization of key environmental aspects (National Research Council 1977). The objective is to establish the range of variation of critical parameters that may reflect the impact of oil and gas exploration and development activity. Thus, the studies are fundamentally descriptive "baseline" studies which are of limited predictive value in assessment of anticipated impacts.

A recent National Research Council (1977) review of the BLM Environmental Studies Program concluded that because of the emphasis on descriptive studies, it does not effectively contribute to oil and gas leasing decisions. Furthermore, the NRC review found the program scientifically deficient because of the lack of explicit hypotheses or statements of the scientific purpose for which the gathered data were intended. At the end of 1977 the decision was made to suspend most of the benchmark studies pending redesign of the program.

Although the studies conducted under the BLM program will provide a wealth of scientific information on the continental shelf environment, it (as with many other recent large studies) has suffered from unrealistic expectations of the utility of descriptive data, an excessively narrow scope of study emphasis, restrictive methological stipulations and overly rigid contractual procurement.

Relatively little attention has been placed on understanding why various parameters are distributed the way they are, other than to perform correlation with coincidentally measured parameters. While the premise that changes witnessed after oil and gas development which can be attributed to development activities may be reasonable for petroleum hydrocarbons, for example, it is assuredly tenuous for many other parameters, especially biotic ones. For these, change following development can only be interpreted with knowledge of the natural factors and processes responsible for observed spatial and temporal variations. Furthermore, decision-makers need predictive information. Descriptions and correlative understanding of environmental parameters are of little predictive value. To meet these needs, more emphasis is clearly needed on experimental "fate and effects" studies.

Environmental research activities on the continental shelf have experienced a quantum increase in the last few years. As noted, many federal agencies are involved. Unfortunately there is too little formal coordination of federal research activities on the continental shelf at national, or even regional, levels. Since there are substantial overlaps in the information needs of the various agencies, it is obvious that both the agencies and the research community would benefit from the cooperative development of research objectives for continental shelf ecosystems.

THE CONTINENTAL SHELF ENVIRONMENT

The preceding parts of this paper are mainly prologue, for my objective is to contribute to a conceptual framework for impact evaluation on the continental shelf. At this point it is necessary to briefly discuss some important features of continental shelf ecosystems which should influence how we study them. I will approach this by initially making two very simple observations: (1) the continental shelf is different from both coastal and estuarine waters and the open ocean; and (2) the environmental characteristics of continental shelves vary widely.

Most marine biological knowledge is based on coastal and estuarine or open ocean organisms. The green waters of the continental shelf have historically been beyond the reach of brown water (coastal) oceanographers and something to travel through for blue water oceanographers. The continental shelf environment is in some respects inter-

Table 1. Summarization of Bureau of Land Management's Environmental Studies Program (National Research Council, 1977).

RECONNAISSANCE STUDIES

- Identification of unique biological assemblage, resources or physical environments which may be perturbed by OCS petroleum development activities

- Identification and quantification of natural hazards or conditions which jeopardize OCS exploratory or production activities

BENCHMARK STUDIES

Chemical Indices

High Molecular Weight Hydrocarbons in:

Benthic organisms
Sediments
Pelagic organisms
Dissolved in seawater
Particulate matter in seawater
Zooplanton

Low Molecular Weight Hydrocarbons in Water

Trace Metals in:

Benthic organisms
Sediments
Pelagic organisms
Particulate matter in seawater
Zooplankton

Biological Indices

Benthos (taxonomy and biomass)

Macroepifauna
Macroinfauna
Meiofauna
ATP - biomass
Demersal fishes
Microfauna (especially Foraminifera)

Water Column

Zooplankton
Neuston
Ichthyoplankton
Pelagic fishes
Bacteria
Phytoplankton

Histopathology

FATE AND EFFECTS STUDIES

Physical Processes

Lagrangian drift
Transport mechanisms
Physical alteration of petroleum (e.g. evaporation, dissolution, emulsification, photooxidation, etc.)
Surface and subsurface current patterns
Weather and wave observations
Hydrography

Biological Effects

Biological alteration of contaminants
Acute toxicity data
Chronic toxicity data
Sublethal physiologial effects
Potential bacteriological indicators of contamination
Biological accumulation and deposition of contaminants

Geological Processes

Suspended sediment (transmissometry, mineralogy, etc.)
Sediment-organism relationships

Chemical Processes

Biogenic sources vs. petroleum-derived hydrocarbons
Chemical characterization of petroleum
Speciation of trace metals

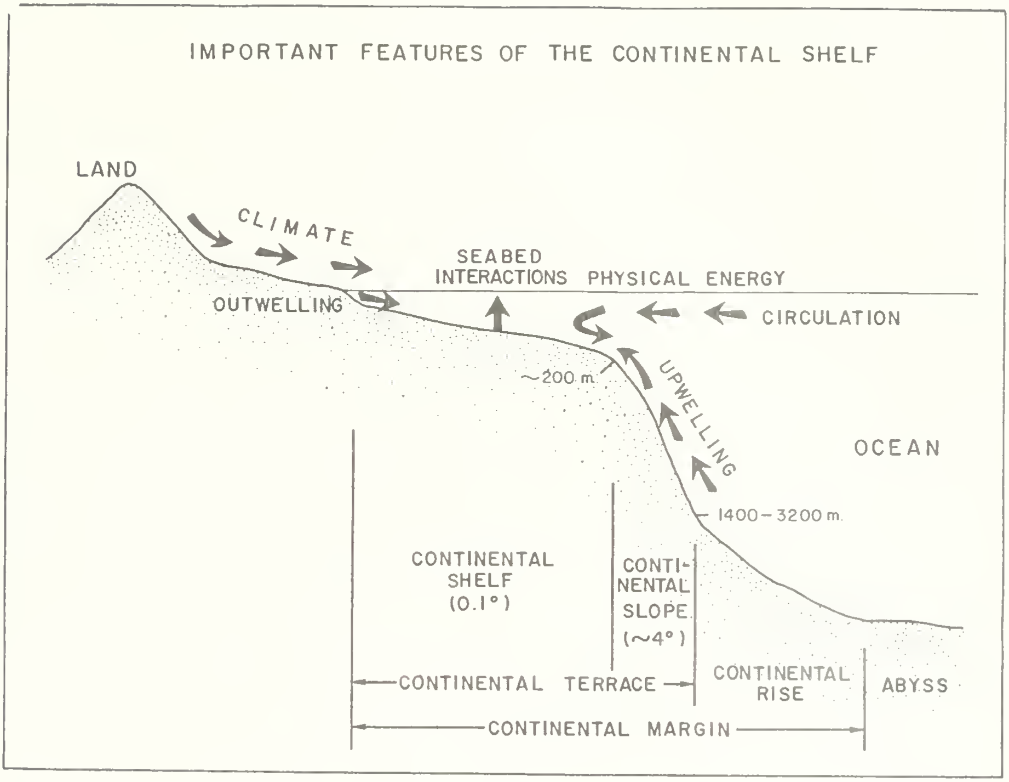

Figure 2. Important features of the continental shelf environment which distinguish it from coastal waters and the open ocean.

mediate between coastal and oceanic environments (Fig. 2). Like the coastal zone, the shelf may be considerably influenced by the climate and the material contributions (outwelling) of the land. On the other hand continental shelves are strongly influenced by oceanic circulation patterns and even by the deep ocean (upwelling or onwelling).

A feature distinguishing the coastal sea from the open ocean is the functional importance of the sea bed on the shelf. On the shelf the seabed supports a much greater portion of total productivity and is more important in the cycling of materials, including nutrients, than the open sea. Furthermore, there is much greater interaction between benthic and pelagic organisms on the shelf, with many benthic species having a pelagic phase of their life cycle and some pelagic species having a benthic phase. The continental shelf environment is further characterized by the dissipation of great amounts of physical energy from geostrophic and tidal currents and, especially, from waves.

These characteristics suggest we should approach the study of continental shelf ecology somewhat like estuarine ecologists, emphasizing interactions of components of the ecosystem (i.e., benthos-nekton-plankton), small scale phenomena and the importance of allochthonus inputs, but without the luxury of working with a discrete and relatively closed system such as an estuary. On the other hand, oceanographic approaches, emphasizing large scale processes and internal regulation have also to be applied.

The diversity of the continental shelves of the United States should be obvious from even the simplified bathymetry indicated in Fig. 1. The shelves are physiographically different, ranging from the narrow, almost nonexistent shelf off California to the very broad shelves of the Atlantic and Gulf coasts which have been produced by the Holocene transgression of the shoreline across a coastal plain. Physiography affects the relative ocean influence, the degree of recycling of materials and the sedimentology of the shelf. Narrow shelves are more greatly influenced by large scale oceanic conditions whereas broad shelves are more internally regulated. Temperature on the Atlantic shelf is greatly influenced by the continental climate while temperature on the Pacific Coast is governed by ocean water mass conditions. Outwelling from land is a major influence on some shelves and is insignificant on others. For example, the Mississippi River is a dominating influence on parts of the Louisiana shelf but the riverine inputs in the Middle Atlantic Coast are mostly trapped in large coastal plain estuaries.

The design of ecological studies and impact evaluations should take into account the important features of the particular environment under study. Standardized study designs and methods should be sufficiently flexible to allow such accommodation.

AN INTEGRATED APPROACH TO BIOLOGICAL IMPACT EVALUATION

As discussed earlier, previous attempts at biological impact evaluation on the continental shelf have suffered several shortcomings. The first two listed -- the inherent difficulty of studying large, open systems and the adequacy of support -- are to a large degree beyond the control of scientists. The last three -- unknown causes of natural variation, inefficient use of baselines and controls, and inability to cast impacts in a frame of reference of resources or ecosystem function -- are potentially solvable with appropriate scientific design. Overcoming these three stumbling blocks should be a paramount consideration in the design of baseline, monitoring and experimental effects studies.

I would like to propose here an integrated approach to biological impact evaluation which starts with baseline studies and incorporates predictive studies with appropriate monitoring. It emphasizes the necessity to dynamically describe and understand the causes of community structure and assess the role or importance of biotic components to ecosystem function and resources. The proposed scheme is iterative, under which impact evaluation programs would dynamically evolve as directed by feedback, rather than be planned in detail from the start. I will not attempt to prescribe subject-specific guidelines for the design and conduct of environmental assessments on the continental shelf. There have been many other attempts to produce such a compendium, notably an unpublished report by the NOAA Scientific and Technical Committee on Marine Environmental Assessment, and the reports of regional workshops convened for this purpose by BLM. Rather, I will focus attention on how the various phases of impact evaluation -- initial impact assessment, baseline studies, prediction studies, monitoring studies and final impact evaluation -- should interact as suggested in Figure 3.

Preliminary impact assessment, of the before-the-fact type characteristic of Environmental Impact Statements begin with estimations of the nature and fate of associated pollutants or habitat modifications and then address the effects of the planned activity on the environment. This requires identification of biotic components which are most susceptible and some preliminary definition of the nature of susceptibility. Potential effects are then hypothetically cast in the large context of impacts on resources or ecosystem properties. These are the conclusions (i.e., regarding biotic susceptibility and its implications) which one seeks to refine by conducting environmental impact evaluations, for it is hoped that these conclusions will affect decisions concerning the conduct of human activities in the environment.

Preliminary impact assessments should of course affect the design of baseline, predictive and monitoring studies. The results of these studies in turn serve to refine the impact assessments. This feedback process should be regularly iterative throughout the course of the studies. That is to say, products of the studies should be continuously used to redefine susceptibility and the redefinition should effect a redirection of studies. While the wisdom of such an approach seems obvious, in practice such regular feedback is often difficult because specifically written contracts or work statements bind the researcher to a set course.

"BASELINE STUDIES"

I will here use the term "baseline studies" broadly to include all those environmental studies which serve to describe, quantify or promote understanding of an ecosystem or its components as it exists before the planned activity. The first phase of baseline studies should involve both broad reconnaissance of the environment in question and collection of data which, with existing knowledge, can serve to provide a basic description of the environment. Such studies would include measurements and descriptions of a wide array of biotic and abiotic components. Broad brush, short-term descriptive studies are an especially valuable first step for the study of poorly known

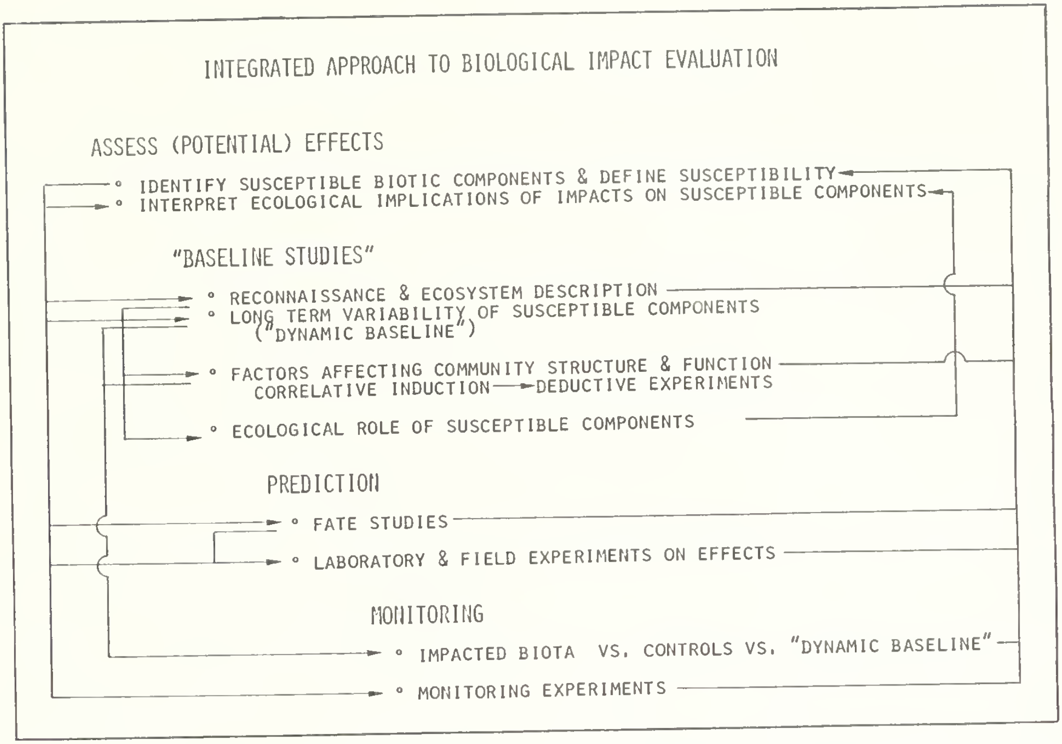

Figure 3. Schematic depiction of interactions suggested in an integrated biological impact evaluation program.

ecosystems such as most continental shelves. The results of preliminary reconnaissance should quickly be applied to redefining susceptibility, pointing out which biotic and abiotic components should be more intensively studied over longer periods.

Study of the long-term variability and dynamics of susceptible components should then begin. Design of these studies should be influenced by reconnaissance and descriptive studies, since it is presumptuous to assume that an efficacious sampling strategy can be blindly designed without a reasonably accurate environmental description. Long-term, intensive studies should be rigorously quantitative and the limits of variation should be described, resulting in a "dynamic baseline" against which changes during or after the impacting activity can be measured. However, the dilemma of the baseline is that no matter how confidently one can demonstrate change in populations, it is impossible, strictly by comparing before and after statistics, to prove cause. Furthermore, organisms being what they are, it would often not be surprising to find the population level of a given species to fall outside the limits witnessed over a long baseline sampling period. This points to the necessity of including in baseline studies, research on factors affecting populations and community structure and function in addition to direct statistical descriptions of biological parameters. To be in a position to unequivocally demonstrate impacts one needs to know the causes as well as the extent of natural variation.

Ecological factors can be partially understood through induction from convincing sets of correlations between environmental variables. To demonstrate causality one needs to experimentally test the hypotheses deduced on the basis of correlations or observations. Manipulative field experiments which are playing a central role in the development of ecology, may be especially useful in this regard. Investigators applying field experiments require substantial latitude in their approach, especially in such a difficult environment as the continental shelf. Experimental failure rates are high, but the payoff of successful experiments in terms of new information and robust understanding is great.

Some effort in baseline studies should also be devoted to determining the ecological role of susceptible biotic components. Earlier, examples were given in which impact to portions of the biota could be demonstrated, but the significance of these impacts to ecosystem health or resource values could not be shown (e.g., in the New York and Southern California Bights), so the effects were termed "insignificant." Considerable effort (and money) is spent in quantifying basic data and statistically testing the significance of effects on the biota, whereas the process of interpreting the meaning of observed effects is most often frightfully non-quantitative and subjective.

PREDICTION STUDIES

The evolving definition of susceptibility as redefined by the early results of baseline studies will act to focus attention on relevant studies concerning the fate and effects of pollutants of habitat modifications. Actually, some "fate" studies, (e.g., general circulation studies), should start in the beginning of the baseline studies program. They may then serve to quickly redefine susceptibility and thus influence the direction of other baseline studies.

Surveys of pollutant such as trace metals and petroleum hydrocarbons in the environment are heavily emphasized in most baseline and monitoring studies. The problems of interpretation of the biological implications of contaminant levels (aside from the omnipresent analytical problems) are in understanding the fate of the materials (e.g., bioavailability and biodegradation) and their effects. There often results an imbalance between contamination surveys and biological interpretation.

More experimental work is clearly needed to assess the effects of pollutants on continental shelf species. However, these studies need to be closely integrated with ecological studies in the field, preferably through the iterative process of redefinition of susceptibility discussed above. Effects studies, if they are to be applicable, must be relevant to the continental shelf environment, using indigenous biota under near-realistic environmental conditions. In this regard, field experiments may be most appropriate, especially for some biotic components, e.g., the benthos. Furthermore, studies on sublethal effects should be directed at physiological or behavioral processes which affect the survival and maintenance of populations. Finally, the predictive limitations of experimental bioassays must be recognized. Used intelligently they can serve to delimit the relative effects of various pollutants, provide an understanding of effects witnessed in the field and indicate that effects are likely if a certain concentration of a contaminant occurs in nature. The experimental null hypothesis that effects do not occur below given toxic levels cannot be extrapolated to the field because it is specific to the individuals on which the test was performed and the test conditions.

MONITORING

Dynamic baseline data are useful in monitoring, both because they serve to redefine susceptibility and thus influence monitoring strategies and because they can be directly compared with monitoring data. The success of monitoring, however, depends on the choice of suitable controls. Finding good control habitats is difficult, partially because no two places are exactly alike and partially because it is frequently difficult to determine if the habitat selected for a control is beyond the effect of the impacting activity. Baseline characterizations can serve the useful purpose of delimiting potential control habitats. Fate and effects studies should help define the extent of potential impact. As in the case of baseline sampling, parallel experimental studies are helpful in interpreting the results of sampling and observations involved in monitoring.

The self-modifying integrated approach outlined here ideally will produce (1) an understanding gained in dynamic baseline studies of the causes of natural population variability, rather than only statistics describing this variability; and (2) an understanding of the effects of pollutants or habitat alterations based on ecologically pertinent experiments. Armed with such an understanding, investigators are more likely to detect impacts and evaluate their importance to the ecosystem and to resources exploitable by man, than with the mainly descriptive and poorly integrated approaches currently employed.

RESEARCH MANAGEMENT

A truly integrated approach to impact evaluation may be incompatible with current research management procedures. Federal sponsors of applied research have moved to the RFP and specifically-worded contract methods of research procurement. This has been due to the necessity of assuring performance standards, increased competition for research dollars and federal procurement policies. On the other hand, the traditional approach of research grants without obliged performance is clearly too loose to assure timely attainment of impact evaluation goals. Some middle ground is needed, so that progress is obliged but there is flexibility to modify research methods and strategies in response to changing perceptions of susceptibility.

Similarly, although the desire to insure minimum performance standards by specifically outlining research stategies and methods is understandable, such specificity can stifle rather than enhance ecological understanding. As Hedgpeth (1973) (irreverently) puts it: "the danger of legislating a current fashion in ecology, or one dimly remembered by an administrator who perhaps did not do so well in the course, is obvious to anyone, or should be." What will be required is a balance of responsibility for the design and conduct of research between the researcher and the research manager.

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EVALUATING THE SIGNIFICANCE OF DEGRADATION IN A LARGE ECOSYSTEM

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INTRODUCTION

Few scientific investigators would deny that New York harbors and inner New York Bight have been seriously degraded by man's contamination over the past few hundred years. New York City's Common Council found it necessary in 1683 to pass an ordinance against fouling its harbors with "any dung, draught, dyrte or any other thing to fill up or annoy ...the neighborhood near the same,..." (New York City, Common Council, 1905). Before 1900 the City of New York dumped street sweepings, garbage, and refuse in New York Harbor south of Coney Island. Floatable wastes were frequently carried by surface currents onto Long Island and New Jersey beaches, prompting relocation of the disposal site into the New York Bight. Even in the Bight, complex dumping schemes failed to minimize the volumes of floatables reaching beaches. So, in 1931 the Supreme Court forbade further discharge at sea of New York's floatable wastes (Gross 1976a).

Several papers published late in the nineteenth century and early in this century described petrochemical impacts on benthos and demersal fishes as well as man's contamination of oysters during the 19th century.

Since these early acknowledgements of environmental problems matters have, of course, become much worse. Several sources of extremely large pollution loads have been shunted into the inner Bight over decades (Gross 1976b). The consequent degradation of the marine ecosystem is not new. However, in early 1970 unusually widespread public concern arose over dumping sewage sludge from the New York area into the Bight. My discussion concentrates upon three series of events since 1970: a scientific chronology, public understanding of the issue, and some consequences. Despite emphasis upon sewage sludge dumping, the significance of its impacts must be viewed in context of all wastes affecting New York Bight, and in the even larger context of pollution in the region as perceived by scientists, decision-makers and the public.

CHRONOLOGY OF THE SEWAGE SLUDGE DUMPING ISSUE

SCIENTIFIC FINDINGS TO 1973

In 1968 a committee of scientists suggested a two-year study of ocean waste-disposal practices in the New York Bight. The suggested definition of the study included: biological communities, physical/chemical properties of sediments, the water column and suspended particulates, and the sources, dispersal, and deposition of waste materials (Gross and Wallen 1968). In response to these recommendations, the Sandy Hook Laboratory (now of the Northeast Fisheries Center, NOAA) carried out a study sponsored by the U.S. Army Corps of Engineers, Coastal Engineering Research Center (CERC). This study's final report, published in 1972, covered benthos, zooplankton, finfish, chemicals, and surface and bottom water movement (MACFC 1972a, b).

Less embracing studies also funded by CERC included: (1) Marine Sciences Research Center, State University of New York at Stony Brook -- characterization of solid wastes and waste deposits in the Bight, (2) Sperry Rand Corp. -- a scheme to monitor ocean waste dumping activities, and (3) Woods Hole Oceanographic Institution -- a bibliographic study on the effects of ocean disposal of sewage sludge and dredge spoil.

A U.S. Food and Drug Administration (FDA) study detected high concentrations of coliform bacteria in waters near the sewage sludge dump site (see Figure 1).

The techniques and findings of the nine-volume Sandy Hook study and of the other less extensive CERC-funded studies, were reviewed by the Smithsonian Advisory Committee (Buzas, Carpenter, Ketchum, et al., 1972 and by Pararas-Carayannis (1973).

The results of pre-1973 research were not interpreted similarly by the scientists involved. The Sandy Hook reports were the most pessimistic:

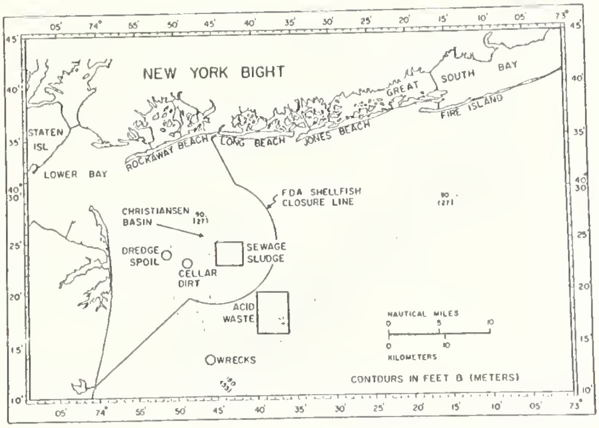

Figure 1. The inner New York Bight with existing dumpsites shown.

Disposal of dredging spoils and sewage sludges has had a significant, and often deleterious effect on the living resources of the New York Bight (MACFC, 1972a, p. 57).

More important than the actual presence of [high concentrations of heavy metals in sediments] is their spread outward from the designated points of disposal. Heavy metals were found at stations north of both dumping sites [(sewage sludge and dredge spoil) and in] concentrations apparently higher than normal...25 nautical miles south of the [sewage sludge] site (MACFC, 1972a, p. 57).

...coliform bacteria were also present in high concentrations throughout the areas receiving dredging spoils and sewage sludges...their pattern of distribution generally follows that found for heavy metals and organic materials (MACFC, 1972a, p.57).

...sludges and spoils cover an area over 20 square miles. The presence of these wastes and their toxic components have significantly reduced the standing crops, or biomass, and diversity of marine benthic communities (MACFC, 1972b, p.2-54).

The impoverished populations of benthic invertebrates and reduced species diversity is probably the result of toxic materials associated with sludges and spoils and severe reductions in amounts of dissolved oxygen available to bottom dwelling organisms (MACFC, 1972b, pp. 2-57 to 2- 58).

[If the presence of the coliforms is indicative also of the pathogens apparently involved in fin rot disease,] then it is likely that causative agents of [fin rot] are being spread into uncontaminated and ecologically important areas (MACFC, 1972b, p. 2-55).

Other scientists felt that, given existing data, the environmental impacts of ocean dumping may have been considerable, but this was not adequately demonstrated in existing reports (Buzas, et al. 1972). These same scientists wrote that neither the areal extent nor magnitude of ecosystem dumping impacts were adequately quantified. They also thought existing studies discovered only the possibility that sewage sludge and dredge spoils caused the observed pathologies of fish and shellfish, although emphasizing that the significance of this finding required further study (Buzas, et al. 1972). Pararas-Carayannis found no evidence for significant long-term biological effects from ocean dumping and wrote that comprehensive, long-term, interdisciplinary studies would be necessary to determine the extent of ecosystem changes due to dumping. "The possibility of pathogenic and chemical damage to finfish and shellfish from the disposal of waste materials, is a point which has not been answered" (Pararas-Carayannis 1973, p. 149). Gross (1970, p. 20) found that "predictions of deleterious effects [of dumped sewage sludge] cannot be made reliably without more detailed information."

No formal studies had been conducted, to my knowledge, on the rest of the sewage sludge problem; on the engineering, sociological, and economic aspects of alternatives to sludge dumping.

In summary, there was no scientific disagreement that considerable environmental degradation existed in the Bight; but to many scientists the causes of almost all specific instances of degradation remained unclear, and the alternatives to existing waste management practices were equally unclear.

PUBLIC INTERPRETATIONS TO 1973

Typically, the full range of scientific findings, reservations about some answers, and acknowledgements of ignorance about some questions did not reach the public. The public read secondarily that sewage sludge and dredge spoils had created a "dead sea" in the Bight, that its 20 square miles were "growing rapidly" and could necessitate closing New York City area beaches in the coming (1970) summer (Madden 1970, pp. 1, 42). These contentions were seriously misleading, given the information available in 1970 and today. However, public accounts of these studies did detail clear indications of environmental degradation -- low dissolved oxygen concentrations, depauperate benthic fauna, diseased fish and shellfish, exceptionally high metals concentrations in sediments, and unusually high coliform bacterial counts in Bight waters and sediments.

CONSEQUENCES TO 1973

As a direct consequence of FDA findings of high coliform concentrations, a circle of 6 nautical mile (11 km) radius around the sewage sludge dump site was closed to shellfishing in May 1970 (see Figure 1). This was apparently the first instance of shellfish closure on any open U.S. continental shelf.

Another major consequence was initiation of a NOAA program to intensively study the broad range of man's impacts on the ocean off New York and New Jersey. I am not able to construct just what motivated NOAA's developing study, of course, but disturbing scientific findings, congressional concerns, and public vexation were probably the main forces. By 1973 NOAA had defined the Marine Ecosystems Analysis (MESA) Program; its first project was to study and provide guidance for environmental management of New York Bight Project. By August 1973 the MESA New York Bight Project had begun field operation.

From the outset the MESA New York Bight Project had a balanced framework of goals: (1) to assess the fate and effects of contaminants on New York Bight and its resources; and (2) to determine the fundamental structure and function of the Bight ecosystem. A third goal related to engineering has since been deemphasized. Thus, ocean dumping of sewage sludge was to be studied as part of a broad examination of both natural and man-induced features of the Bight.

SCIENTIFIC FINDINGS 1973 TO 1976

The tempo of research in the Bight increased substantially with the initiation of MESA-sponsored work in 1973. MESA began supporting research of NOAA scientists and outside contractors/grantees from universities, corporations, and other governmental agencies. The U.S. Environmental Protection Agency (EPA), FDA, universities, and state and local agencies also had studies under way in the Bight.

Because of widespread concern about sewage sludge dumping, EPA's Region II formally asked NOAA for information and guidance about the advisability of relocating the sludge dumping site, and possible alternative dumping locations. MESA scientists, consulting with others both in and outside government, began a continuing accelerated analysis and review of available data relevant to sewage sludge dumping and its impacts.1/ Even at this stage (in early 1974) available knowledge of the Bight ecosystem was rather extensive, but several vitally important facts were unknown about how best to manage sewage sludge.

Details were known of the bathymetry and surficial sediment distribution within the inner Bight. Offshore surficial sediments were not mapped precisely, although broad features were known. For example, patches of fine organic sediments are common in the nearshore zone off many coasts; these "mud patches" are often eroded or covered by adjacent sediments due to the strong wave action of storms. Such a patchy pattern of organic mud patches was found off the Rockaway and Long Beaches (see Figure 1) by an early MESA cruise and by other cruises. Extensive surficial sediment sampling for physical and chemical attributes permitted a reasonably accurate definition of the gradient from heavily contaminated sediments near the dump site toward Long Island. The recent observations did not differ perceptibly from the data of Gross, Black, Kalin, _et al_. (1971) and MACFC (1972b), particularly since these earlier studies did not quantify precisely the areal extent of contaminated bottom deposits (Buzas, _et al_. 1972).

The average patterns of water movement and the significance of local, short-term current viability were known, albeit not precisely. The seaward discharge of the Hudson/Raritan estuary and much stronger ebb flood tidal currents dominate the vicinity of the entrance to Lower Bay (Figure 1). Outside this estuarine influence, evidence pointed to a clockwise gyral circulation during at least part of the year. Previous bottom drifter studies (MACFC, 1972a and b; Bumpus 1965) and the initial results of a MESA drifter study showed a bottom flow from the

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1/ I mention below the consequences of public concern over sewage sludge dumping, but I should emphasize here the serious and widespread concerns that sewage sludge was moving rapidly from the dump site to Long Island bathing beaches. From December 1973 to fall of 1974 they were insistent enough to significantly influence the kinds of research emphasized by MESA and others.

inner Bight toward Lower Bay and Long Island's south shore. Preliminary current meter measurements in the inner Bight also indicated more than enough high-frequency energy in bottom currents to suspend and transport bottom materials and mix them into the water column. Thus, while there was no direct evidence that sewage sludge was being carried to the Long Island beaches, it did seem likely that the light fractions of sewage sludge would become entrained in the inner gyral circulation, be carried clockwise toward Long Island, then east and south again, with unknown amounts settling out into topographic lows such as the Christiansen Basin because of reduced wave and current action there. Indeed, solid evidence even early in 1974 showed that Long Island and New Jersey nearshore sediments contained material derived from sewer outfalls or sewage sludge.

EPA (1974) and other agencies measured concentrations of fecal and total coliform bacteria frequently and intensively in the surf zone and nearshore areas off Long Island's southwest beaches and consistently found the waters safe for contact reaction by state and local standards.

Perhaps the missing information most needed was a reliable measure of sewage sludge content in sediments and the water column. Without such a measure it was impossible to say just where sewage sludge went after dumping. Qualitatively at least, large quantities of most constituents of sewage sludge were known to enter the Bight from various sources: sewage plant effluents, urban runoff, dredge spoil dumping, industrial wastes, atmospheric fallout, and adjoining bay waters. Several contamination measures were assessed. Unusually high sediment concentrations of total organic carbon, coliform bacteria, and metals such as lead, zinc, and chromium were all clear indications of contamination, but the sources could only be inferred, not determined simply from physical/chemical analyses. Although the highly contaminated sediments of the Christiansen Basin (see Figure 1) were presumed to be principally sewage sludge, because of their proximity to the sewage sludge dump site, there was no evidence for or against substantial proportions of these contaminants having settled out from Hudson/Raritan estuarine outflow or being carried laterally from dredge spoil dumps. Attempts were made to distinguish sewage sludge by ratios of heavy metal concentrations, particularly Cr/Zn (Harris 1974), but the technique was not very useful. The ratio in sediments of carbohydrate concentration to total organic carbon was also evaluated; higher ratios apparently indicated the presence of sewage-derived material. Though this is a useful indicator, it cannot be used to distinguish sewage sludge from dredged material containing sewage wastes or wastes from the outfall pipes of sewage treatment plants. The ratios of carbohydrate to total organic carbon were much higher throughout the inner Bight than is typical of coastal sediments, indicating probable contamination by sewage-derived material. Microscopic analyses of inner Bight sediments also seemed useful in distinguishing sewage-derived material, although not necessarily sewage sludge per se. These analyses detected geographically variable concentrations of processed cellulose fibers (mainly toilet paper) and soot-like particles. The highest concentrations of artificial particles were near the sewage sludge dump site, but small fractions (1-3.3% of all sediment grains counted) occurred in the Long Island and New Jersey nearshore sediments.

During this intensely controversial time most of the newly analyzed scientific information was provided directly to the press, concerned citizens, and governmental agencies, with very little opportunity for prior review by other scientists. Only late in 1974 and 1975 did the reviewed results of these and later findings begin to appear in technical literature. By the time an environmental impact statement on the ocean dumping of sewage sludge was being drafted (February 1976) substantially more insight was available in publications having the benefit of technical review (e.g., see Swanson 1976; O'Connor 1976).

An important consideration in the sewage sludge dumping issue is the anticipated increase in the quantity of sewage sludge from the New York area. Since 1968 the volumes of sewage sludge dumped annually have ranged from 2.9 to 4.3 million m^3. By 1981 an estimated 10.2 million m^3 of sludge, more than a threefold increase, is anticipated because several new and upgraded treatment plants will be generating additional sludge (U.S. EPA 1976). Indeed, even more stringent, future waste treatment requirements may result in much more sludge, which may contain proportionately more of the total contaminant load.

In March 1974 the MESA Project proposed two alternative areas on the continental shelf as potential sewage sludge dump sites in the event existing sludge dumping practices should cause public health hazards. MESA did not propose that either of these sites be used;

only that they be identified and studied in case an emergency dictated their use to avoid public health problems (MESA 1975). The outer limit of both sites is 65 nautical miles (120 km) from Lower Bay (Figure 2).

simple, two-dimensional diffusion model was used to predict the fate of sewage sludge dumped at each of the alternative sites. The model estimated that only a small fraction of dumped sludge would reach the seafloor

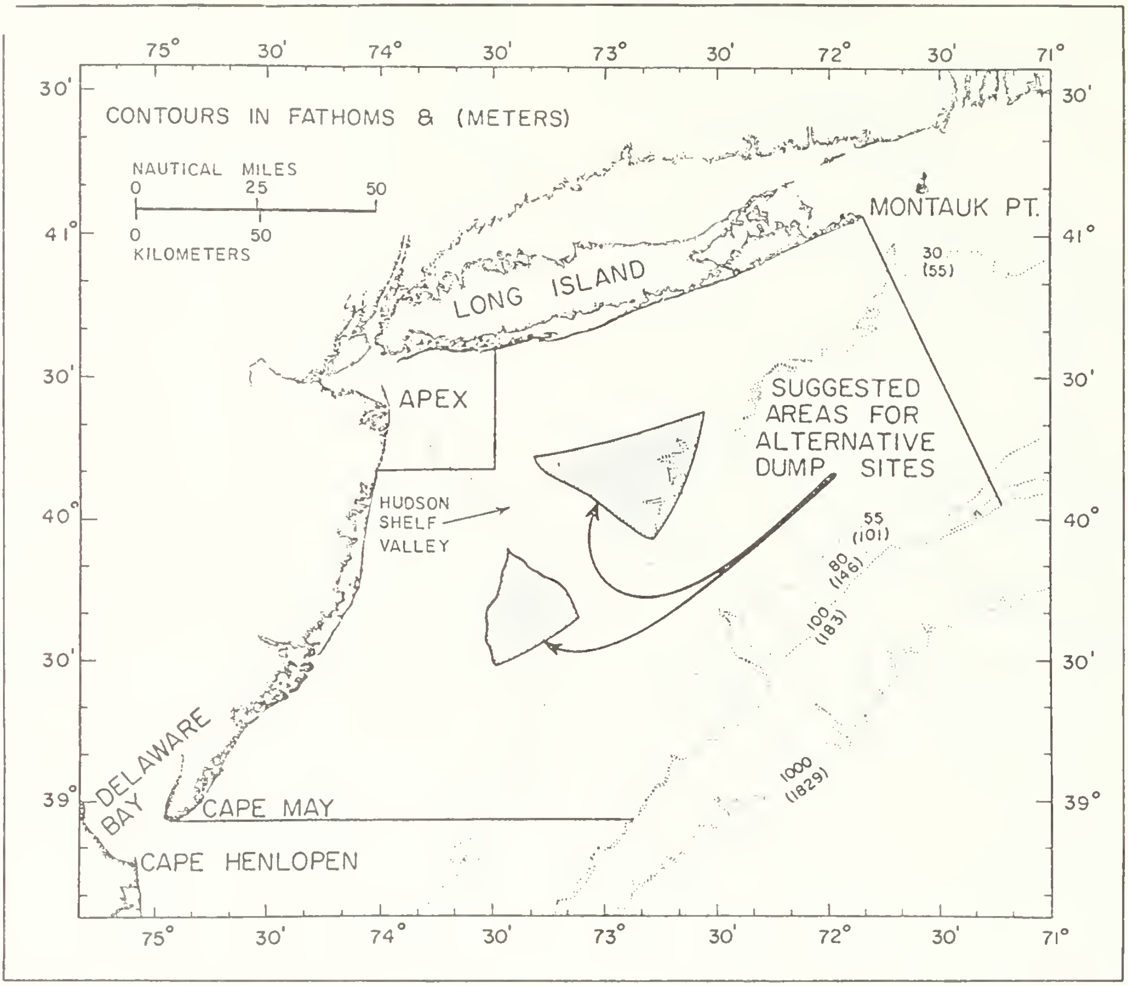

Figure 2. The New York Bight. The Apex is a defined MESA study area of the inner Bight. Portions of the shaded areas were considered as potential alternative sewage sludge dumpsites.

Detailed knowledge of bathymetry, stratigraphy, bedforms, and surficial sediment characteristics of the inner Bight and offshore of the potential alternative sewage sludge dump sites is documented by MESA (1975, 1976). Surficial sediment analyses and bottom current measurements showed clearly that bottom agitation by wave-surge action at both alternative sites is sufficient to keep existing concentrations of fine sediment suspended in the water column until the material is transported out of the area (MESA 1975). A

around the dump sites (U.S. EPA 1976). Most sludge material dumped at either offshore site would probably be carried with prevailing currents: southwesterly toward the Hudson Shelf Valley from the northern site and roughly parallel to the southern New Jersey shoreline from the southern site (see Figure 2).

Several measures of sediment contamination were precisely contoured in the inner Bight (MESA 1975) and comparable measurements were made at the alternative sites (MESA 1976). Several heavy metals, several nutrients, bacteria of terrestrial origin, and organic carbon were also measured in the water column. As expected, strong gradients exist in the concentrations of water column and sediment contaminants from the inner Bight to the open ocean (MESA 1976). Data from current meters in the Hudson Shelf Valley, and several water mass characteristics of the valley all lead to the conclusion that, on the average, waters move inshore up the shelf valley (MESA 1976).

The major procedural difficulty of distinguishing dumped sewage sludge from other wastes, particularly from other sewage wastes, remains unsolved even now in my view. Attempts to characterize some mud patches off Long Island as contaminated by dumped sewage sludge and others as contaminated by bay sediments on the basis of Cr/Zn concentration ratios (Harris 1976) remain unconvincing to me. It does appear possible to detect sewage-derived material in sediments or suspended particulates from microscopic analyses and from high concentrations of carbohydrates relative to total organic carbon (TOC). Sewage sludge contains a substantial amount of carbohydrate (Walker 1961), mostly as cellulose and hemicellulose (Hunter and Huekelekian 1965), both of which are resistant to biological degradation in seawater. The carbohydrate-to-TOC ratio of normal coastal sediment is about 0.1:1, and that of sewage sludge is about 0.3:1 (MESA 1975). As the more labile fractions of sewage sludge are degraded by bacteria, the original ratio (0.3:1) would be expected to increase. Measurements of this ratio yield values over 0.6:1 near the sewage sludge dump site (see Figure 1) and values greater than 0.4:1 over most of the inner Bight and 40 nmi seaward in the Hudson Shelf Valley (MESA 1975). Thus, these areas are extensively enriched with carbohydrates, apparently of sewage origin. Microscopic analyses of inner Bight sediments also indicated widespread dispersal of cellulose fibers and other artificial particles, most presumed to be of sewage origin (MESA 1975). These artificial grains composed about 11-16% of all sediment grains near the sewage sludge dump site and 1-3% in Long Island and New Jersey nearshore sediments (MESA 1975).

The dissolved oxygen concentrations in stratified bottom waters of the inner Bight are exceptionally low for oceanic coastal areas. Summer saturation values have been below 30% in the Christiansen Basin, and values below 50% have been persistent over many square miles prior to 1976. The major sources of oxygen demand are probably

1. the input from Lower Bay and from dumping of 2000 to 2500 metric tons of organic carbon per day (including dissolved organic matter and large volumes of plankton cells);

2. phytoplankton production stimulated by shelf onwelling of nutrient-rich oceanic waters as postulated by Riley (1967); and

3. phytoplankton production in the Inner Bight stimulated by nutrients from the Hudson/Raritan estuary.

As these carbon loadings settle into the bottom waters they contribute to observed bottom oxygen depletion. Additional sources of oxygen depletion from resuspended sediments and from direct oxidation of bottom sediments are significant, but apparently less important (MESA 1976).

The quantities of nutrients and organic carbon introduced by sewage sludge dumping are relatively minor. Only about 10% of the organic carbon, less than 10% of the nitrogen and phosphorus, and less than 6% of the heavy metal inputs to the Bight region are from sewage sludge (Mueller et al. 1976).

Several significant biological impacts have been found in the inner Bight (O'Connor 1976). Gill blackening and exoskeletal erosion in crustacea has been observed for some time (MACFC 1972b; Pearce and Young 1975), as has fin rot disease in fishes (Ziskowski and Murchelano 1974). Extensive changes have been documented in the structure of benthic communities in Lower Bay and near the major dump sites in the inner Bight (MACFC 1972b; Pearce and Radosh 1976). However, even after intensive sampling there is no evidence that any substantial area has no benthic macrofauna. Some bacteria of human origin resist unusually high concentrations of several heavy metals and antibiotics and exhibit the transfer resistance phenomenon indicating that this broad spectrum resistance is at least potentially transferrable as plasmids or R+ factors to several genera of the Eubacteriales (Koditschek and Guyre 1974).

During 1974 and 1975 the U.S. EPA sponsored an engineering-oriented study of sewage sludge management techniques. Phase I of this study concluded that dewatering by filter presses followed by pyrolysis would be the most feasible alternative to sewage sludge dumping, but that such a system might require ten years for full implementation (U.S. EPA 1976). Subsequent analysis revealed that ocean dumping remains the least expensive method of sewage sludge disposal, and that the most feasible alternatives for the region are composting and pyrolysis followed by landfill disposal of residues (Interstate Sanitation Commission 1976). Even today there has been minimal study and evaluation of land-based alternatives, and no broader analysis is known to the author of New York area waste management as a system. Further, I am not aware of any assessments of the most significant socioeconomic aspects of the broad problem.

PUBLIC INTERPRETATIONS 1973 TO 1976

Public concern over the sewage sludge dumping issue was minimal until preliminary unpublished observations from limited sampling were released to the press in December 1973 and early 1974. The press accounts included references to:

1. a "dead sea" from sewage sludge dumping (Shanov 1973);
2. migration of the sludge bed to within one-half mile of Long Island bathing beaches (Bird 1973);
3. predictions that the sludge would soon wash up on beaches (Bird 1973; Pearson 1974a; Carroll 1974); and
4. warnings about potentially serious public health hazards from heavy metals, bacteria, and viruses (Kline 1974; Carroll 1974; Pearson 1974b).

The public also read that the existing sewage sludge site could be used for only one more year because the "dead sea" created by sludge was moving toward Long Island beaches. This ominous-sounding deadline for offshore displacement of the sludge site gained credibility because it was attributed to "an authoritative EPA source" (Pearson 1974c), that is, to a responsible regulatory agency. These accounts are a small part of the more than 100 newspapers accounts I have read. Some accounts were carried in West Coast newspapers, some appeared on radio and television, and in national magazines (Kidder 1975; Souci 1974). Even EPA issued a report indicating "We clearly recognize that the practice [of oceanic sewage sludge dumping] over the past 45 years has created a 'dead sea' in the general area of this site" (U.S. EPA 1974b, p. 27).

Several public hearings were held during 1974 and 1975 to inform the public, governmental agencies, and state and Federal legislators. Hearings were organized by EPA and Federal and state legislators from the New York City area. Extensive hearings were also held in August 1974 by the U.S. Senate Subcommittee on Environmental Pollution and the Committee on Public Works. These hearings did gain the written testimony of most scientists, engineers, and administrators concerned with the sludge dumping issue. Although the written records of these hearings were not widely distributed, they did include balanced sources of information for the press and others.

CONSEQUENCES 1973 TO 1976

Both the scientific findings of 1973/74 and the major public issue surrounding sewage sludge dumping greatly stimulated governmental efforts to study the environmental effects of sludge dumping. Also, regulatory agencies were strongly urged by the press and public officials to find alternatives to existing dumping practices.

In 1974 EPA, Region II notified the municipalities responsible for dumping sewage sludge that they would be expected to use an alternative offshore sludge dumping site within two years.

As indicated above, the MESA Project defined two potential alternative sites for EPA (Figure 2) and began studies of the probable impacts of sewage sludge dumping in these areas. EPA also funded additional contractual studies of these areas in anticipation of an environmental statement on sewage sludge dumping. Another EPA study assessed environmentally acceptable land-based alternatives. EPA, Region II also announced its intention to require an end to ocean dumping of harmful sewage sludge in the Bight by 1981.

As another consequence of the 1974/75 issue the MESA Project spent a much greater proportion of effort than NOAA had expected (75%) in sewage sludge related studies. This effort is reflected in a 1975 MESA report emphasizing sewage sludge, a major report to EPA (MESA 1976) for use in preparation of the EPA impact statement on sewage sludge disposal (U.S. EPA 1976), and several technical reports and papers on specific aspects of the problem.

The culmination of this issue to 1976 was EPA's release of a draft environmental impact statement with four main recommendations:

1. development of land-based alternatives to sewage sludge dumping, to be implemented as soon as possible;

2. continued use of the existing sludge dump site for the present;

3. development of a monitoring program to determine when and if the environmental effects of sewage sludge dumping warrant the phasing out or abandonment of the existing dump site; and

4. designate the northern alternative dump site identified by MESA for potential use if and when the existing dump site must be abandoned or phased out.

The criteria for determining the necessity of moving the dumping operations are "the protection of public health and welfare and ...the prevention of coastal water quality degradation" (U.S. EPA 1976, p. 277).

These recommendations were essentially those made by MESA, except that MESA recommended the southern alternative site rather than the northern one (MESA 1976). The choice of different sites resulted largely from two considerations:

1. MESA weighted the impact on unexploited shellfish resources more heavily, and on mineral resources less heavily then EPA; and

2. MESA considered more serious than EPA the danger that contaminants from the northern site would be transported to the Hudson Shelf Valley and up the valley to the inner Bight.

Both NOAA and EPA agreed that the existing site should be used until sewage sludge dumping could be phased out or new evidence indicated the likelihood of public health hazards or other ecosystem degradation. Major considerations are the realization that dumping sewage sludge at either alternative site would have some impact upon what are now relatively pristine areas and would probably alleviate the degradation of the inner Bight very little because the pathogen and contaminant contributions of sewage sludge are so small compared to other sources (Mueller et al. 1976).

CONCLUSIONS AND SUGGESTIONS

Extensive oceanographic research efforts clearly demonstrate that the inner New York Bight is one of the most, if not the most, degraded coastal ecosystems of the United States, but that sewage sludge dumping is a relatively small contributor of contaminants to the Bight. Less clear is the significance of sludge dumping impacts relative to other waste sources, but the impacts do not seem to justify moving the existing dump site to another ocean location. No serious assessment of the benefits and impacts of land-based alternatives has been carried out. Despite these rather reliable generalizations, known as early as 1976 and rather widely postulated within the scientific community by 1974, some consequences of this issue did not fully benefit from what was known. Nor were serious efforts made to gain information obviously lacking from a broad understanding of sewage sludge disposal (particularly on the costs, time lags, benefits and impacts entailed in land-based sewage sludge disposal alternatives). These land-based costs and benefits are still not well known insofar as I am aware.

The aim of rational planning to manage these impacting operations on behalf of the public implies that the decision-makers, and the public for whom they decide, are as well informed as possible on the extremely broad range of factors involved. The importance of public awareness and participation are explicitly embodied within NEPA.

Clearly the public was informed accurately enough about this issue to urge a rational decision upon its decision-makers. The public was informed almost entirely by the press. Neither do I find any evidence that the decision-makers or we, the scientists, contributed very much to improving public understanding of sludge dumping impacts and the likely impacts of realistic alternatives. The factual content of hearing testimony was not synthesized for the public by government or the press.

In this case study it seems that a combination of the public and some public officials (1) insisted, with effect, that a broadly based research effort be focused narrowly on a presumed crisis and (2) demanded, without effect, a precipitate and unsupportable decision to "immediately" move sewage sludge dumping operations much further to sea. Pressure for these changes came from those lacking adequate information about the issue; information existed within a small group of scientists and those with whom they communicated directly. The issue became so notable and influential largely through inadequate information transfer to the public and decision-makers. It illustrates well how incomplete and inaccurate information can distort rational planning. This may be another instance where a precipitate and unwise decision was avoided because under NEPA a rational plan for sewage sludge management had to be formalized before action could be taken.

The short-term decisions made so far seem appropriate, at least from a limited scientific perspective, but long-term decisions require more broadly based study than we now have. For example, the most appropriate alternative(s) to ocean dumping of sewage sludge need further study and engineering tests (U.S. EPA 1978), and appropriate financing for these alternatives should be determined in the context of the entire waste management system of the New York metropolitan region and its total impacts. For instance, it seems likely that increasingly stringent waste treatment requirements will result in (1) sludges containing larger proportions of the most harmful wastes and (2) greater sludge production. Hence, sewage sludge may well become a more significant and troublesome waste relative to other contaminant sources. Alternatively, future waste treatment strategies may minimize contaminant concentrations in sludges through more effective recycling in homes and industries, and through reclamation at treatment plants.

Whatever the degree of technical insight, its effective transfer to the public and to decision-makers is needed for improving the planning process. This transfer can use any media to present interesting, brief, and understandable information to the people -- films, exhibits, simplified models, short reports, and brochures. More effort and innovation are needed to inform the lay audience.

For example, the MESA Project is supporting an Atlas Monograph series on the New York Bight; a series of 30 monographs are being published on different topics related to the Bight. Each monograph was written by an acknowledged expert in a particular field and each undergoes thorough technical and professional editing. Emphasis is on colored graphics and readability by laymen.

I have two principal suggestions for scientists in helping evaluate the social significance of environmental impacts.

First, we must keep in mind that science alone cannot evaluate the social significance of proposed "major Federal actions significantly affecting the quality of the human environment." Evaluating the "significance" of impacts under NEPA was intended to require wide perspective -- from ecologists, other scientists, public decision-makers, and the general public. The "significance" of impacts from major federal actions to be determined broadly on behalf of "each generation as trustee ... for succeeding generations; [to] Assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surrounding ..." and other ends outlined in NEPA. Narrow interpretations by scientists and interested citizens are not only essential in assessing the broad social significance, but can also stimulate "creative tension" and wise planning in government. However, impact assessment in the Bight includes several examples of narrowly-based and apparently inappropriate recommendations for governmental action. Perhaps this realization that science and scientists can provide only part of the necessary perspective would help insure the kind of humility urged upon us so eloquently by Kesteven (1969).

Related to this plea for perspective is a suggestion that scientists distinguish between technical descriptions of actual or projected impacts and emotional responses to impacts. Like the general public, scientists feel negatively or positively about proposed "major federal actions." Such emotional responses are generally considered inappropriate in environmental impact statements and other technical literature. Whether a scientist's emotional responses in the popular press or public lectures should be identified as personal, not scientific, is debatable. The danger, of course, is that legitimate personal views of a scientist may be misinterpreted by laymen as scientific results (Lundberg 1961). The particular obligation of the scientist to offer reliable advice to the wider community from his specialized knowledge is explained forcefully by Kesteven (1969).

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USE OF REGIONAL RESOURCE EXPERTISE IN ENVIRONMENTAL PLANNING

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INTRODUCTION

We find ourselves as the only representatives among the symposium participants of a major development agency. Additionally, we seem to speak for one of the very few planning groups here. As such, we cannot resist the opportunity to structure this paper toward the "real world" of the agency planner -- an arena toward which the biological evaluation concepts and methods of this symposium are directed. The situations described will suggest that the effective environmental planner must be prepared to work in many media encompassing field biology, research, planning, public participation as well as agency and local politics. The innovative approaches sought at this meeting potentially have much to offer to the real world practitioner, but we caution participants to ask themselves how well their suggested approaches really fit our situation.

In our office, the Environmental Resources Section of the Seattle District, U.S. Army Corps of Engineers, although we have consciously endeavored to be more effective through innovative approaches, we feel strongly that for most day-to-day planning, problems of data collection and methods of analysis and presentation of data have not changed much from pre-NEPA. It seems all too frequently that our main problem is not how to understand biological cause-effect pathways, nor to unearth a clever method of displaying our findings, but just to find the means to obtain basic information on the impact area of a proposed project and to use that information effectively in the planning process. There is a great deal of old-fashioned biological inventory, analysis and evalution to be done, and the time and money remaining to pursue new concepts and methods are woefully short. Assistance on new methodologies must necessarily come from organizations such as those represented at this symposium, although we never seem to have enough communication between the researcher and the practitioner to assure that assistance is effective.

In our routine work, we need any and all biological information and assistance that we can beg, barter or borrow and therein derives the origin of this paper's title. Only through the assistance of the available expertise of the region can we accomplish a creditable job of planning. This assistance may take the form of hard data, personal impressions, names of knowledgeable people to contact, review of our draft reports or simply the pressure that outside sources can exert upon an agency to assure that relevant environmental considerations are embraced.

In keeping with the theme of this symposium -- "to examine" and "to stimulate the development and application" of concepts and methods of treating the biological significance of impacts -- we set out to assemble information to illustrate key activities involved in effective environmental planning. The nucleus of the paper is built on the subject of wetland significance and the assistance of regional resource expertise in conveying the importance of such areas to the nonbiologist -- other planners, the public and decision-makers.

As planners for a water resource-oriented development agency, we see wetlands being dredged for purposes of commercial navigation facilities or small boat basins, filled by disposal of dredged material from channel and harbor maintenance, covered and altered by levee construction and channel modifications, flooded by reservoirs or altered for innumerable types of commercial or recreational development. Wetland, as a threatened category of natural areas, seems to be an ideal focus both for discussions of regional expertise, and also of the planning system within which we function. It is altogether too easy for the researcher, the philosopher, the administrator and even the planning practitioner to become lulled by the logic of inventories, data analyses and the like and not recognize what really does or does not get the job done -- the job of developing good plans and planning sound development.

REGIONAL EXPERTISE AND ERS

While environmental concerns have been increasingly incorporated in Corps planning in the last decade, it wasn't until a few years prior to the passage of NEPA in 1969 that true environmental expertise began to exist in Seattle District. This relatively short period of time, however, was enough to influence the District's eventual response to the new law and its implementation of CEQ Guidelines.

A fisheries biologist was hired in 1965 to satisfy a perceived need for better communication with the biologists in state and federal resource agencies with whom coordination under laws such as the Fish and Wildlife Coordination Act was becoming increasingly difficult. This fisheries biologist, like several of those who now comprise the existing Environmental Resources Section (ERS), was recruited from a state resource agency and, thus, became the first extension of the District into the realm of identification and use of existing regional environmental information. Over a period of about 4 years, this biologist was followed by other biologists and landscape architects. Mission assignments of this group centered around recreation, esthetics and fish and wildlife mitigation associated with two large dam and reservoir projects and the controversy of initial, serious attempts at maintenance dredging planning and coordination.

Thus, when NEPA became law, it was considered a relatively minor addition to, rather than genesis of, a large and expanding environmental workload. In fact, there was (and is) some feeling that Congress was merely making formal and mandatory what Seattle District had been doing for more than 4 years, with resultant apathy by some Corps personnel regarding the importance of NEPA.

The low level of importance attached initially to NEPA and a laborious, erratic evolution of agency responsibilities, combined to anchor Seattle District implementation of the NEPA and CEQ Guidelines into a "reality" from which we are now still emerging. Other agencies are undoubtedly in a similar position. Within Seattle District, the environmental planner's responsibilities have continued to expand and our mission can be best described as "keeping the Corps moving environmentally." We constitute the Seattle District's staff in the environmental arts and sciences to prepare EISs; landscape design plans; master plans for resource management and development at operating projects; recreation planning; general environmental planning to support the planning, design, construction and operations arms of the District; archeological and historical resources surveys; contract supervision for investigations on fish, wildlife, habitat, water quality and cultural resources; and provide specific environmental assessment functions for the Corps' Section 10/404 permit program, outgrants of real estate and emergency flood control actions.

In more recent years, ERS has developed into what could be termed an interdisciplinary team as called for in the Guidelines and NEPA and equaled by few offices in government. A variety of technical disciplines are represented and background and experience are even more diverse. The staff includes agency experience from the Washington State Departments of Fisheries, Game, Natural Resources and Highway, the U.S. Forest Service, Department of Housing and Urban Development, National Marine Fisheries Service, National Weather Service, Atomic Energy Commission, U.S. Army Map Service and the Soil Conservation Service. Former Corps assignments include the Portland, Oregon, and Huntington, West Virginia, Districts and the Chief of Engineers' office in Washington, D.C. Formal training includes five masters and five PhD-level programs and provides ample expertise to authoritatively address the biological significance of wetland issues and includes degrees in general biology, fisheries biology, wildlife ecology, forest science, soil science, forest ecology, marine ecology, aquatic biology, limnology, shellfish biology, zoology and botany. Other staff have degrees in landscape architecture, sociology, urban planning, English-journalism, geography and archeology. Additionally, major expertise through training exists in the fields of economics, statistics, chemistry and recreation planning. While this diverse background within ERS is very useful in itself for the Corps' interdisciplinary team, it is the access to contacts and information sources which really provide the skeleton of a working regional resource information system. These contacts and information sources can generally be grouped in six categories: federal agencies, state agencies, academic, private consultants, environmental interest groups, and the general public.

Other federal agencies are obvious pools of information and expertise, but all in all, we have found that the information needed concerning impact areas is not always readily available from those federal agencies which have (in the words of NEPA) "jurisdiction by law or special expertise with respect to any environmental impact involved." EPA has been our most helpful federal source.

Overall, state agencies have been our biggest help -- when they choose to be involved. Our personal contacts and working relationships are of major value here, although we also formally contract with them for specific studies. It is inflexibility in funding and hiring procedures that prevents state agencies from being of more value to us. In addition, fluctuations in federal funding are partially responsible for reluctance of state agencies to hire people for specific investigations. The state agencies often have the most up-to-date information and are willing to share it to the extent that funding will allow. We often find that data furnished by a federal agency are merely getting to us in a round-about fashion from the files of a state agency. This is particularly true of fish and wildlife information. We would be truly handicapped without state-level assistance.

We have developed numerous pipelines into the academic world of regional colleges and universities through former employees, personal contacts and formal contracts. The expert information gained here is to some extent automatically suspect by our Corps colleagues, and we spend considerable time defending our informants' viewpoints. The trouble has generally proven to be worthwhile. The "concern" is that the academician raises an issue via citizen comments, or perhaps as an expert critic, and then is conveniently available to contract with the Corps for detailed studies.

Contracts with private consulting firms have been a necessary part of our work. This is counterproductive to some extent in that our own capability has been diluted by contract administration more than we like. We have found, too, that the contract firms usually limit their efforts to the same type of information gathering that we would have accomplished, i.e., contacting federal, state, local agencies and academia, without always having the first-hand knowledge of study parameters and the same personal contacts. In addition, contracts are difficult to use continually because an education program is required for each new contract. Once a consultant is well-versed in our procedures and requirements, the study is complete and we often must start anew with a different firm for the next exercise.

Environmental interest groups have, to date, been of limited help in providing substantive data due to their fiscal constraints and largely volunteer staff. They have, however, been invaluable in alerting us to unsuspected concerns and in furnishing needed conceptual viewpoints and bases for trade-off analysis. We deal with them regularly, both informally and formally, and they generally have much to offer.

The public, or rather the publics other than those already discussed, holds a large block of information of varied quality. How to acquire, interpret and qualify this information is always a problem. This is not news, of course, but what is news, perhaps, is that we really do "care" and are trying. Some of the methods employed include informal workshops, brochures and opinion surveys. An example of attempts we have made will be described later in this paper.

A final note in this general overview of our pool of regional expertise before describing how we use it and what happens when we do: in all agencies, environmental groups and academia, the help we obtain depends on the attitude of a few individuals and the time they can afford in their schedules to furnish largely unpaid information that must be compiled after regular duties. Thus, we constantly strive to maintain cooperative, credible, mutually beneficial working relationships and to develop new relationships.

THE PRE-PLANNING MEDIUM - THE WASHINGTON ENVIRONMENTAL ATLAS CASE STUDY

Most Corps planning that involves a significant commitment or alteration of resources seems to be conducted in an atmosphere ranging from contention to apprehension. The Corps' public image as a sensitive environmental planner and developer is not all that it might be. Consequently, the collection of broad planning information outside the emotion of specific project studies has a potential for greater objectivity of public and agency input.

In 1970 an Environmental Advisory Board was established in the Office of the Chief of Engineers to provide advice on matters of broad environmental concern. A particular activity encouraged by the Board was the initiation of an environmental information program to explore the need for environmental information in Corps water resource planning and development activities; to develop approaches for information collection, compilation, use and updating to meet those needs, including consideration of inventories, baseline studies and monitoring, and to recommend actions aimed at implementing these approaches. It was decided that the Corps would conduct statewide inventories of resources and amenities of "statewide or national significance" with these values to be articulated by the state's citizenry, interest groups and governmental agencies. Washington was one of four states selected for an intensive pilot effort, which in this state culminated in publication of the Washington Environmental Atlas in mid-1975. While the inventory concept had its genesis in Washington, D.C., the majority of the work was accomplished locally. Seattle District contracted with the University of Washington's Institute for Environmental Studies to mock up an early draft document and coordinate a major public review. The draft was later revised and supplemented through ERS staff efforts.

The Atlas documents environmental information as supplied by governmental resource agencies and interest groups, including but not limited to environmental groups, and expresses many of the values of the state's general citizenry. Surprisingly, with a few exceptions, the more vocal environmental interest groups did not respond en masse to calls for information, even when those calls were made repeatedly by members of their own top echelon. Numerous members of many groups participated, but as individuals rather than as representatives. As such their input of information was broad. Response by governmental agencies was sporadic -- assistance by personnel of the Washington Department of Game was particularly outstanding.

The publication is divided into 11 major sections, including maps and invitational papers discussing geological, hydrological, biological, archeological, historical/contemporary cultural features, and aspects of environmental use and management. Eight full-color maps identify over 5,000 sites of state and national environmental significance.

Eight of the eleven major sections in the Atlas contain overview papers written by noted members of academia such as Gordon Orians (ecology), Rexford Daubenmire (botany), Harvey Rice (archeology), Gordon Alcorn (biology), David Rahm (geology), Victor Scheffer (marine biology), and Earl Larrison (biology); by local authorities such as Terence Wahl, Gary Fuller Reese, Wolfe Bauer, Joan Thomas, and Polly Dyer; and by members of resource agencies as Eugene Dziedzic (Washington Department of Game). These authorities provide the reader with important background information which helps clarify the environmentally significant features displayed on accompanying maps. Most of these mapped sites are then supplemented by explanatory text grouped by counties in the back of the document. Some of the more useful information is discussed below.

IMPORTANT SPECIES

Wildlife are the most visible and appealing environmental resource available to most persons. "Reduced carrying capacity" or "lower estuarine production" are fine conceptual phrases, but are meaningless to the average person. To say, "fewer great blue herons, waterfowl, falcons or whales" provides the average citizen, and often the average planner, with a more basic concept, from which the more complex system of environmental relationships may be grasped.

In the section entitled "Some Important Wildlife of Washington," 108 different wildlife species are highlighted by range maps and brief descriptions which often include critical habitat requirements (Figure 1). Six of the species, or their subspecies, which occur in Washington are listed as "Endangered" by the U.S. Fish and Wildlife Service. Numerous other species have been identified by groups such as the National Audubon Society, the Wildlife Society and the International Union for the Conservation of Nature as declining in population, or whose status is undeterminable by current data. The avian species discussions are particularly useful in examinations of wetlands, given the strong dependence of large numbers of these fauna on this particular habitat type for resting, nesting, breeding, feeding and nursery functions. Other wildlife species and their ranges are documented throughout the rest of the Atlas, both in terms of specific sites submitted or through the species lists provided.

CRITICAL HABITAT

Critical habitat requirements of wildlife species were described and mapped where such information was available. A special paper was developed to describe Washington's place and function in the Pacific Flyway. In this paper, the State's major wetlands were specifically cited for their importance to migratory waterfowl. Additional discussion focuses on this vital habitat type, listing specific sites in Washington that are critical to avian populations. Marine mammal experts stated their concerns regarding wetlands important ecosystems in support of marine mammals. Fishery biologists stressed the vital functions performed by wetlands in maintaining the valuable fishery resource, again defining specific areas of great concern either because of threats to the integrity and productivity of wetlands, or because of their critical relationship to other sections of the state's estuarine or marine ecosystems. Assembled and integrated as they are in the Atlas format, these data and stated values

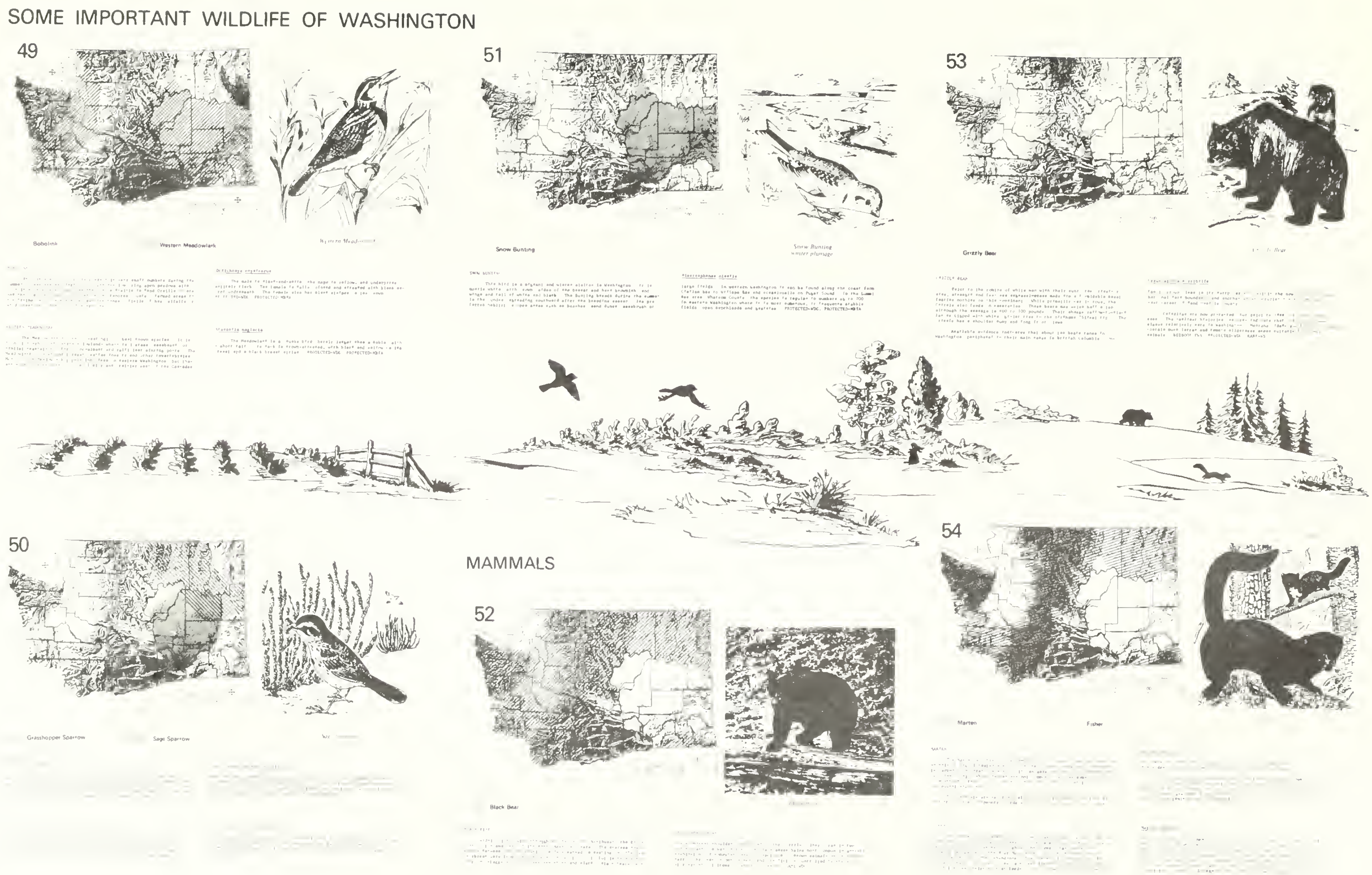

Figure 1. Representative Page: "Some Important Wildlife of Washington" (Washington Environmental Atlas)

provide considerable evidence and authority as to the significance and value attached to wetlands.

LIFE-ZONE OVERLAY

The ecological life-zone system was utilized as a unifying concept for biological evaluation. A transparent acetate overlay was constructed defining the state's six major life zones based upon the C. Hart Merriam system (Figure 2). The overlay is an updated version of a 1906 map, corrected through composite photointerpretations of ERTS Satellite imagery obtained in 1972. A key was provided to allow translation from Merriam's system into a zone system more familiar and pertinent to botanists. The overlay was scaled to fit over any of the resource maps and the ERTS photograph of Washington.

This life-zone system was supplemented by a habitat matrix which indicates general habitat types to be found in each life zone. Use of predicted habitat types permits extraction of probable species from statewide lists of wildlife. Thus, as a precursor to field examination, one may determine much about a site's physical environment as well as the approximate makeup of its biotic communities. This first-step familiarization can be extremely valuable in the too frequent cases where time and/or money is short. A conceptual framework of the site's resources may be gained with easier, later field investigation and collection of specific data. Questions raised in familiarization using the Atlas are "alert" points the investigator can address on-site.

There are numerous directions from which one seeking specific information may approach the Atlas. Following processes set up by the editors, one would proceed through the document, discovering not only the single bits of data sought, but the connection that information has to other fields, processes, or areas. A particular wetland site could be identified on one map as a significant shellfish harvest and anadromous fish migration area, and in another map as being a migratory waterfowl resting area. Further examination might reveal that the area possesses unique geologic formations, a potentially rich archeological heritage, and perhaps is a critical habitat for endangered species. Additionally, the specific site could contribute significantly to the functioning of a species or ecological processes surficially far removed from the site in question. All this information is pertinent to the planner's analysis of the situation and his arrival at a decision that will preserve or develop in a sound manner.

The above information may be easily utilized in any planning study, and have been used to prepare environmental impact statements and assessments within this District. Species lists developed for various sites using Atlas material have been examined and found extremely accurate by persons intimately knowledgable about the sites. Perhaps the greater significance to arise from the Atlas has been to identify for District environmental personnel those persons in an area under study who may serve as regional experts and provide site-specific information to the environmental planner that may be useful to influence in-house decisions.

ANALYSIS

In theory, the Atlas represents an inventory of "red flags," and acts as a single compilation of generally accepted significant environmental information. In reality, there is a dichotomy of information presented in this planning tool. On one hand, such notably objective items as resource maps, range maps with brief writeups on significant and recognized threatened wildlife species, an ecological life-zone overlay, and a life-zone habitat matrix which is supported by statewide comprehensive species lists for bird, mammal, reptile and amphibian species represent comfortable and accepted input for the planner.

On the other hand, there is considerable verbiage which is labeled opinion, since these words are not necessarily based on scientific data. The public was encouraged to suggest resources and amenities they believed to be important, with no attempt made to ask the contributors to dissect or defend the bases for their beliefs. These opinions, thus, provide excellent insights into a second kind of "red flag." One elderly woman submitted the bit of information that a bushy-tailed woodrat, a species common to western Washington, lived in her backyard. Viewed by itself, the incident was and remains slightly humorous; however, the woman placed sufficient value on that particular animal that she felt it worthy of submission for documentation. When one realizes that a great number of the state's citizenry submitted their own valued places and things, albeit not so provincially, the significance of such submissions must be taken more seriously. Individual, personal values are indeed red flags to be taken into account by the planner in his development of a sound project.

Figure 2. Life Zone Overlay (Washington Environmental Atlas)

It is exactly this dual nature of the Washington Environmental Atlas which makes it such a valuable document for the planner and for the average citizen. Both scientific data and general or specific values of which the planner might not have been aware are identified. Discovering that these data or values do indeed exist, the planner or public is alerted. It then becomes extremely difficult to simply ignore such information, a modest data base is established which may then be improved upon.

The question arises as to whether the investment in time and money to provide the Atlas was worth it. The present document represents over 4 years of effort and a cost exceeding $200,000. The information gained from the document and contacts developed during its compilation are highly useful. In a very real sense, the encyclopedic nature of this type of reference demands periodic updating or expanding since data are incomplete and values change. While we believe such expansion highly desirable, were it to reduce environmental planning funds available for specific studies, we could not justify it. The Corps rationalized the initial effort partially on the basis that someone had to make a pioneer effort to determine the payoff, and partially because we could not pass up an opportunity to enhance our supply of environmental information. To some extent, this is still true.

In developing the Atlas concept, the Corps primarily sought the advantages of good data and advance knowledge of prime environmental concerns. They were not unmindful, however, of the public relations value of such a publication. Some, perhaps, anticipated that EISs could be produced solely from this compiled information and that resources and amenities not identified in the Atlas would be more susceptible to alteration. Others were concerned that the information in the Atlas would preclude any further development. These conflicting views were also held by some agencies and developmental groups outside the Corps. Happily, these views have diminished. In retrospect, the Atlas technique offers much, but at a tremendous cost compared to conventional project-oriented data collection. It was worth doing in the first place and with funding would be worth doing again. Since resource development tends to be controversial, it is likely that the Corps will continue to have some credibility problem in utilizing the regional information sources. Consequently, the Atlas technique, when utilized, will collect basic information -- preliminary information that can be expanded in routine planning.

THE PROJECT-ORIENTED MEDIUM

GENERAL

We deal regularly with our counterparts in federal, state and local resource agencies and with environmental groups in coordinating our operating projects, our various planning studies and our regulatory activities. This interaction with regional experts has led to some potentially successful approaches to assuring environmental values are considered in our day-to-day business of dealing with the future of wetlands.

One approach led to development of an informal document prepared for the Section 10/404 permit program to delineate the bases for determining significance (requiring an EIS). A generalized version of these tests is attached as an appendix. This document describes such "tests" as relative size, cost and type of project; cumulative biological impacts; loss or gain of threatened wetland resources; controversy; and registered cultural resources. It has been furnished to one entire group of important permit applicants -- the various ports within Seattle District affiliated with the Washington Public Ports Association. The thrust of this effort has been to assure that the ports are cognizant of environmental analysis requirements early in their development planning both in the interest of reasonable consideration of environmental amenities and timely, efficient processing of permit applications. The transmittal of these evaluative criteria to the ports was followed up by a presentation at a recent Port Association meeting in which the need for early consideration of these matters was again stressed.

PLANNING STUDIES

A further example of situations where close coordination with the agencies can result in modest consideration of the environment is a typical planning study. While this would seem obvious in a large, complicated study involving a potential major dam and reservoir, it is less so for relatively minor proposals such as levees and small boat basins which we deal with under our Continuing Authorities Program or for smaller survey studies. At the District level, funding for our environmental planning and for the eventual EIS documentation of planning for small to medium studies seldom exceeds $40,000 -- or about $20,000 spendable dollars after our District overhead and office indirect charges are deducted. Considering that data collection, analysis, field trips, salaries, typing, report printing and report review come out of this figure, the funding is marginal. Since budgets are submitted approximately two years in advance and funding for all study components is tightening, the situation is constraining and not totally predictable. Thus, a detailed painstaking day-to-day contact and field analysis approach with our counterparts in other agencies can make up for some funding constraints and result in notable environmental improvement in planning and design. An example before getting into the remaining case studies is the planning associated with a proposed flood damage reduction plan for the Yakima River between Yakima and Union Gap, Washington.

The Yakima levee project has involved several years of careful planning with the fish and wildlife agencies. Formal coordination (public meetings, public brochures and letter reports and responses) and informal coordination (numerous phone calls and field trips) have resulted in proposed levee alignments generally being set back from the main river channel and its associated riparian vegetation, and with a revegetation plan which would, in the long term, result in insignificant losses to wildlife. In the semi-arid environment of central Washington's Yakima River Valley, the zone of riparian habitat has an obvious importance to numerous natural systems. Approximately nine river miles are involved in this plan. In the early planning phase, we (again with the help of the fish and wildlife agencies) actively pursued the feasibility of including an extensive park in an area of periodic inundation along with our plans for flood damage reduction. Such a park would assure that the area will remain undeveloped with retention of the majority of the biological values in an area close to urban Yakima. Due to contraints by our own authority and local sponsor financial problems, the floodway park had to be dropped. Recently, however, the local community has received state funding to finance a master plan for the proposed floodway park, and it appears the locals may now benefit from our joint planning efforts. Considerable hard work by many paid off in obtaining setback levees partly because cost-effective alternative alignments were found and partly because outside agency pressure helped point the Corps in that direction. A major factor in favor of the floodway park was that a plan with that feature in it was particularly salable to certain agencies and some publics.

EMERGENCY ACTIONS

Some of the success we have had in cooperation and use of agency resource expertise with planned small projects, has, in a sense, been largely negated by some practices under our emergency response mission associated with floodfighting. While agency environmentalists are generally sympathetic and helpful, if critical, in a planning exercise, they see rehabilitation actions following flooding, necessary and otherwise, as major factors in destruction of freshwater wetlands, including fish spawning and rearing areas and riparian habitat. Many of these emergency exercises, in a matter of days, can alter more landscape, channelize more stream and level more vegetation than the entire small project planning program in several years. While the agencies recognize the need for immediate, sometimes drastic action in truly emergency situations, they sometimes seriously and justifiably question the Corps' (and local authorities') judgment in defining these situations. There is a long way to go in this field, and we have just begun, but a reasonable partial solution seems to be to enlist agency experts in various fields to help conduct workshop "show and tell sessions" to explain and demonstrate the value of environmental "things" and otherwise sensitize emergency field evaluators and construction crews prior to major flood events. This use of regional resource expertise we've just begun to tap.

WETLANDS AND MAINTENANCE DREDGING STUDIES

The proper understanding of the functioning of natural systems and an ability to predict the implications of project-induced impacts are prime problems for the environmental planner. Solutions sometimes lie in seeking an articulation of known information and sometimes require lengthy scientific investigations. Examples of both are available in our maintenance dredging studies and offer useful insights.

There is no shortage of verbiage which endeavors to convey to planners and decision-makers the biological importance of various types of wetlands to their respective ecosystems. These articulations are based on sound ecological theory and have been variously stated in published policy statements of numerous federal agencies, including the Corps of Engineers. The Corps' regulations on processing of permit applications (33 CFR 209.320) and on the conduct of maintenance dredging (33 CFR 209.145) discuss wetlands at some length and state:

> "As environmentally vital areas, they constitute a productive and valuable public resource and the unnecessary alteration or destruction of which

should be discouraged as contrary to the public interest."

The EPA Guidelines (40 CFR 230) established under Section 404(b) of the Federal Water Pollution Control Act Amendments (PL 92-500) state in part:

> "From a national perspective, the degradation or destruction of aquatic resources by filling operations in wetlands is considered the most severe environmental impact covered by these guidelines."

Policies center on the direct habitat values of wetlands to fish and wildlife but also include the role of wetlands for floodwater storage, groundwater recharge, nutrient sinks and sources, producers of organic materials and assimilation of wastes. In the marine environment the salt marshes associated with an estuarine system receive most attention. Of equal concern should be the seemingly barren, expansive tidal flats associated with the fringing marshes. On the west coast of the United States, salt marshes occupy a relatively narrow fringe bordered by uplands on the one side and tidal flats on the other. Their elevational range is generally limited to levels between mean high and extreme high tide.

The intent here is not to establish, clarify, or expand upon the accepted natural values of salt marshes but rather to describe workable approaches to gauging their importance by environmental planners when proposed projects threaten to destroy or severely alter them. Two examples representing different levels of detail in information gathering serve to illustrate how environmental concerns are input to the planning process. In both cases, the level of detail was tied directly to the necessity of acquiring information usable in an established planning process with predetermined time and funding constraints. It should be pointed out that these studies provide useful examples only because considerable time and money were invested.

THE WILLAPA BAY CASE STUDY

The Willapa Bay evaluation was initiated after several years and a plethora of events which resulted in an agency decision to re-evaluate the maintenance dredging project -- socially, economically, and environmentally. The entire exercise was tied to preparation of an EIS, in this case, the prime decision document for recommending a plan of project maintenance. The central concern which catapulted the agency into a need for a fresh project evaluation was the issue of wetland alteration -- specifically, dredging and filling of tidal marshes in the bay. A quite thorough public involvement program to determine the opinions and values of the local populace (as well as obtain substantive information they held) was also developed to augment the data acquired from the broad traditional regional sources for this EIS.

Willapa Bay, an estuary of exceptional significance according to a National Estuary Study released in 1970, is a large Pacific coastal estuary in the southwest corner of the State of Washington (Figure 3). Its area is about 259 square kilometers of which about one-half is exposed at low tide and much of the remainder is less than 2 meters in depth; about 129 square kilometers of the bay are intertidal wetlands, either salt marsh or sand and mud flats. The bay, noted for its undeveloped condition, is primarily a center for commercial and sport fishing, some wood products processing, and limited export of saw logs. In recent years, the Willapa Bay region has suffered a significant decline in jobs, due in part to a decline in navigation traffic.

A main navigation channel extends from the bay mouth upstream to the town of Raymond, Washington, and has been regularly maintained by the Corps of Engineers for over 60 years. Corps maintenance has removed an annual average of 375,000 cubic meters of sediments from the channel. For many years, the disposal of these sediments was random and largely unrecorded. Recent records of dredged sediment disposal are available and were used to develop a history of wetland filling through disposal operations. By examining existing conditions, we estimated the amount of wetlands which had been diked, diked and filled, or left basically unaltered. Projected amounts of wetlands to be filled with dredged material in future years were also made. Combining historical data with data on existing conditions, and projections of project-related filling allowed us to place the impacts of a given project into some quantitative perspective.

Much of the analysis was conducted by a local consulting firm in a closely coordinated effort with Seattle District environmental planners, using data on past and projected wetland filling provided from Corps records. Ground-truth surveys provided data for identifying wetland types from aerial photographs. Primary emphasis was placed on salt marshes because (1) they were the most likely areas to be used for future dredge material disposal, and (2) they were considered

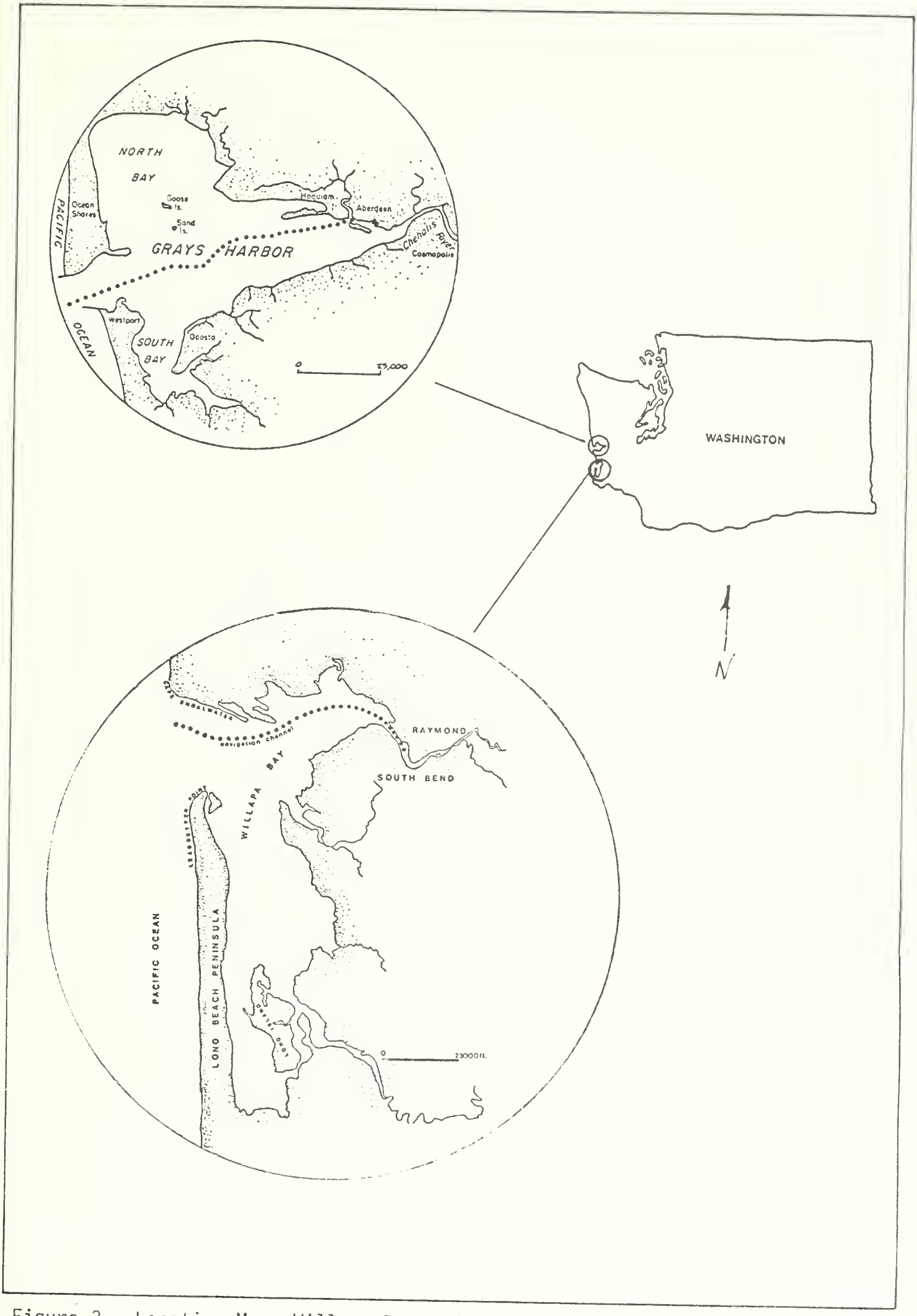

Figure 3. Location Map - Willapa Bay and Grays Harbor.

to be among the most critical estuarine habitats.

The wetlands were classified into types, mapped and areal extents determined. Total vegetated* wetlands in Willapa Bay and its contiguous drainage area were estimated to be about 6,000 hectares. Of this total, about 2,500 hectares have been diked for various purposes. Some of the diked areas remain as agricultural grasslands still under some tidal influence, while others have been filled to become uplands. All are partially or wholly removed from directly interacting as a part of the estuarine ecosystem (Table 1).

in the northern area of the bay in which the main navigation channel is located. To continue project maintenance for the next 20 years in the manner suggested by strict project economics would require diking and filling an additional 121 hectares of salt marsh.

In addition to areal quantification, effort was made to relate salt marsh primary production to secondary and tertiary faunal production. The conversion factors developed were based solely on reviews of published information relying heavily on the work of Day (1973) on Louisiana salt marshes. Results of the analysis are summarized in Table 2.

Table 1
AREAL EXTENT OF SOME WETLANDS IN WILLAPA BAY
(Modified from Northwest Environmental Consultants, 1974)*

Wetland Area (Undiked)	Hectares
Low salt marsh	1,055
High salt marsh	1,326
High salt marsh/wet grassland	203
High salt marsh/grassland	77
Salt marsh	364
Wet grassland	449
Sand dune	87
Freshwater marsh	124
Subtotal	3,685
Wetland Area (Diked)	
Diked grassland	2,060
Diked grassland/freshwater marsh	419
Newly diked	27
Other	9
Subtotal	2,515
Total Wetlands	6,200

*Categories of marsh listed in this table were derived independently, but nevertheless correspond closely to categories developed by Jefferson (1975) during a detailed survey of Oregon salt marshes.

An estimated total of 121 hectares of salt marsh have been diked and filled (thus converted to upland) by dredged material between 1962 and 1975. This is about 3.3 percent of all salt marshes of the bay and about 18 percent of remaining salt marshes

While difficult to accurately estimate, since the wetland evaluation was only a part of a broad study, the total effort by the consultant cost about $10,000-$15,000.

*The term vegetated is used with reference to phanerogams only.

Table 2

ESTIMATED ANNUAL ESTUARINE PRODUCTION LOST THROUGH ELIMINATION OF 121 HECTARES OF MARSHLAND
(Data derived from formulation in Northwest Environmental Consultants, 1974)

Organism Type	Kilograms Dry Weight
Insects	2,921
Polychaetes	2,921
Snails	5,552
Crabs	2,267
Mussels	1,811
Shrimp	810
Oysters	1,838
Herbivores	783
Primary carnivores	572
Mid-carnivores	8,022
Top carnivores	7,218
*Birds	13

*An extremely low estimate for Willapa Bay.

Projections in Table 2 were developed directly in response to pressures to quantify impacts on natural systems. Lack of specific information and hesitancy to project or extrapolate data is easily interpreted as a lack of real significance by the nonbiologist. The complexity and interrelatedness of a natural system cannot be conveyed easily in the context of a typical study exercise. We have progressed from answering the question of "What biota are affected?" to "How are these biota affected (qualitatively)?" to How much are these biota affected (qualitatively)?" This last question is exemplified in the above table of biomass data. The next question we will have to deal with requires contrasting the relative amount of affected biota to that of unaffected biota. Loss of several thousand Dungeness crabs to a hopper dredge in an embayment during one day's dredging should sound significant, but when related to the entire 259 square kilometer estuary and the knowledge that one crab will produce in excess of one million offspring per year, this premise is open to question.

Concurrent with the environmental analyses, economic analyses of the dredging project were also completed. Suffice it to say that annual benefits were found to be $333,300 compared to annual costs of $593,000. Less than 10 full-time jobs in the local community were found to be dependent on shipping commerce using the main navigation channel.

PUBLIC PARTICIPATION

Though the biologist may at first assume that there is little to be gained via the public participation medium, the Willapa study indicates that this is not necessarily so. Unless considerable effort is exercised to educate and inform the various publics, and unless some reasonable feedback is obtained from them, the likelihood of developing acceptable plans diminishes.

The Willapa Harbor EIS study diverged from the typical maintenance dredging EIS planning process by involving the public early (analysis of needs, data collection) and also involving them in each subsequent planning step (alternative formulation, evaluation and plan recommendation).

We began with a public meeting, the intent of which was to "overview" problem areas and identify environmental, economic and socially sensitive areas. Feedback obtained at this public meeting suggested that more and better information on problem definition was needed. The general atmosphere surrounding the study at this point was one of controversy.

A complementary step in our problem definition phase was the drafting of a public opinion survey, aimed primarily at gathering an objective and quantitative description of public values. To involve the public as fully as possible in this exercise, the survey was mailed to each household within Pacific County. The total mailing came to over 6,600 survey forms of which 1,007 were returned -- a response rate of over 15 percent. Of major importance to our agency planners was the local public's interpretation of their economic, social and environmental surroundings. The opinion survey delved into citizen attitudes regarding human use of the Willapa wetland habitat resource. For instance, the majority category of respondents, about 37 percent, indicated that past dredging and filling of wetland notwithstanding, the Willapa environment had not changed. However, a near equal number, about 32 percent, felt the area had deteriorated, while a much smaller number, about 15 percent, felt the area had improved.

Results of questions concerning the economic environment indicated that the overwhelming majority of respondents, about 60 percent, felt the area needed more industrial development. However, in response to a similar question, over 59 percent felt that new industrial development should be environmentally restricted. The preferences given for new development ranked the fisheries industry at the top, followed by recreation, forestry and agriculture.

On the issue of whether past dredging and filling activity was beneficial or harmful, more than 70 percent of the respondents indicated beneficial compared to less than 6 percent who indicated that dredging was unnecessary. Those indicating that dredging was beneficial most often cited the reasons of job protection associated with logging, and water transportation industries. Other reasons given indicated that dredging operations provided needed land through reclamation for expanding residential, business, and industrial use; and feelings that dredging minimized flooding and erosion problems. The survey identified that nearly 70 percent of the respondents were not born in Pacific County, with about 30 percent having moved into the area during the last 10 years. Those who indicated that dredging was harmful cited reasons as harm to fish and oyster industries; harm to ecological and life-supporting production of wetlands; and problems associated with shoreline erosion.

Concurrently with the drafting, mailing and (later) quantification of opinion survey results, Corps planners collected and analyzed detailed environmental, economic, and social characteristics of the area, and efforts were taken to initiate ongoing communication between the Corps and all interested groups and individuals, state and local.

A fairly concise definition of local problems, needs and desires resulted; and from the data collected, our planners were able to identify 12 viable alternatives for future dredging, ranging from project termination to continued dredging as in the past.

At this stage, a rather detailed and fairly inclusive description of the several alternatives was mailed to Pacific County citizens via a project "studygram." This studygram evoked only minimal response. Of the 6,609 copies sent out, only 1.7 percent was returned with citizen comment. The purpose of the studygram was to provide county residents with information regarding dredging alternatives which had been developed partly from the citizen attitudinal data gained from the opinion survey. The studygram also included space for citizens to register their opinions of the alternatives presented, and again asked for opinions regarding the beneficial and harmful aspects of dredging activities.

Most respondents strongly favored continued dredging and did not feel that significant environmental impact was caused by the dredging. However, dredging alternatives which minimized environmental impacts were favored even though much higher costs would result. Those who indicated that dredging was beneficial favored the continuation of past dredging practices, but with re-evaluation at 5-year intervals. During the 5-year re-evaluation periods, detailed studies would be conducted documenting environmental effects of dredging. Although such a program would not immediately resolve environmental problems, most felt that the short-term social and economic fabric of the project area would be maintained.

Respondents indicating that past dredging had been harmful favored either abandoning the project at once or gradually phasing out the program. Conversely, this group was opposed to a program allowing unconfined disposal on wetlands.

After citizen feedback on the studygram was obtained, efforts concentrated on the actual drafting of the EIS. When a reasonably firm recommended plan was developed, Seattle District briefed our regional office, the Chief of Engineers' office, the Director of the State Department of Ecology, key state congressmen and the Governor of Washington (separately and in that order) to obtain their views on the recommendation. A final public meeting was held and the recommended alternative was discussed. The meeting was wellattended, and the public seemed particularly well-versed in study details.

ANALYSIS

An eventual decision was made to phase out project maintenance over a 3-year period and proposed dredging methods were modified to nearly eliminate filling of marshlands during that time. From an environmental (and economic) perspective, a sound decision was made based on an interweave of data input from all available sources and reflected both environmental and economic concerns. One may gain insights by noting some of the philosophies articulated by various decision-makers during the decision-making period. One expressed sentiment was to downplay the wetland aspects of the recommended plan lest the environmental adversaries assume that the Corps bowed solely to their pressure. Another sentiment expressed was termed the "jugular theory." In considering an impact such as the loss of 121 hectares of Willapa wetlands, the loss is contrasted to either cutting off a thumb or cutting the jugular vein. If the biologist can argue that a jugular impact is at issue, then the concern is translatable but when Willapa has 6,000 hectares of wetlands, the thumb truly seems expendable. A contrast of a thumb versus an arm or a leg was the next evolution of this approach to conceptualizing the impact of wetland filling. Yet another view held that the decision should be purely economic and that the environmental evaluations were very secondary. In conclusion, however, changes in dredging methods for the 3-year phaseout period, as well as the basic decision itself, were in direct response to environmental as well as economic concerns since the District Engineer concluded that 121 hectares of salt marsh did constitute a resource worthy of serious consideration.

The efforts taken to seriously involve the public in decision-making elevated the EIS process within the overall planning process, and diminished its role as an ex post facto exercise in justifying preconceived actions or environmental impacts. By the time the draft Willapa EIS was issued, most groups were familiar with its content and the issues involved. The draft EIS included the views and preferences of the public, providing the most complete and realistic document possible. In this manner the emphasis of the EIS shifted from that of an end product to that of a viable means for achieving public interaction.

While the results of the public participation activities were not dramatic, they reflect a good example of concerted interaction with the public and with agencies. Our particular concern for wetlands, was not echoed as one might hope. Concern for loss of jobs if dredging was curtailed was the overriding sentiment, although the public seemed to favor dredging alternatives that minimized environmental impact even when greater costs were involved. When jobs tied to dredging were identified as a major concern (not at all surprisingly), an effort was made to carefully quantify this impact in the EIS and in the final public meeting. Certainly, the finding that less than 10 full-time jobs were dependent on deep draft navigation at Willapa helped the public "accept" the Corps' recommended plan. Perhaps the identified wetland impacts helped too -- we can't be sure, but are left with the particularly uncomfortable feeling that we aren't doing our job properly if we fail to convey the vital relationship between Willapa wetlands and the fish and wildlife resources, and the natural values that attracted the citizen to Willapa in the first place. That the study began in rather heated controversy and ended in a businesslike manner speaks well for the success of the public and agency participation. As planners, we can gauge something about our ability to articulate information so we may be more effective in the next study.

THE GRAYS HARBOR CASE STUDY

The Grays Harbor evaluation was initiated after several years of continued conflict and controversy over the appropriateness of maintenance dredging methodologies being employed. Consequences associated with wetland filling were at issue but not the only issue. Wetland evaluations were undertaken as one part of a broad study of the environmental effects of maintenance dredging in the harbor. Evaluations were not tied to a specific decision or decision document but were to provide input for development of a long-range (next 20 years) maintenance dredging plan for the harbor. This plan was developed in close coordination with the federal and state resource management agencies. The entire study cost more than $400,000; the wetland evaluations including food chain studies involved costs of about $100,000.

Grays Harbor is a Pacific coastal estuary similar in size to Willapa Bay, located about 32 kilometers north of Willapa (Figure 3). Its area is about 223 square kilometers of which more than half is bare at low tide. Harbor depths exceed 24 meters only near the mouth. More industrial activity occurs on the shores of Grays Harbor than at Willapa Bay, and maintenance dredging is greater. Annual dredging amounts to nearly 1.5 million cubic meters over a 37 kilometer main navigation channel. This history of this project extends over the past 75 years.

Wetland evaluations in Gray Harbor were concerned with areal extent, but field ecological data on species utilization of the wetland resources were also determined. Mapping of wetlands was combined with seasonal inventories of vegetation, benthic fauna, fish, birds, and mammals; food habit studies on selected species were also completed and elevations and substrate particle size of major habitats were correlated with species abundance and distribution.

Technical research studies, funded by the Corps of Engineers, were conducted primarily by the Washington State Departments of Game, Fisheries and Ecology, and Grays Harbor Community College. Study scope was continually coordinated with the U.S. Fish and Wildlife Service, National Marine Fisheries Service and Environmental Protection Agency with specific technical input requested intermittently. These are the principal agencies involved in normal project plan coordination, and the Grays Harbor study provided an opportunity for their direct input to the Corps' planning process. This also placed an onus of responsibility on the agencies since they had been justifiably critical of Corps dredging and disposal methods, but had been hampered by lack of data in providing soundly based technical analyses.

Table 3

AREAL EXTENT OF SOME WETLANDS IN GRAYS HARBOR

Wetland Type*	Hectares
Unvegetated tidal flats	5,106
Salt marshes (7 types)	2,203
Eelgrass beds	4,743
Used for disposal since 1950	1,555

*Categories of marsh listed in this table are the same as those developed by Jefferson (1975) during a detailed survey of Oregon salt marshes.

STUDY FINDINGS

A very abbreviated review of a few major findings is sufficient for discussing how technical environmental information is (or is not) input to the planning process. Wetlands extent in Grays Harbor, summarized in Table 3, provides a data base for some first order conclusions. Of the 13,608 intertidal hectares in the harbor, 1,555 or 11 percent have been used for disposal of dredged material since about 1950.

One of the rarest salt marsh types in the harbor, sedge marsh, has been most frequently diked and/or filled for disposal of dredged material. In fact, its present rarity is due in some measure to dredging and filling -- not because of any insidious desire to fill the rarest habitat areas, but simply because sedge marshes occur(ed) in the inner harbor where developable land is most coveted and ample dredged material has been available as fill. Some of these fills have evolved into present sedge marshes although usually of lesser area than before. An added note is that food habitat and inventory studies showed a rather important dependence of some ducks on sedge marshes.

Other results illustrate the dependence of a wide range of faunal species on the salt marshes, eelgrass beds and other intertidal areas. Data were complete enough to construct some detailed food chain relationships shown on Figure 4. Shorebirds, principally dunlins, red knots and sandpipers, feed almost exclusively on the benthic invertebrates. When these feeding areas were elevated to greater than 2.5 meters above mean lower low water by placement of dredged material, the food resources abruptly disappeared. Both elevation and substrate particle size changes contributed to the disappearance and to the absence of repopulation.

As suspected, geese and ducks did eat eelgrass and when intertidal elevation increased or the physical character of the substrate became unsuitable, eelgrass did not grow. It was even deemed necessary to

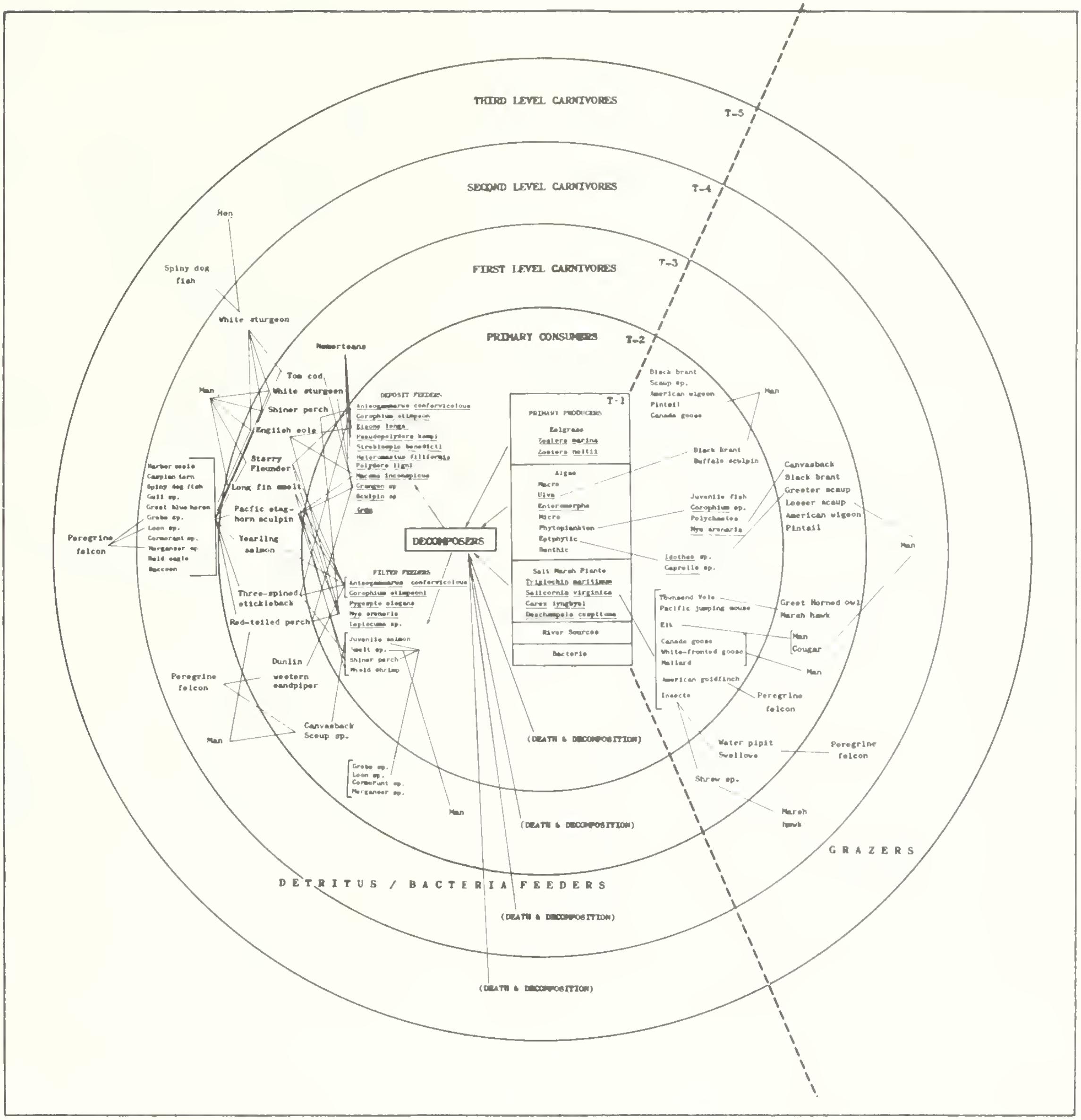

Figure 4. Some Food Web Relationships in Grays Harbor.

document that a great many fish species heavily utilized shallow intertidal areas at high tide for feeding on the benthos and for nursery areas. As alluded to earlier, ducks, especially pintail, teal and mallards, did depend heavily on salt marshes for feeding, nesting (perhaps breeding) and resting. Pintail and teal ate Carex lyngbyei seeds from the salt marshes. In fact, as many as 215,000 birds visited Grays Harbor in a year's time. Many fed on dense populations of amphipods (50,000-60,000 amphipods/m2).

Although primary production of salt marshes and eelgrass was not specifically determined, their annual cycle of organic contribution was observed. The marshes were lush and green in the spring and summer; by late fall nearly all above-ground production was gone having been contributed to the energy budget of the estuary to be utilized by that myriad species which impact statements often list in appendices.

These results are not necessarily profound, but they are soundly based on good data. The studies were technically excellent and the conclusions are not spurious. The data are site specific for Grays Harbor and show that lo and behold, those prime sites for development, known as wetlands, do provide the "support systems" and energy for many organisms in the harbor. Further, when salt marshes and other wetlands are converted to uplands or otherwise severely altered, the essence of this support and energy input is lost -- not temporarily, but irreversibly and irretrievably.

INPUT OF RESULTS TO THE PLANNING PROCESS

The final chapter in the Grays Harbor study program has not been written, but an unusually good opportunity for an excellent planning process presents itself. Some data are available, local interest in planning (Port, Regional Planning Commission, municipalities, industry) is apparently high, organized environmental groups as well as many individuals are watching Grays Harbor rather closely, and all major federal and state resource management agencies have expressed a desire and willingness to work with the Corps of Engineers in development of a dredge plan.

Major inputs, outputs and information flow for the process can be ideally illustrated by Figure 5. Not all components are represented, of course, since coordination with environmental groups, the public, and local governmental entities will continue. However, most of this coordination will not be formally conducted in the form of public meetings, studygrams, brochures, etc. -- it will take the form of numerous telephone calls, workshops and informal correspondence with documentation then being coordinated for review and further analysis.

Success or failure in development of a long-range plan will depend on many things, but there are some encouraging signs at present. There has not been a propensity to nitpick, minimize the significance of, nor attempt to completely reinterpret the technical findings. For the most part, there has been a willingness to accept the good as well as the bad. Dredging methods have been altered to avoid unconfined tideland disposal.

A variety of smaller actions or proposed projects in Grays Harbor have involved use of regional resources in the decision-making process. One example involves a recent permit application to fill a 14-hectare salt

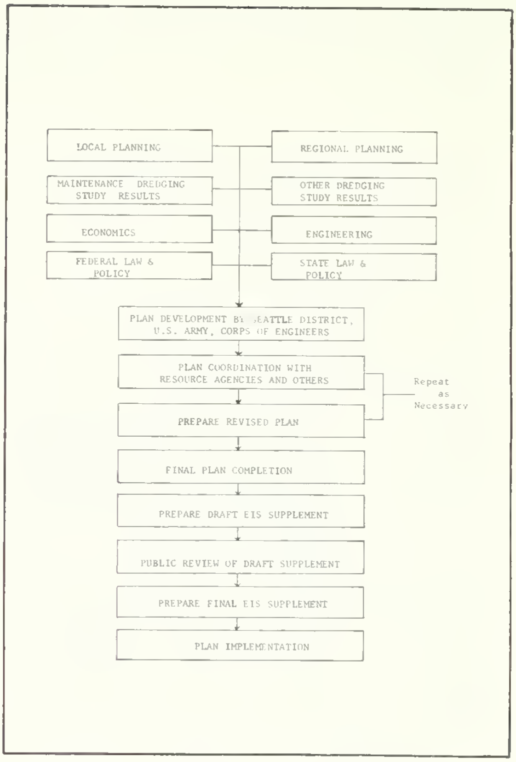

Figure 5. Some Input and Information Flows in Development of a Long-Range Maintenance Dredging Plan for Grays Harbor.

marsh in Grays Harbor to develop an industrial area. This action would fill approximately 12 percent of the harbor's remaining sedge marsh. After a high-powered pitch by the co-applicants, the Port of Grays Harbor and Kaiser Steel Corporation, and support of the cities involved, followed by an equal counter-pitch from regional representatives of major environmental groups, there remained little question in the minds of mid-level decision-makers that the permit should be granted. Soundly based technical projections derived by ERS from research described earlier on Willapa Harbor and Grays Harbor were also input to the decision process. An eventual decision was reached by the District Engineer to prepare an EIS prior to making a decision on permit issuance. Inner convictions of the District's decision-makers, however, hold the view that although the biological systems of Grays Harbor estuary, in general, and the sedge marsh specifically, may be affected by the demise of this 14-hectare marsh, the loss is not "jugular." Further, the loss of the marsh appears to be an acceptable trade-off when contrasted with the proposed use of the site. Influencing these convictions are the following factors: (1) the state and local authorities have already given their approval for a state permit to fill the site; (2) the region needs the economic boost that Kaiser Steel Corporation offers; (3) the use of the site for construction of offshore oil drilling rigs seems to be a priority action due to the "energy implications"; (4) the marsh site is located in the midst of a developed urban industrial area presently zoned for development; (5) the fact that the marsh exists on old dredged material and is thus not "totally natural"; and (6) federal agencies, although voicing earlier objections to permit issuance, did not, at this time, have objections. The credibility and insistence of ERS staff that the marsh filling for the proposed industry was a significant action, and the requests by the environmental groups to be involved in a planning process, were the prime factors influencing the District Engineer to prepare an EIS. Thus, the combined efforts of staff biologists and the regional expertise of the environmental groups served an essential function to assure full consideration of the values involved.

As pointed out, the marsh in the above example is thriving on previously placed dredged material. This fact has produced a logic by some that the marsh is "artificial" anyway, and thus, is more expendable and filling is acceptable. Of course, the fringing marsh which formerly occupied a position immediately landward of the present marsh has long since been converted to uplands and the "artificial" marsh has, in a sense, compensated for very early fill activities. A diked and riprapped fill (as proposed now) will not create a situation where a new marsh can develop seaward of the currently proposed fill project.

PROJECTS ON TOP OF PROJECTS

The basic approach to maintenance dredging projects described earlier is sound -- acquire technical data, then develop a plan acceptable to all entities, taking cognizance of individual agency responsibilities and desires of interest groups.

During the Grays Harbor maintenance dredging study, a Corps planning effort was progressing separately relative to the maintenance study. This involved a proposal to widen and deepen the main navigation channel at Grays Harbor. Political pressure was applied, largely through the efforts of the Port of Grays Harbor, to accelerate the study of widening and deepening and submit the report to Congress for early authorization of detailed studies for the new project (prior to completion of the maintenance dredging study). Outside pressure was resisted but the timing of the maintenance dredging study resulted in a paradoxical situation whereby an acceptable conceptual dredging plan for 12 million cubic meters of initial dredging, plus 2-1/4 million cubic meters per year maintenance, had to be developed before the "lesser" problems for planning the routine annual maintenance of the existing project were resolved.

It is, at first, difficult to understand how an agency could seemingly conclude that $400,000 spent over 2 years was necessary to figure out how to handle 1.5 million cubic meters per year, but conceptual planning for 12 million cubic meters, plus 2-1/4 million cubic meters per year, could be completed in a much shorter time period. Much of the paradox is explained by the Corps' planning process, which requires preliminary plan development with modest funding. Planning proceeds to more and more detailed levels, in phases, with each phase designed to reaffirm or reformulate the original preliminary recommendations, whichever is appropriate, based on all available data inputs. Further, the planning and the maintenance dredging studies were separate investigations conducted under different authorities, pursuant to different Corps functions. Internal coordination was thus bound to be difficult. To explain this Corps planning process to other agencies, other environmental groups, and individuals, though difficult, was possible, but as expected, did not make a lot of sense to them.

While the District's decision-makers would have liked to delay the planning study to take full advantage of the findings of the maintenance dredging study, the political pressure made this difficult. We advised that we would have some results of the investigation, however, before the decision was made to proceed rapidly with the planning study. This is not to criticize political pressure, which is an accepted fact of life. The local sponsor, feeling transportation demands and operating costs and necessarily sharing in project construction costs, has a major stake in successful completion of project reports. Clearly, pressure exerted by a port on the behalf of its public, plays an understandable, perhaps necessary, role in assuring that the methodical machinery of the bureaucracy does not become too lethargic. Such pressures play a real, albeit not totally predictable, role in our planning environment -- one that is particularly influenced by regional expertise from many sources.

Resource agency response has been as expected -- negative. They were being asked to participate in an effort to develop an acceptable operation and maintenance dredging plan and simultaneously being asked to approve a planning project of much greater magnitude for the same shipping channel. The major question was: What happened to environmental planning for the new project? And the corollary questions were: Where are the data for good environmental planning? Where were we when the planning took place?

One eventual result was an official position by the State of Washington that no decision on widening and deepening should be made until appropriate data collection and environmental planning had occurred. Also before the Corps is an official U.S. Fish and Wildlife Service Coordination Report suggesting that $170,000 would be necessary to "develop" studies for evaluating the widening and deepening project. The eventual cost of the studies was estimated to be as high as $5 million, with mitigation costs to be added later. The usual amount of funding for environmental studies of projects this size is normally in the 5-figure range.

The report on widening and deepening has not gone to Congress, and the proposal has not been authorized. Preliminary congressional authorization will not authorize or provide funds for actual construction. It will provide at least two years for additional study, which, if used constructively, will assure that a sound project is recommended. Nevertheless, the example illustrates how broadly based, textbook planning can be shortcut resulting in a "catch-up" approach which may or may not prove acceptable.

CONCLUSIONS

The earlier sections of this paper which have reviewed examples of data acquisition and utilization techniques using regional expertise have been shown to influence planning and decision-making in varying manners. We feel that, as a concluding observation, it would be useful to examine why this is so.

The mechanisms and methods we have discussed, for the most part, are not complex. The Atlas development and the listing of tests for significance were really rather uncomplicated exercises; the Willapa opinion survey and follow-up analysis exercise weren't new concepts even when they were carried out. Workshops, research, data collection, field trips and intensive person-to-person communication are standard tools in any study effort. Yet, successful input to the planning process in each of the examples we have discussed has varied. Why? It's not a lack of laws, regulations and guidelines. It is not for lack of detailed assessment and analysis methodologies -- we are amply supplied with workable versions, though the emphasis, clarity and thrust of many could be improved. Then why?

We submit that it is because of the system, the people who run it, and inertia -- because of what directives like the CEQ Guidelines do not, perhaps cannot, say about planning. Specifically:

-- Budgets, schedules, reporting requirements which are oriented to years of experience with "technical" studies -- concrete, foundations, excavations, sideslopes and so on -- with a lesser ability to accommodate "nontechnical" problems -- ecosystem analyses, water quality sampling, habitat improvement;

-- Political pressure, real and imagined, on all participants in the planning process, but especially on those who are used to it and don't mind too much;

-- How truly difficult it is to fairly convey all values (significance) of resources and amenities for tradeoff analysis;

-- Local sponsors who think the EIS, and other environmental requirements, are fine as long as the alternative selected is the one they want, and they don't have to pay too much for it;

-- Environmental obstructionists, agencies, groups or individuals, who make it nearly impossible to plan thoughtfully when local sponsors do temper the use of political pressure and bureaucrats do really try;

-- The business-as-usual philosophies of some entrenched bureaucrats who, for the most part, view environmental business as something to put up with, at best -- at worst, as a personal threat.

We perceive these as some of the constraints under which we, or any environmental planner, must function.

A final point is this: The agency biologist must function in an administrative, bureaucratic, political system every bit as complex as the natural ecosystem whose values he/she must champion. Any failure or weakness at the level of this biologist, or those assisting with new methodologies and concepts, is particularly critical -- perhaps equivalent to a failure at the level of the primary producers in an ecosystem. We suggest, then, that some of these constraints become the tests of your methods, and we challenge you to apply a few from our "real world."

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APPENDIX

ENVIRONMENTAL IMPACT STATEMENT EVALUATION CRITERIA

These criteria have been developed to more efficiently evaluate federal agency actions as to their significance and, consequently, their need for an environmental impact statement. From CEQ Guidelines (40.1500.6,c):

> "Each agency should review the typical classes of actions that it undertakes and in consultation with the Council, should develop specific criteria and methods for identifying those actions likely to require environmental statements and those actions likely not to require environmental statements."

While ER 1105-2-507, the Corps' guidance for accomplishing this review, indicates specific actions which by definition will require an EIS, it also cites those which may require an EIS -- permits for example. No "tests" for significance or nonsignificance are provided.

The District Engineer must consider whether or not an EIS is necessary at the earliest time during the processing of an activity which is not routinely subject to an EIS. This will be done when he can make an assessment of the environmental impact of a proposed activity, which in some cases may be very early due simply to the magnitude of the proposed project or the nature of the area involved.

Still, specific criteria which may indicate, at any stage of a planning process, a major federal action significantly affecting the quality of the human environment has not been formulated in the District. A positive test, however, for the following factors singly or in combination indicates the need for an EIS.

(1) Type of project - test project type. Some projects or actions by their unique, rare nature or by their precedent establishing potential may be EIS actions. The lack of knowledge of impacts associated with a unique action constitutes a demand for that analysis.

(2) Physical size of project - evaluate project size. While sheer physical size may not necessarily signify the necessity for an EIS, it does usually indicate resource utilization, and thus, the need for environmental analysis in considerable depth.

(3) Relative magnitude of project - compare project size. A project considerably greater in physical size than other projects with a similar purpose indicates potential need for an EIS.

(4) Project expense - determine project cost. High actual monetary cost indicates commitment of resources. A $1 million investment is judged by many to require an EIS.

(5) Specific impacts on natural environment. The following potential primary and secondary environmental impacts will be evaluated for important potential effects.

(a) Biological impact. Determine specific biological impact, including an evaluation of the effects of the proposed action on the total ecosystem, including (1) fish and wildlife, with emphasis on fish spawning and nursery areas, fish spawning cycles, and migratory patterns and routes; (2) wetland structure and function, including food chain production, nutrient cycling, and provision of habitat for aquatic and land species; (3) submerged and emergent vegetation; (4) benthic invertebrates; (5) plankton and nekton; and (6) macroalgae.

(b) Cumulative biological impact. Evaluate a particular wetland area with the recognition that it is part of a complete and interrelated wetland resource. Although a specific project may result in only a minor alteration of wetland area, consideration will be given to the potential cumulative effect of numerous such minor alterations, which together could result in a major modification in an area's wetland resources and related fish and wildlife resources.

(c) Air quality impact. Evaluate any modifications in ambient air quality in view of compliance with applicable air quality standards. Important parameters to be considered will include arsenic, carbon monoxide, sulphur oxides, hydrocarbons, particulates, and photochemicals.

(d) Water quality impact. Evaluate any significant effects on ambient water and sediment quality in view of compliance with applicable effluent limitations and water quality standards during construction or operation of the proposed action. Important parameters to be considered include suspended solids, total dissolved solids, heavy metals, synthetic organics (including pesticides), phenols, oil and grease, fecal coliforms, biochemical oxygen demand, dissolved oxygen, radionuclides, heat, color, and forms of nitrogen and phosphorus.

(e) Noise impact. Evaluate modification in ambient noise level, with a view toward compliance with applicable noise level standards.

(f) Esthetics. Evaluate the potential effect on esthetic quality of the project area.

(g) Scenic and recreational values. Consider the potential effect of the proposed action on the enhancement, preservation, and/or development of recognized scenic, conservation, or recreational values in the project area.

(6) Irreversible commitment of resources. Identify and evaluate the extent of any irreversible resource commitments due to the proposed action. This involves an identification of the extent to which the action irreversibly curtails the range of potential environmental uses.

(7) Loss or gain of threatened wetland resources. Evaluate the proposed action relative to the loss of threatened wetland resources. Wetlands constitute a productive, valuable and rapidly diminishing public resource, any unnecessary alteration or destruction of which should be discouraged as contrary to the public interest.

(8) Economic and social impacts. Evaluate the potential effects of the proposed action on the following economic and social parameters, pertinent:

(a) Economic parameters:

(1) Local government finance, including tax revenues and property values.

(2) Land use patterns, including recognition towards state, federal and local land use classifications or federal controls or policies. The evaluation will be consistent with, and avoid adverse effects on, values or purposes for which those classifications, controls, or policies were established.

(3) Public facilities.

(4) Public services.

(5) Local/regional activity, including regional growth and relocation.

(6) Real income distribution.

(7) Employment/labor force.

(8) Business and industrial activity.

(9) Agricultural activity, including farm displacement and food supply.

(b) Social parameters:

(1) Population factors, including growth, migration patterns, density patterns, and displacement of people.

(2) Housing.

(3) Transportation, including highway access and rail service.

(4) Community cohesion, community growth; health.

(9) Legal considerations. Evaluate a proposed action with a view towards comparison with any relevant or pertinent legal considerations. Historically, the courts, in determining whether a cumulative or immediate impact on the human environment is significant, have been most concerned with the following issues:

(a) The extent that the proposed project is in character with the surrounding environment.

(b) The degree of controversy that the project will, or has, engendered.

(c) Any potential involvement with the destruction of any highly valued or unique areas, including marshlands and intertidal lands.

(d) The extent of objections from federal, state and local agencies.

(e) The extent to which persons living in the project area would undergo changes in the quality of their lifestyle.

(10) Preparation of SEPA EIS. The existence of an EIS in compliance with a state Environmental Protection Act constitutes a reasonable indication that the proposed action would be a significant action affecting the quality of the human environment.

(11) Setting of precedent. Evaluate the proposed project to consider any precedent created for future activity and the potential cumulative effect that could result therefrom. Even minor actions can be considered as actions having significant environmental impact as they may have the potential for establishing a precedent for future major actions, having significant adverse impacts, or several actions with individually insignificant but cumulatively significant adverse impacts.

(12) Controversy. A proposed action may be considered significant and require an EIS when the project or its real or perceived environmental impact is considered highly controversial, as measured by responses from various agencies and the public. This may be particularly true when identified more environmentally acceptable alternatives have been rejected.

(13) Cultural resources. Any proposed action having significant adverse effects on cultural resources in an area listed in, or eligible for listing in, the National Register of Historic Places; or resulting in potential irreparable loss or destruction of significant scientific, prehistoric, historic, or archeological data is considered as having significant environmental impact.

TOWARD A STRUCTURED ECOLOGICAL BASE FOR USE IN ENVIRONMENTAL IMPACT ASSESSMENT - THE NATIONAL WETLAND INVENTORY

John H. Montanari[1/] and Joseph E. Townsend[1/]

INTRODUCTION

The need to consider and use sound ecological information in forming decisions concerning policy, planning and operational management of our natural resources is a well-known concept of long standing. It is also common knowledge that this concept has been and is the subject of a lot of talk, much writing, and even several significant laws including the Fish and Wildlife Coordination Act of 1934 as amended, the Endangered Species Acts of 1966 and 1969, the U.S. Forest Service's Multiple Use Act of 1960, the Forest and Rangeland Renewable Resources Planning Act of 1974, the Marine Mammal Protection Act of 1972 and, of major significance, the National Environmental Policy Act of 1969.

Despite all of this, instances of gross mismanagement of our natural resources still occur. We see the ecological systems comprising these resources being restructured and redirected to channel all their energy and nutrients into a single product. We see many of our ecosystems being mutilated and wiped out by pollution as well as by urban, industrial and agricultural development. Why is this?

Certainly, short-term economic gain and its political implications are involved. However, we believe the majority of our nation's people, including the policymakers planners and managers, would like to do their best for future generations as well as meet our short-term needs. The major problem is simply that the information needed to make environmentally sound decisions, for one reason or another, is not effectively used in the decisionmaking process.

This conclusion is not new. Many have reached it before us. In fact, research is increasingly being directed toward the discovery of essential biological and ecological information. And, of considerable significance for the resource managers, a plethora of information systems are being designed to accumulate, store, analyze and produce this information.

These systems which are designed to get the needed information into the hands of the decisionmakers (which includes the American public) are a major step toward environmentally-sound resource management. However, the current situation of unilateral development of many different information systems, containing basically the same data and intended to satisfy the same kind of need, does not seem to be the most efficient or effective approach. We believe it is time for a coordinating effort which will bring these systems into some measure of compatibility and structured integration, at least in terms of fish and wildlife habitat related information.

Consequently, we have designed the National Wetland Inventory so that it will provide a single, universally applicable system of wetland information which will describe all wetlands on an individual and/or cumulative basis in terms of their ecological and physical characteristics, geographic location and natural resource values. Further, we will use this endeavor to provide a base and guide for the development of an all-habitat inclusive system designed to include classification, ecological characterization (Hirsch 1976), geographic location and evaluatory information needed in natural resource policy formulation, planning and operational management.

Both the National Wetland Inventory and the more comprehensive Habitat Classification and Analysis Project are described in the following sections.

1/ John H. Montanari, Project Leader, National Wetland Inventory Project, Office of Biological Services, U.S. Fish and Wildlife Service. Joseph E. Townsend, Manager of Systems and Inventory Projects, Office of Biological Services, U.S. Fish and Wildlife Service. We thank the hundreds of scientists in the federal and state agencies, the universities and private consulting firms who have assisted with these projects. Within the Fish and Wildlife Service, Drs. Lewis Cowardin, Henry Sather, Allan Marmelstein, Bill Wilen, Allen Hirsch and Mrs. Mary Markley have provided essential assistance.

NATIONAL WETLAND INVENTORY

The U.S. Fish and Wildlife Service, Office of Biological Services is conducting an inventory of all the wetlands of the United States, including its territories and possessions. The National Wetland Inventory (NWI) will create a data base, in both map and computer form, in which wetlands data will be collected, interpreted, stored and reproduced.

The last national wetland inventory, which surveyed only the lower 48 states, was completed in 1954 (S.P. Shaw and C.G. Fredine, 1956). Since the 1954 inventory, a large amount of wetlands modification has occurred. In addition, the importance of wetlands in the biological and physical environment is more widely appreciated, and a better methodology exists for classifying and inventorying this resource.

THE NEEDS FOR WETLANDS INVENTORY DATA

At the federal level alone, there are at least 10 groups within the Department of Interior, as well as nine other federal agencies (including Corps of Engineers, Environmental Protection Agency, and National Marine Fisheries Service) which have indicated a need for the data to be produced by the NWI. A wide range of regional, state and local governmental bodies, and private conservation groups have stated specific needs to apply this data to their own programs.

Within the Fish and Wildlife Service, there are three major uses of wetlands inventory data:

1. FWS is currently required to process approximately 35,000 permit applications per year for activities using wetlands. The recent court decision broadening the scope of Section 404 to include all waters of the U.S. will add to this workload. The NWI products will identify wetlands, help establish boundaries to controlled areas, and allow an area, region or flyway analysis. This will reduce costly field examination and time-consuming permit-by-permit procedures.

2. Each year a considerable amount of money is authorized for the migratory bird wetland acquisition program. The NWI products will allow critical areas to be identified in order to set priorities for wetland acquisition.

3. The federal-state cooperative migratory bird management program requires a continuing qualitative and quantitative analysis of wetland habitat. The NWI will provide an accurate, comprehensive data base for this analysis.

GOALS AND LONG-TERM OBJECTIVES

1. Provide needed information that will aid the FWS, other interested agencies (state as well as federal), private organizations and individuals to achieve resource management and habitat preservation objectives.

2. Develop an inventory system that can be easily and economically maintained.

3. Develop the system and gather the basic informational needs in as short a period of time as is technically and economically feasible.

4. Present the information in a variety of products to insure its maximum usefulness to the user (maps, data bank, reports and work materials).

PRE-OPERATIONAL PRODUCTS

The National Wetland Inventory project is still in the pre-operational stage. Five major pre-operational products are completed or scheduled to be completed by July 1976. They include:

1. A new wetland classification system. The system used in the 1954 inventory identified 20 wetland types, all of equal rank. Other existing wetland classification systems use a similar "horizontal" system. The classification system developed for the NWI is hierarchical or vertical in nature. The uppermost levels are ecoregions and physiographic provinces and the system proceeds through several decreasing levels ending with highly detailed and specific wetlands characteristics.

There are several advantages to this "vertical" structure, the principal one being the ability to utilize the classification system to levels of detail as required by the individual user. Thus, while local governments or agencies may wish to describe wetlands in detailed fashion, a state or regional agency may only desire a general description. A hierarchical classification system is designed to function at varying levels of detail whereas a horizontal system is not.

The classification system will be tested at several sites (at least eighteen) in the country during the summer of 1976 to determine its ecological soundness and its applicability in inventorying the diverse wetland types found in the United States.

Additional work is also underway to devise a systematic method for determining the value of the various wetland types (described in the classification system) as fish and wildlife habitat. This evaluation system will ultimately be combined with the wetlands data bank so that a user may have access to information on the type, location and ecological value of the wetlands in any area of interest.

2. A survey of existing wetlands inventories. This survey compiles information on wetland inventories conducted by federal, state and local governments, and private conservation groups since 1965. The National Wetland Inventory will utilize these inventories to avoid duplication of efforts. This survey will also be of immediate value to other agencies that wish to locate detailed inventories of specific areas.

The survey will be published in two volumes. Volume I, representing each of the six FWS regions, will contain 1:750,000 state maps showing the location and extent of major wetland inventories. There will be six issues of this volume, one for each of the six FWS regions. Volume II will contain a narrative description, by states, of all known inventories since 1965. Included in the narrative description will be inventory information such as the classification system used, the purpose of the inventory, the methods used, the legislation involved, and how an interested user may obtain additional information concerning a particular wetland study.

3. An atlas of recent, high altitude aerial photography. The NWI will use, in part, aerial photographic interpretation techniques to inventory the wetlands of the U.S. Compilation of a graphical index of existing, high-quality aerial photography was a necessary step in order to locate the imagery needed to conduct the inventory.

The atlas will display, on 1:750,000 state maps, recent aerial photography (since 1970) subject to specific parameters based on the requirements of the National Wetland Inventory. These parameters are:

a. Scales of 1:24,000-1:130,000;

b. Only blocks of imagery covering at least 50 sq. miles;

c. Exceptionally high quality (0% cloud cover, etc.);

d. Preference will be shown in order for color infrared, color, black-and-white infrared, and black-and-white film emulsion types.

4. A series of 1:250,000 maps delineating ecoregions, physical subdivisions and land surface forms of the U.S.. The first levels of the wetlands classification system are ecoregions as defined by Bailey (unpublished) and physical subdivisions and land surface forms as defined by Hammond (1964). This series of 468 maps, covering the conterminous 48 states, displays the boundaries of these units on standard 1:250,000 USGS maps sheets. Alaska, Hawaii and U.S. Possessions will be completed during fiscal year 1977.

5. Wetlands protection guidebooks for use by local units of government, states and interested citizens. Existing state and local wetland protection efforts will be digested and alternative model statutes and ordinances will be drafted. Two guidebooks will be prepared. One will be a scientific and legal handbook detailing technical planning issues (including wetland inventories), legal issues, and regulatory and nonregulatory approaches to wetlands protection. A second guidebook, specifically for local units of government, will present model ordinances and a step-by-step approach in adopting local wetlands regulations.

OPERATIONAL PRODUCTS

The operational phase of the NWI is scheduled for initiation in FY 77 and completion in FY 79. The inventory system and products will be designed so that they can be continuously maintained or periodically updated. The current status of wetland modification or loss may be monitored and recorded in the future. The major products will include:

1. The National Wetland Inventory Map Series. The maps will display wetlands, classified according to the system described in the preoperational products section, at a scale of 1:100,000 for the entire United States. Acreage of each wetland will also be displayed. In areas congested with a large number of small wetlands, as in the Florida karst terrain or the prairie pothole region of the Dakotas, maps of 1:24,000 scale will be produced. The base maps will be enlarged versions of the standard USGS 1:24,000 quadrangle sheets for the 1:24,000 series. These base map sheets display necessary locational information such as state and county boundaries and major highways.

2. A NWI data bank. All information gathered for each wetland, as displayed on the map series, will be digitized and stored in an "open-ended" computer data bank. Each wetland will be located by Universal Transverse Mercator Grid Coordinate, physical subdivision and ecoregion, major watershed,

flyway, state, county and census district. This information can then be retrieved and manipulated by the user to produce either tabulated printout sheets or computer-generated maps at any scale.

Due to a technological "breakthrough" in aerial photograph interpretation and information digitization (accomplished by project personnel working with one of our contractors) we have the potential for economically generating computer tape information which will allow products of superior accuracy. As an example, maps generated by our computer tapes will be considerably better than the established "National Map Accuracy Standards."

3. Regional and National Summary Reports These reports will summarize the findings of the inventory in each FWS region and for the entire country. They will include tabulations of data for wetland type, political division, and natural physical division (such as land surface form, flyway and watershed).

4. Work materials . While conducting the inventory, a vast amount of collateral data, aerial photography, compilation maps, work sheets and field reports will be collected. These materials will be made available, on a limited basis, to those organizations that have a need for such information.

Implementation Strategy

Several criteria were fundamental to development of strategy:

- The need to qualitatively standardize the results of the inventory across the country;
- The need to establish a system of management control for a project of this magnitude;
- The need to establish a system that maximizes the efficient use of fiscal resources;
- The need to develop inventory products that meet the needs of the largest number of potential users.

The following strategy meets these criteria and will be implemented (subject to Congressional appropriations).

A central NWI Operational Group will be the focal point for coordinating all activities concerning the inventory. This Group will acquire all work materials necessary for performing the inventory, develop a set of guidelines (operations manual), and provide technical assistance and guidance, as well as the work materials, to seven Regional Wetland Coordinators (one to be established in each of the six FWS Regional Offices plus Alaska).

The Regional Coordinators will be responsible for the inventory of wetlands within their region and the preparation of regional reports.

The collection of inventory data will actually be accomplished under contract. Contractors will be directly responsible to the Regional Coordinator. They will use the work materials supplied by the central office, inventory wetlands as directed, and provide the Regional Coordinator with completed final "field" compilations (summary reports and inventory maps). The contractors could be states, private industry, or branches of the federal government.

When geographic areas are satisfactorily completed, they will be forwarded to the central office where the materials will be edited and the final products completed and made ready for distribution to users. This effort includes development of the data bank, completion of narrative reports, maintaining qualitative uniformity between regions and preparation of final maps.

The operational strategy also provides that other "interested" federal agencies will be invited to participate, at their own expense, in the operation of the central office. Although this is not critical to the operation of this facility it can accomplish several things. First, it will facilitate the collation of existing collateral data that exist within other federal agencies. Second, it will expand levels and scope of expertise, i.e., soils, hydrology, etc. Third, it will provide an interchange of ideas and a means for operational-level, interagency coordination and dissemination of information.

Because it is necessary to initiate the strategy (on a phased basis) early in calendar year 1976 in order to begin operational activities in October 1976, and since the actual inventory is scheduled for completion in three years, it seems appropriate to supplement the central office staff by a support/service contractor. This will accomplish two things: access to needed personnel in a short period of time on an as-needed basis, and secondly, will not require excessive permanent or temporary staffing by the FWS beyond the actual inventory period, i.e., when the inventory effort is complete the service/support contract is terminated. This contractor would provide additional wetland inventory expertise, cartographic and graphic arts staff, computer software, digitization capability and some general office assistance.

The operational strategy for FY 77 is to initiate inventory activities in October 1976 in Florida and to proceed in all phases of activities so that by the end of that fiscal year the coastal wetlands of the conterminous U.S., the lower Mississippi Flood Plain region and a major block of the prairie pothole region are completed.

In FY 78 operations will begin in Alaska, the interior regions of the lower 48, Hawaii, Puerto Rico and the Virgin Islands. During FY 79 the inventory would be completed.

Unforeseen needs may cause us to rearrange the scheduling for any given area, but the three years total time to do the whole inventory will probably not change.

The reasons for the above approach are:

1. We should start in an area where we know at this time that we have a source of the needed work materials to initiate activities since approximately 150 days lead time is needed to locate and obtain those items.

2. Initiation of activities should start in a region where field activities are possible in order to train personnel and resolve inventory operational problems early in the project.

3. The coastal zone is of extreme interest to the Corps of Engineers, NMFS and the office of Coastal Zone Management (NOAA). The coastal zone plus the other FY 77 priority areas are of interest to FWS's migratory bird and permit review programs.

HABITAT CLASSIFICATION AND ANALYSIS

This section discusses a project recently (June 1976) implemented by the Fish and Wildlife Service. The purpose of this effort is to develop an all-habitat inclusive system designed to include classification, ecological characterization, geographical location and evaluatory information needed in resource policy formulation, planning and operational management. It will eventually incorporate an expansion of the hierarchical wetlands habitat classification system to include terrestrial habitat and also a similarly expanded version of the wetlands computerized data management and information system. The basis for and nature of such an activity are discussed in the following sequence:

- Needs for systematic habitat classification and evaluation in terms of environmental and institutional consideration,
- Requirements of such a project to satisfy these needs,
- Benefits that would occur from this activity,
- Fish and Wildlife Service role in this area based on agency responsibilities and current activities,
- Project description including discrete tasks and tentative schedule for completion.

I. Needs:

A. Environmental Considerations:

It is apparent that increasing stress will be placed on the nation's natural living resources within the near future. Continued growth of the human population of the United States, which is expected to attain the 280 million level by the year 2000, will result in increasing demands on these resources. Utilization of U.S. energy resources in order to lessen dependence on foreign energy will require massive development of domestic sources. For example, up to 50,000 acres of western lands may be strip mined annually by 1985 in order to utilize surface coal deposits, and the exploitation of remaining domestic oil and natural gas reserves will impinge on sensitive arctic, estuarine and marine environments. Accelerated development of domestic non-energy minerals, such as phosphate, is anticipated in the near future, and will result in additional land and water disturbances, especially in western regions of the country. Increased production of agricultural commodities and forest products, in order to meet growing domestic and world food and fiber needs, will also require more intensive farming and timber management practices with consequent major perturbations and changes in millions of acres of fish and wildlife habitat.

A significant factor in evaluating the cost that will occur as a result of these developments, and in assessing alternative courses of action, is the impact on the nation's fish and wildlife resources. Especially important in this regard is the potential loss and/or degradation of habitat which support fish, wildlife and other living organisms. In a memorandum delineating Fish and Wildlife Service priorities, Director Lynn Greenwalt noted that "the greatest difficulty facing fish, wildlife and habitat resources is habitat destruction."

A first step toward the protection and management of the nation's fish and wildlife, including the achievement of the national energy, food production and related goals in the least harmful manner possible, is the development of a universal habitat assessment system including classification, inventory, characterization, and evaluation of existing fish and wildlife habitats.

B. Institutional Considerations:

The management of most federal and other public resource lands is based on the multiple use concept. Multiple use management includes optimization of fish, wildlife and supporting resources, in concert with other management objectives, and is dependent on accurate and timely information on the distribution and value of fish and wildlife habitats. Similar information obviously is also required for efficient management of the large areas of public land that are wholly or primarily devoted to the perpetuation of fish, wildlife and other living resources (e.g., wildlife refuges, game ranges, wilderness areas, and national, state and local parks, etc.).

The programs of several federal agencies[1/] presently involve the classification, inventory, characterization and evaluation of natural habitats as a basis for natural resource use planning and/or management.

In spite of the widespread need for such information by the various agencies, no uniform system for assessment of fish and wildlife is presently applied either within or outside the federal establishment. The absence of such a systematic approach is an impedance to the achievement of national resource development and environmental protection goals. Specific consequences of this deficiency include:

- Inadequate incorporation of fish and wildlife considerations in the decisionmaking process caused by the use of unstructured and inefficient data bases, acquisition of inadequate and/or low priority baseline information and lack of rigorous ecological assessments of baseline and inventory data;

- Waste of considerable federal resources due to both unilaterally redundant programs of different agencies and the

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1/ These agencies include the Forest Service, the Soil Conservation Service, the Army Corps of Engineers, the Bureau of Land Management, the Bureau of Reclamation, the National Park Service, the Geological Survey, the Office of Coastal Zone Management, the National Marine Fisheries Service, the Office of Land Use and Water Planning, the Federal Highway Administration, the Environmental Protection Agency, and the Fish and Wildlife Service. Additional agencies also require habitat information and a systematic basis for habitat assessment, in order to make regional determinations for energy and other developments, and to develop guidelines for facility siting and operation. All federal agencies, when their activities potentially impact the environment, are required to make habitat assessments in order to develop "Environmental Impact Assessments and Statements." In addition to the federal agencies, all state governments are heavily involved in similar activities in accordance with their individual state responsibilities and authorities.

traditional habit of starting anew with data collection, analysis, etc. for each new problem encountered;

- Necessary development of natural resources to meet our national needs for energy, food and fiber are delayed because we cannot determine potential environmental impact and are thus legally restricted from taking <u>any</u> action;

- More importantly, avoidable detrimental actions are often undertaken, while reasonable alternatives are not recognized, or are discovered too late for consideration, all due to lack of a defensible, scientifically sound, rationale for habitat assessment.

C. <u>Other Considerations:</u>

Additional considerations indicate the need for this Habitat Classification and Analysis Project:

(1) National Comprehensive Resource Management -- we are well into an era wherein our important natural resources will be managed in accordance with policies based on the findings of national inventories and evaluations of these resources. This appraisal is based on the following information:

- The Forest and Rangeland Renewable Resources Planning Act of 1974 (PL 93-368) required the U.S. Forest Service in cooperation with other agencies, states, territories, and private organizations to: Inventory and assess the renewable resources of the nation; prepare a "Renewable Resources Program" for the National Forest System; develop resource management plans based on integrated consideration of physical, biological, economic, and other criteria and assist state and other organizations in developing management plans for renewable resources on non-federal lands. The year 2000 was established as a target date for comprehensive management of the resources of the National Forest System.

- Similar legislation concerning the Soil Conservation Service's program is pending in Congress. This legislation is designated as Senate Bill 2081 and listed as an amendment in the Congressional Record of October 1, 1976, page S-17198.

- Other agencies have expressed interest in similar legislation for lands under their jurisdiction.

(2) It is apparent that the Fish and Wildlife Service shares with many agencies the challenge of conducting its business in less manpower-intensive, more cost-effective ways. There has been, up to the present, a unilateral proliferation of biological information and assessment systems among various agencies. The time is propitious for a significant effort to coordinate these common activities. This project represents a significant step in this direction.

(3) The state-of-the-art in development, analysis and mechanical manipulation of resource information, as well as advances in planning technology, makes it possible to conceive and conduct comprehensive natural resources planning, programming and operations.

(4) Given all of the above, it is evident that national resource evaluation and management programs are emerging and will be well underway in the next decade. Assessment of fish and wildlife habitats should be a major component of this large-scale thrust. This will require comprehensive, well-coordinated habitat conservation programs based on accurate,

accessible data and evaluations.

It is timely for FWS to initiate an effective habitat strategy to aid in meeting its own responsibilities, to significantly assist the other agencies, and to fully participate in new resource management programs.

II. Requirements:

The Project will incorporate the following elements:

- A methodology for classifying all fish and wildlife habitats. Such a method should be hierarchical in structure permitting use of various levels of resolution, applicable to all natural environments and provide a flexible structure for inventory data requirements.

- Standard, cost-efficient techniques for acquisition of resource inventory data. Inventory procedures should encompass all parameters of interest and utilize applicable existing information.

- Ecological characterization data which relate the structure, components and functions of biotic components to habitat units attained by inventory (Hirsch 1976).

- Strategies and methods for determining the value of habitats for fish, wildlife, and other living resources, and assessing the effects of change in those habitat values. Methods should: incorporate meaningful ecological criteria; provide quantitative assessments; facilitate comparisons between habitats and between areas; and serve as a basis for determining costs, risks, and benefits associated with a wide range of environmental perturbations as well as any resource management actions.

- A flexible and accessible data storage and retrieval system to support habitat classification, inventory, analysis, and evaluation.

III. Benefits:

A primary aim of development and adoption of a uniform habitat assessment system is to provide an ecologically sound and scientifically defensible basis for the support of habitat preservation, conservation and management activities. Of special importance in this regard are valid inputs regarding the costs, risks, and benefits to fish and wildlife of proposed energy developments and other land and water use activities, and recommended mitigations. Application of the system will support assessments of a broad spectrum of activities ranging from national and regional development plans to the siting of specific facilities.

The adoption of uniform classification and evaluation procedures will permit a more efficient application of the resources of federal (as well as state and local) agencies in the collection and assessment of information pertaining to fish and wildlife impacts and the management of public lands. A comprehensive effort in this area will also increase the application of advanced ecological principles and methods among federal resource managers and upgrade the capabilities of various agencies, including the Fish and Wildlife Service. The development of uniform methodology will also promote more effective interaction among public agencies and enhance coordinated approaches to planning and resource management. Habitat data that are classified according to recognized criteria and evaluated on the basis of significant ecological parameters will provide a more defensible basis for impact assessment, and result in considerable savings in planning and adjudication.

IV. Fish and Wildlife Service Role:

The Fish and Wildlife Service has responsibilities (derived from various laws, regulations, orders and agreements) to obtain and develop information necessary to protect and enhance fish and wildlife habitat, and to ensure effective incorporation of that information into the management plans and actions of other resource agencies as well as those of the FWS.

With the primary exception of Refuge System lands, the Fish and Wildlife Service has only limited operational involvement in land and water management. Primary responsibilities in this area are vested with other federal agencies, state and local jurisdictions, and the private sector. The Service is thus in a unique position to establish a framework for determining habitat values on the basis of sound ecological criteria and relatively free of the encumberances associated with authorizing, administering, promoting or otherwise regulating specific developments and activities that could affect these resources. A habitat assessment system derived by the Service would have general applicability, neither oriented specifically toward any particular types of activities nor incorporating any values other than those pertaining to fish, wildlife and other living resources.

Further, the Service has acquired substantial experience in habitat assessment technology as a result of several ongoing programs. In addition to the National Wetland Inventory, these include the Coastal Ecosystems and the Coal Projects of the Office of Biological Services (OBS).

The Coastal Ecosystems Project is utilizing several approaches in assessing near shore environments, such as selected faunal studies and ecological characterization of coastal areas based on synthesis of existing information.

As part of the Coal Project, efforts are underway to develop and test an ecologically-based classification system for upland ecosystems that indicates wildlife values with a hierarchical system of geological, soil, aquatic, vegetative and climatic information. The system is intended for use in computerized analysis of coal extraction areas.

Several other projects within OBS incorporate approaches, tools and environmental impact methodologies that bear on habitat assessment. These include the ecological assessment activities of the Western Energy and Land Use Team in such areas as oil shale and geothermal development, and the Biological Indicators Project that seeks to identify and employ ecological indicators or sets of reliable environmental observations and measurements for monitoring habitat changes of an ecologically significant magnitude and for tracking and assessing the impacts of planned and unplanned actions.

The habitat classification and analysis project will be a natural extension of these ecological classification and assessment efforts already underway.

V. Project Description:

A. Approach

(1) The Habitat Assessment Group:

The Habitat Classification and Analysis Project will be centered in a support group established specifically for this activity in Ft. Collins, Colorado, during July 1976. It will include representation of the following disciplines:

- Plant Ecologist/Geographer - expertise in description, mapping and analysis of meso-scale plant communities;
- Wildlife Ecologist - expertise in wildlife/habitat interrelationships under a variety of ecogeographical contexts;
- Aquatic Ecologist - expertise in aquatic faunal/habitat interrelationships under a variety of ecogeographical contexts;
- Resource Systems Analyst - expertise in the synthesis and analysis of geo-based inventories and their application to resource management;
- Resource Inventory and Data Handling Specialist - expertise in remote sensing, multi-scale sampling, and surface ecological mapping.

(2) Tasks:

The project will consist of the following sequence of activities or tasks:

Task 1. Survey and Integrate Existing Habitat Classification Methods. A number of habitat classification and inventory activities are underway or are being planned by FWS and other agencies. Present OBS projects include: The National Wetland Inventory; development of a structured information synthesis system for coastal environments by the Coastal Ecosystems Team; and development of an ecologically-based classification (ECOSYM) for upland habitats under the Coal Project. The Project will assess these systems, and those employed by outside agencies, and develop the necessary modifications and extensions to permit the classification of all U.S. fish and wildlife habitats.

The project will produce and publish this synthesis of existing methods, modified and augmented as necessary, as the basis for FWS habitat management programs. The published system will be available for adoption or consultation by other federal and state resource management agencies to support their activities which involve habitat evaluation or modification.

Task 2. Analyze Habitat Assessment Requirements of Other Agencies. The information and methodological needs of other federal agencies, as well as state and local jurisdictions, will be assessed. The Project will seek to incorporate the requirements of other programs in developing classification structures and systems of wide applicability and utility.

Task 3. Develop Habitat Classification, Characterization and Inventory Methodology. Components of the methodology will include hierarchical classification schemes that will provide a framework for referencing specific data bases, and procedures for collecting habitat inventory data including remote sensing and other advanced techniques. Methods will encompass ecologically significant features required for habitat evaluations.

Task 4. Develop Strategy and Methodology for Habitat Analysis. This task will identify significant ecological features and incorporate these parameters in standard analyses suitable to FWS and other agency needs. Methodology will emphasize the value of habitats for fish and wildlife and will be structured to permit a variety of analyses and evaluations suitable for various users.

Task 5. Devise a Geo-based Habitat Information System. Extant information handling systems will be surveyed and elaborations made in order to develop a comprehensive system for indexing and accessing habitat information according to geographical location, descriptive classes, and analysis parameters. The scope of the system will likely require computerization to effectively manage the mass of data elements.

Task 6. Design Procedures for Providing Required Information. A variety of information will be developed by the habitat project including: indexes of habitats according to the classification system and parameters for analysis, habitat inventories, analytical procedures, and analytical statistics and formulae. This task will result in capabilities for the production of a wide range of outputs required by users including: maps, overlays and other graphic materials; textual documents; data tabulations; and results of analyses. A capability will also be established for providing staff expertise to assist users with special problems.

Task 7. Implement Habitat Classification and Analysis Systems. The project will be designed with a capability for classifying and analyzing all U.S. fish and wildlife habitats. However, initial implementation of the systems will be on a test case basis (for a specific region or ecogeographical unit) followed by systematic expansion to additional regions or ecogeographical units. The initial systems application will be directed toward an area of high current FWS priority (e.g., coastal ecosystems, western energy regions).

Task 8. Maintenance and Upgrading of Program. Following initial implementation of habitat classification and analysis systems, a continual effort will be applied in maintaining the project's usefulness and upgrading its capabilities. Advances in inventory and analytical strategies and methods, and in the storage, access and transfer of information will be incorporated in order to improve the technological and scientific capabilities of the project and its utility.

B. Project Schedule

We have initiated the project (July 1976) with the establishment of the Habitat Assessment Group. Rate of progress depends on three factors:

- Adequacy of project management and personnel capability and performance;
- Adequate and timely funding; and

- Establishment of a "common thrust" cooperative effort among the state and federal resource management, regulatory and service agencies involved in habitat assessment.

Although the tasks are scoped in a sequential format, several could be performed concurrently.

Our "best progress" estimate is a minimum of three years to have the above numbered tasks completed to the extent necessary to realize significant benefits in savings and resource conservation. Any deficiencies in the above three progress factors would delay or limit the implementation of "operational systems," (i.e., Task 7). However, each task will be structured so that discrete segments of work when finished will not only contribute to the over-all project development, but will also constitute a useful product by itself.

SUMMARY

The United States Fish and Wildlife Service with the cooperation of other federal and state resource management, regulatory and service agencies is engaged in two major fish and wildlife habitat information projects.

The first of these is the National Wetland Inventory which will produce a universally applicable system of highly accurate wetland information describing all wetlands on an individual and/or cumulative basis in terms of their ecological and physical characteristics, geographic location and natural resource values.

Pre-operational products are now being published. They include:

- A new wetland classification system;
- A national survey of existing wetland inventories;
- A national atlas of recent, high altitude aerial photography;
- A national series of maps delineating ecoregions, physical divisions and land surface form; and
- A wetlands protection guidebook.

The operational phase will start (with Congressional approval) in October 1976 and take three years. It will produce:

- The National Wetland Inventory Map Series;
- A NWI data bank;
- Regional and National Summary Reports;
- An indexed set of work materials and collateral data available for limited use.

The second project, Habitat Classification and Analysis, is an expansion of the concepts and technology used in the National Wetland Inventory to provide an all-habitat inclusive system designed to include habitat classification, ecological characterization, geographic location and evaluatory information needed in natural resource policy formulation, planning and operational management.

Information will be accessible in formats which are compatible with resource managers, needs for impact assessment, environmental monitoring and natural resource multiple-use planning.

The purpose of these projects is to provide an accurate, valid and comprehensive fish and wildlife habitat data base and information system for the use of all resource management entities.

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Author's note: The activities described in this paper are essentially being carried out. Some significant changes in strategy have been made between June 1976 and October 1979. These are:

National Wetland Inventory

1. The initial inventory completion date was extended to 1982;

2. The areas to be covered by that time were limited to the most important resources issue areas in the United States including the coastal, Mississippi River, Great Lakes, Northern Prairie and several specific problem areas such as important western coal fields;

3. A study to determine the national trend in wetland status was initiated with results to be published in 1982.

Habitat Classification and Analysis

1. The classification and inventory tasks are being accomplished through a cooperative effort supported by the Fish and Wildlife Service, U.S. Forest Service, U.S. Soil Conservation Service, Bureau of Land Management and U.S. Geological Survey with cooperation of the National Governor's Association, the Council of State Planning Agencies, the National Conference of State Legislators, the Council of State Governments and the International Association of Fish and Wildlife Agencies; Methods for habitat analysis, a geo-based information system and procedures for providing the information to users have been developed by the Fish and Wildlife Service and are being phased into operational use.

THE NATIONAL BIOLOGICAL MONITORING INVENTORY: A POTENTIAL AID TO PLANNING ENVIRONMENTAL IMPACT STATEMENTS[1,2]

Homer T. Kemp and Robert L. Burgess
Environmental Sciences Division
Oak Ridge National Laboratory[3]

INTRODUCTION

Preparation of the biological portions of an environmental impact statement (EIS) or report (ER) and presentation of testimony in related court hearings or trials require substantial consideration of the relevant technical information. The unavailability of pertinent background can cause environmental impact studies to be inadequate or wastefully redundant. It can lead to delays in statement or report completion, in court proceedings, and in initiation of proposed construction, mitigation, or other activities. Biological information, or the lack thereof, is also an important factor in shaping the planning and implementation of environmental study programs. To the environmental impact investigator and others involved in these processes (e.g., information system specialists and librarians), the process of identification and acquisition of biological information is a complex and difficult problem for the following reasons:

1. Sources of information (i.e., journal articles, localized in-house reports, varied referral and abstracting services, local, state, and federal information and numerical data repositories) are virtually innumerable and often widely scattered.

2. Varied information formats make assembling and evaluating printed information a formidable chore.

3. Delays in the availability of information can occur due to prolonged publication procedures, administrative approval requirements, and abstract service processing.

4. Inadequacy of language in current literature and keywords in abstracting and referral services used in characterizing technical literature is evident. If an information need or interest centers on a special or obscure topic, i.e., one that is not uniformly keyworded or indexed, then that information cannot be identified easily, much less acquired with speed and efficiency.

"Biological monitoring" or "biomonitoring" (used interchangeably in this discussion) are not keywords consistently used throughout abstract or referral services. The inclusion of alternative words, such as, "survey," "census," "check-list" and related terms is required to search hardcopy abstracts and journals and to search computerized information files. Varying degrees of success result from attempts to search for biomonitoring projects in these sources, and often the information obtained is insufficient to permit determination of its applicability.

Alternative approaches to solving these problems include more intensive manual searching of libraries, personal interviewing of researchers for the desired information, and mailed information requests (inventories) to pertinent researchers. The latter was employed for the National Biological Monitoring Inventory as we believed it had the highest probability of success within a reasonable time. The mailed inventory, coupled with systematic and objective arrangement of information received and input into a computerized file (database), constitutes a simple description of activities involved in developing "A National Inventory of Selected Biological Monitoring Programs."

The extent of information requested (and acquired) and the manner in which it is entered into the computer file allow tabulation of state-by-state, agency-by-agency, technical category, and other types of informational summaries. We can determine quickly

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[1]Research supported by the President's Council on Environmental Quality, the Office of Biological Services, Fish and Wildlife Service (USDI), the Energy Research and Development Administration, and the National Marine Fisheries Service (USDC).

[2]Publication No. 907, Environmental Sciences Division, ORNL.

[3]Operated by Union Carbide Corporation for the U.S. Department of Energy.

who is doing what, where, when, how, and the intensity level of the biomonitoring activity.

In addition, we are also attempting to identify gaps in biomonitoring coverage throughout the U.S., identify duplications in biomonitoring efforts, and provide program planners and decision-makers with objective, ordered, and succinct summaries of information in critical areas of local, regional, and national concern.

Although perhaps difficult to assess at this time, the Inventory appears to be reasonably successful, as judged by the percentage of returns and the informational content of these responses. The Inventory is viewed as an evolving effort in which principal investigators will be continuously identified and queried, and in which project information will be updated periodically.

OBJECTIVES

The primary objectives of the Inventory are:

1. To comprehensively identify and collect information throughout the U.S., including continental shelf waters, on biological monitoring studies at the principal investigator/project level. We asked for information only on current and recently completed projects;

2. To systematically organize the information in computerized files for on-line, interactive searching; for computer production of reports on technical subject categories, including organisms, study types, management focus, and geographical sites or regions; and for providing complete information retrieval and response/referral services;

3. To specifically identify and fully characterize those projects that establish changes, i.e., time trends, of populations or communities of naturally-occurring flora and fauna.

Scientists, agencies (federal, state, and local), consulting firms, and educational institutions need to be aware of the nature of the Inventory and the services that can be provided in planning and conducting the biological aspects of environmental impact research. For example, through our files we can quickly identify working biologists currently studying organisms of concern in impact assessment at specific locations.

Although the objectives are to identify time trends indicated only by biological monitoring studies, the utility of the program for impact investigators lies both in the actual monitoring projects ($\sim$ 1000), and in the baseline studies ($\sim$ 2100) currently in the database. Studies presently characterized as "baseline" are either one-time surveys (where questionnaires were returned despite definitions and instructions), or bona fide monitoring projects which have started only recently, and consequently have only a single data point in time. Of these, we believe many are viable, well-funded studies that will continue (and thus achieve "biomonitoring" status), while some others, of course, will cease to function. It is almost impossible to determine which way some of these projects will go, so at present all are categorized as "baseline" studies. Information from both types of projects, however, is of potential value in planning and implementing environmental impact studies.

A summary of selection responses to the Inventory will be published by the end of calendar year 1976. The accounting database, MINI-BIOMON, is now accessible for on-line searching locally at Oak Ridge National Laboratory on the ORLOOK program of the ORCHIS system (Singletary 1975). The main database consisting of all publishable responses will be made available nationally for on-line searching by means of ERDA/RECON (Gilchrist 1974).

METHODOLOGY

The National Inventory of Selected Biological Monitoring Programs was initiated in June, 1975 to identify *current* or *recently completed* biological monitoring projects throughout the U.S. Key administrators were identified through a variety of sources, mainly from a series of environmental directories (listed in the reference section). Identification of principal inventigators was accomplished by telephone and other communication with key administrators in all states, and natural resource agencies of local and federal governments. The key administrators were asked for the names and addresses of principal investigators working on specific projects. From this effort, a total of about 7000 names and addresses of principal investigators was compiled. Computer-generated mailing labels were utilized to send project documentation packages, including questionnaire-type forms. The first page of the form (Fig. 1) shows our sponsors, our address, and the beginning of the information requested from participants. Many of the questions are posed in a "circle-the-item" system that provides a

№ 28895 B

PROJECT DOCUMENTATION

NATIONAL INVENTORY OF BIOLOGICAL MONITORING PROGRAMS

PRESIDENT'S COUNCIL ON ENVIRONMENTAL QUALITY

NATIONAL MARINE FISHERIES SERVICE

U. S. FISH AND WILDLIFE SERVICE

U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

PLEASE RETURN COMPLETED FORM TO:

BIOLOGICAL MONITORING INVENTORY
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37830

PHONE: (615) 483-8611
EXT. 3-0391

(Please print in black ink or type) *ADVISORY: THE INSTITUTE OF ECOLOGY*

PRINCIPAL INVESTIGATOR

1. (NAME) (Last, First, Initials)
2. (BUSINESS ADDRESS)
3. (CITY) 4. (STATE) 5. (ZIP)
6. (INVESTIGATOR'S AFFILIATION)
7. (PHONE) ( ) Ext.

DESCRIPTION OF YOUR BIOLOGICAL MONITORING PROJECT

(If you are in charge of more than one project, please use additional enclosed forms as appropriate)

8. (PROJECT TITLE)
9. (PROJECT PURPOSE(S)) (Briefly)
10. (PROJECT SPONSOR(S)) 11. (SPONSOR'S PROJECT OFFICER)
12. (DATE OF INITIATION)
13. (ANNUAL PROJECT FUNDING) (Circle one, or fill in) OTHER (Specify)
a. Exact Amount $ b. <$10,000 c. $10-50,000 d. $50-100,000 e. >$100,000
14. (WILL PROJECT BE CONTINUED?) (Circle one)
a. Yes b. No c. Unknown d. Terminated
15. (MAJOR OBSERVED CHANGE(S) IN TIME) [Briefly describe biotic change(s) identified as a result of your project]
16. (PROGRAM NAME) (If applicable)
17. (PROGRAM DIRECTOR OR ADMINISTRATOR) (If applicable)
18. (ECOSYSTEM OR BIOME TYPE) (Circle all applicable terms)

A. Terrestrial
1. desert
2. forest
a. coniferous
b. deciduous
c. tropical
3. savanna
4. grassland
5. tundra
a. arctic
b. alpine
6. wetland

B. Freshwater
1. stream
2. river
3. lake
4. reservoir

C. Marine
1. coastal
2. estuarine

OTHER (Specify)

NOTE. We would also appreciate receiving any descriptive documents or reports about your project.

UCN-11687
(3 8-75)

Figure 1. First page of the Project Documentation form.

systematic set of code words which are further enhanced with additional keywords provided by responders. Also requested for each project are an abstract, geographical location, data status, statistical treatment, computerization, and availability of data.

For the purposes of the Inventory, we developed a one-page definition of terms that began with a series of word equivalents (Table 1). Projects monitoring natural biota and demonstrating quantitative change through time for a particular population community are the kinds of projects for which we seek information. Excluded from the biomonitoring inventory are projects concerned with human population attributes, agriculture, monoculture forestry, domestic animals, economics, LANDSAT and other remote-sensing studies, and those in which *only* hydrological,

Table 1. Heading and first few entries on the Definition Sheet for the Bio-Monitoring Inventory. Some items are defined by equivalent terms.

"A NATIONAL INVENTORY OF BIOLOGICAL MONITORING PROGRAMS"

DEFINITIONS

BIOLOGICAL MONITORING - BIOMONITORING - MONITORING NATURAL BIOTA

ANALYSIS OF CHANGES WITH TIME - CHANGES - CHANGES WITH TIME

NATURAL BIOTA - ALL NATURALLY OCCURRING PLANT AND ANIMAL SPECIES EXCLUDING HUMANS AND DOMESTIC ANIMALS AND CROP PLANTS

PROJECT - LOWEST LEVEL ORGANIZATIONAL FIELD UNIT, I.E., JOB, TASK OR SUB-PROJECT IN SOME ESTABLISHMENTS

PROGRAM - ORGANIZATIONAL GROUPING OF PROJECTS FOR ADMINISTRATIVE OR COORDINATING PURPOSES AT NATIONAL, INTERSTATE, REGIONAL, OR LOCAL LEVELS

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meteorological, or physical-chemical water quality data are obtained.

The biological monitoring inventory documentation package consists of:

1. A covering letter explaining the project and soliciting response from the principal investigator.

2. A definition sheet.

3. Three copies of the documentation form in the event the principal investigators could report more than one project. We encouraged distribution of extra forms to colleagues.

4. A franked, self-addressed envelope for convenience in returning the response.

Form design, package contents, timing of mailings (including reminder letters), and other procedures were based on a literature review of questionnaire campaigns (Kemp et al. 1978). Form design was based on experience with the US/IBP Abstracts journal (Kemp 1975), and study of a number of previously-employed questionnaires. The form was finalized after review by ORNL coworkers, cosponsor agencies, and nationwide pretesting through The Institute of Ecology.

The main biological monitoring database and supporting databases are interrelated (Fig. 2). The directory database contains the names and addresses of principal investigators (about 7000) to whom the documentation package was mailed. The MINI-BIOMON database briefly records all responses to the Inventory (more than 3100). The bibliographic database contains citations to published documents (about 2000) received with the responses. The main biomonitoring database, only recently initiated, will contain about 1000 selected project responses judged to be the most pertinent and containing the most complete information.

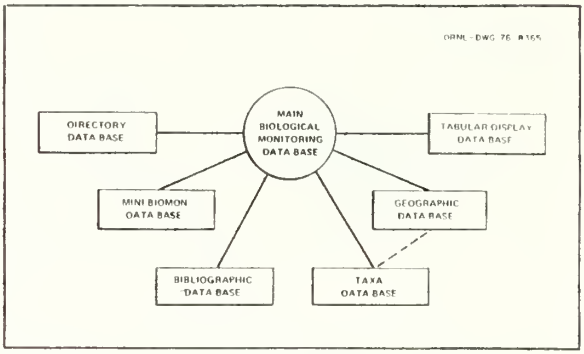

Figure 2. Interrelations of the Main and Supporting Biological Monitoring Data Bases.

Procedures for developing the remaining databases (taxa, geographic description, and tabular display) are established and these will be initiated as time and funds permit. Each will contain more complete project information in selected fields than is contained in the main biological monitoring database. For example, the geographic description database will contain a number of locational descriptor variations that will make it compatible with other geographically-oriented systems. Research will be required since much of the desired information is not contained in the responses received to date.

RESULTS

Through May, 1976, the biomonitoring inventory responses totaled 3132, from all states of the Union, some U.S. territories, Canada, Mexico, and several countries in the Caribbean. To date, about 50 percent of the forms mailed out have been returned. Another documentation package mailing is planned for the near future, principally addressing referrals from returned forms.

A conservative estimate of the funding for projects currently in the files is $126 million per year. This figure is based on the median of the funding level information requested <$10,000; $10-50,000; $50-100,000; >$100,000 and takes no cognizance of the many project responses which contained no funding information. The actual total must be considerably higher, but even an annual budget of $126 million is impressive and indicates the magnitude of the national effort in biomonitoring. The small amount invested in bookkeeping (through this national inventory, for instance) is thus well spent. The projects are sponsored by a diversity of state and federal agencies, teaching institutions, private concerns, and others (Table 2). The federal government leads in numbers of projects sponsored, while the private sector is poorly represented. While this may reflect an appropriate division of responsibilities, this group is also the most difficult to identify and inventory.

The information received can also be characterized by management focus (Table 3). By far, the focus most frequently indicated by principal investigators is environmental impact. The small number of air pollution projects indicated is due to the inclusion of only those studies in which natural biota are measured. For the entire U.S., there are only 35 currently identified air pollution projects that qualify, and this is reflected in information shown in subsequent tables.

Figure 3 is a cartographic display of responses from the Inventory by the study site indicated by the principal investigators. California leads in number of programs indicated by responses to the Inventory. This is probably a reflection of its population, its ecological diversity, the magnitude of environmental concern, and state-level environmental policy legislation. There is also excellent response from Alaska, Florida, Louisiana, Michigan, North Carolina, New York, Texas, and the state of Washington. At present, we are checking the number of responses for completeness on a state-by-state and agency-by-agency basis. Initial results indicate excellent coverage in some instances and low coverage in others.

The following summaries (Tables 4-7) are intended to show the flexibility with which the information can be manipulated and organized. Examples selected are Alaskan studies, Florida marine projects, Atlantic Coast wetland studies, and programs in the Four Corners of the Southwest. Throughout *all* of these, environmental impact again is the most frequent management focus indicated.

Table 2. Number of Projects in Categories of Funding Sponsors, Based on Responses to the Inventory. Approximately 9 Percent of the Projects have Multiple Sponsors.

CATEGORY	NUMBER OF PROJECTS
FEDERAL GOVERNMENT	1557
STATE GOVERNMENTS	776
TEACHING INSTITUTIONS	491
PRIVATE CONCERNS	269
SOCIETIES, ETC.	74
NOT FUNDED	482

Table 3. Number of Responses to "A National Inventory of Biological Monitoring Programs" by Management Focus Categories.

MANAGEMENT FOCUS	NUMBER OF PROJECTS
AIR POLLUTION	35
ENDANGERED SPECIES	479
ENVIRONMENTAL IMPACT	1630
FISHERIES	844
FORESTRY	386
INDICATOR SPECIES	880
POLLUTION CONTROL	843
POWER GENERATION	305
RADIOLOGICAL	108
RANGE	387
RESOURCE PLANNING	671
RIGHTS-OF-WAY	60
WATER QUALITY	1017
WILDLIFE	785

Every major subject area of biomonitoring interest in Alaska (Table 4) is covered by documentation in our files, from grizzly bears, to off-shore oil drilling, and to North Slope development with accompanying tundra destruction. We acknowledge that we do not have all such monitoring projects now in progress in Alaska, but we believe that a significant percentage are now part of the biomonitoring inventory.

Florida marine studies (Table 5) reflect somewhat greater interest than Alaskan studies in endangered and indicator species and in water quality. The degree of interest in power/energy and resource planning appears to be about the same in both these locations. Results similar to those for Florida are evident for the Atlantic coastal wetlands (Table 6).

Note that in none of these three locations (Tables 4-6) are there significant numbers of entries under either Air Pollution or coal. As mentioned above, nationwide there were relatively few air pollution studies in which biological monitoring is involved. With respect to coal as a management focus, it is not surprising that most of the studies documented in our files (69 total to date) originate from inland states.

The Four Corners region includes segments of Arizona, Colorado, New Mexico, and Utah. The combined project responses from these states (Table 7) are twice the number of projects shown for the other locations. Clearly, this region is significantly covered (from a biological monitoring viewpoint), and the numbers of air pollution and coal project responses from the region lend credence to this conclusion.

The matrix format used in Tables 4-7 can serve as a means of making judgments regarding the adequacy of biological monitoring coverage throughout the U.S. Care must be exercised in making interpretations of this type, however, due to limitations imposed by our definition and to the degree of coverage achieved. The matrix can be enlarged to dozens of subject categories along each axis, but this may be impractical for tabular display purposes. The computer can be used to prepare alternate matrices that

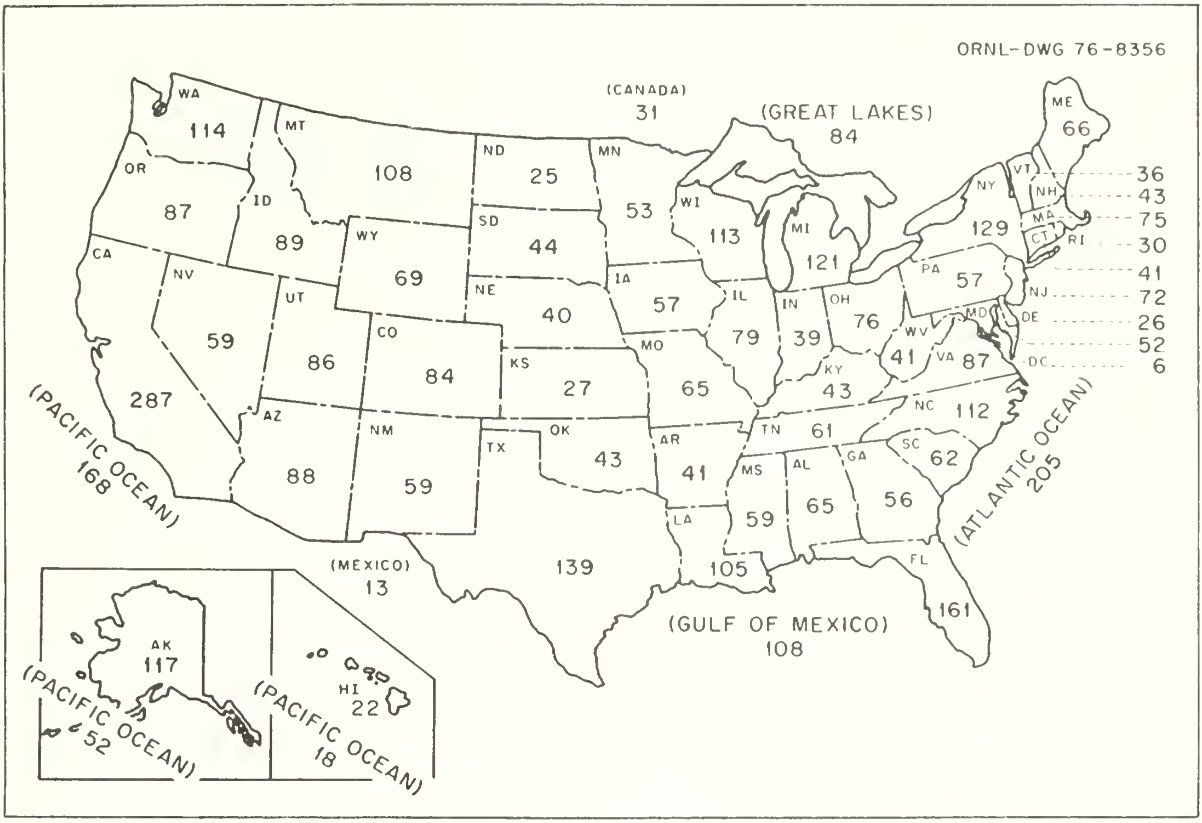

Figure 3. Project responses, by state or region, to a National Inventory of Biological Monitoring Programs through May 1, 1976 - 3087 Total.

may be required by any potential requestor for any of the individual states of the U.S. and for any U.S. regions that can be defined by state boundaries. Further refinement of geographic descriptions (longitude/latitude; county name or code; etc.) will allow more precise summaries. These can be used to precisely locate projects that can then be described in considerable detail from filed information.

In recent months we have provided summarized information to all of our sponsors (CEQ, ERDA, FWS, and NMFS) and also to several officers or laboratories of the Environmental Protection Agency, the Corps of Engineers, the U.S. Geological Survey, the National Oceanographic and Atmospheric Administration, the National Park Service, the Nuclear Regulatory Commission, and the National Science Foundation. We are exchanging information with these and other organizations such as the Arctic Environmental Information and Data Center, Texas System of Natural Laboratories, the Nature Conservancy, Oceanographic Institute of Washington, Cornell University Bird Observatory, Battelle-Columbus Laboratory, and the National Focal Point for the United Nations Environmental Program, International Referral System.

SUMMARY

The current and on-going "National Inventory of Selected Biological Monitoring Programs" has been described and presented as a source of information for those involved in planning and conducting environmental impact studies. Although not fully developed at this time, searches of computer files can provide extensive information summaries on individual states or selected regions and a wide variety of technologies. The degree and diversity of responses to the inventory indicate the need for it and its probable future utility. The ability to derive more fully refined information from both the main and supporting data bases will improve as these are developed and supplemented with further information.

Table 4. Number of Responses to "A National Inventory of Biological Monitoring Programs" for the State of Alaska (117 Total), Arranged by Subject and Management Focus. Numbers in Columns are not Additive since Projects were Characterized by Multiple Usage of Keywords and Codewords.

	SUBJECT CATEGORY								
MANAGEMENT FOCUS	BASELINE	MONITORING	REGIONAL	SITE SPECIFIC	PLANTS	ANIMALS	FRESHWATER	MARINE	TERRESTRIAL
AIR POLLUTION	1	0	0	1	1	0	0	0	1
ENDANGERED SPECIES	7	4	3	8	4	9	4	8	8
ENVIRONMENTAL IMPACT	52	19	8	63	35	49	17	35	46
INDICATOR SPECIES	16	7	2	21	12	16	5	10	15
POWER/ENERGY	17	13	3	27	12	19	12	17	16
COAL	0	0	0	0	0	0	0	0	0
OIL	6	5	1	10	6	6	1	7	5
NUCLEAR	2	3	1	4	3	3	1	2	3
RIGHT-OF-WAY	3	2	0	5	1	3	2	4	1
OTHER	6	4	2	8	5	6	2	6	5
RESOURCE PLANNING	23	10	4	29	17	22	9	17	23
WATER QUALITY	12	6	0	18	4	12	14	11	6
TOTAL	(79)	(38)	(12)	(105)	(46)	(86)	(37)	(52)	(72)

Table 5. Number of Responses to "A National Inventory of Biological Monitoring Programs" for Florida Marine Studies (92 Total), Arranged by Subject and Management Focus. Numbers in Columns are not Additive (See Table 4).

	SUBJECT CATEGORY							
MANAGEMENT FOCUS	BASELINE	MONITORING	REGIONAL	SITE SPECIFIC	PLANTS	ANIMALS	ESTUARIES	WETLANDS
AIR POLLUTION	0	0	0	0	0	0	0	0
ENDANGERED SPECIES	19	4	0	23	9	19	18	7
ENVIRONMENTAL IMPACT	43	18	7	54	22	49	40	12
INDICATOR SPECIES	24	9	5	28	10	31	20	6
POWER/ENERGY	16	8	3	21	7	17	19	3
COAL	0	0	0	0	0	0	0	0
NUCLEAR	8	1	1	8	3	6	7	1
OIL	2	0	1	1	0	2	0	0
RIGHTS-OF-WAY	0	1	1	0	1	1	1	1
OTHER	6	6	0	12	4	11	9	8
RESOURCE PLANNING	27	4	5	26	9	24	20	4
WATER QUALITY	22	14	2	34	11	30	33	6
TOTAL	(67)	(25)	(14)	(78)	(27)	(74)	(61)	(15)

Table 6. Numbers of Responses to "A National Inventory of Biological Monitoring Programs" for Atlantic Coastal Wetlands (126 Total), Arranged by Subject and Management Focus. Numbers in Columns are not Additive (see Table 4).

	SUBJECT CATEGORY							
MANAGEMENT FOCUS	BASELINE	MONITORING	REGIONAL	SITE SPECIFIC	PLANTS	ANIMALS	MICROORGANISMS	FISHERIES
AIR POLLUTION	0	0	0	0	0	0	0	0
ENDANGERED SPECIES	14	4	3	15	9	16	3	8
ENVIRONMENTAL IMPACT	36	19	12	48	28	42	23	22
INDICATOR SPECIES	22	12	9	24	12	27	17	15
POWER/ENERGY	13	10	8	15	8	18	15	10
COAL	0	0	0	0	0	0	0	0
OIL	0	2	0	2	0	1	2	0
NUCLEAR	2	3	3	2	2	4	5	2
RIGHT-OF-WAY	4	2	3	3	5	6	3	3
OTHER	7	3	2	8	6	7	3	3
RESOURCE PLANNING	22	11	6	27	22	26	12	11
WATER QUALITY	20	13	7	26	21	24	21	17
TOTAL	(83)	(43)	(17)	(109)	(71)	(87)	(36)	(30)

Table 7. Number of Responses to "A National Inventory of Biological Monitoring Programs" for the Four Corners Region (AZ, CO, NM, and UT, 276 Total), Arranged by Subject and Management Focus. Numbers in Columns are not Additive (See Table 4).

	SUBJECT CATEGORY							
MANAGEMENT FOCUS	BASELINE	MONITORING	REGIONAL	SITE SPECIFIC	PLANTS	ANIMALS	AQUATIC	TERRESTRIAL
AIR POLLUTION	4	1	1	4	4	1	0	5
ENDANGERED SPECIES	39	16	8	47	30	44	20	50
ENVIRONMENTAL IMPACT	100	49	30	119	80	99	55	117
INDICATOR SPECIES	56	23	16	63	41	52	33	57
POWER/ENERGY	40	16	14	42	31	35	27	42
COAL	8	1	2	6	5	7	4	8
NUCLEAR	9	6	1	14	9	6	8	11
OIL	6	0	1	5	2	5	1	5
RIGHT-OF-WAY	3	1	0	5	3	4	3	4
OTHER	9	5	7	7	5	9	7	9
RESOURCE PLANNING	48	20	11	57	46	42	24	58
WATER QUALITY	23	24	9	38	15	33	57	21
TOTAL	(191)	(85)	(55)	(221)	(133)	(185)	(90)	(219)

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APPLICATION OF DIVERSITY INDICES IN MARINE POLLUTION INVESTIGATIONS

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INTRODUCTION

Research on fundamental relationships between species diversity and environmental factors has stimulated many attempts to assess the effects of pollution on diversity patterns in marine communities. Unfortunately, results have been inconsistent and the efficacy of diversity indices is still uncertain. Some ecologists have proposed that diversity indices derived from information theory (especially the ubiquitous Shannon equation, H') provide appropriate biological criteria of environmental quality (Wilhm and Dorris 1968; Haedrich 1975) while others have concluded that H' patterns are not necessarily indicative of the impact of human perturbations (Livingston 1975; Logan and Maurer 1975). This confusion results from semantic and theoretical ambiguity in the diversity concept (Hurlbert 1971), a plethora of quantitative indices of diversity (Peet 1974), and inconsistent empirical observations of diversity in polluted habitats. The lack of standardized indices remains a serious obstacle to comparative investigations of the environmental effects of pollution and natural stresses (Barrett, Van Dyne, and Odum 1976). In this review I will examine the concepts of diversity which are most pertinent to pollution research, indices through which they can be quantified, and examples of diversity alterations in macrofaunal benthic assemblages exposed to various forms of stress.

CONCEPTS

Diversity is a broad concept which is generally regarded as having two basic elements: the number of species (richness) and the evenness of distribution of individuals among the species (equitability) (Lloyd and Ghelardi 1964; Pielou 1969, 1975; Hurlbert 1971; Peet 1974). The distinction between equitability and richness is important because diversity will appear greater in assemblages of equal number of species when individuals are more evenly distributed among them (Table 1).

Diversity, richness, and equitability are rather ambiguous terms. To avoid semantic confusion ecologists must define the exact context in which they are used. The total number of species in marine assemblages is very difficult to estimate. Comparative richness indices are therefore based on either the number of species per unit area or other measure of sampling effort (areal richness) or the number of species per unit number of individuals (numerical richness) (Hurlbert 1971). Areal and numerical richness are distinctly different aspects of diversity. The former provides an estimate of the relative density of species which is independent of the equitability pattern. Numerical species richness is obviously affected by both equitability and the number of species. Importance values for equitability indices are usually based on the number of individuals belonging to each species, but biomass or some measure of a species' functional significance may also be appropriate. The choice of importance criteria can certainly affect equitability comparisons. Many ecologists believe that richness and equitability should be integrated in a single diversity index. The variety of diversity concepts and indices necessitates careful selection of those that are most pertinent to specific research objectives.

From a theoretical perspective, diversity patterns should be indicative of environmental deterioration due to pollution. Sanders' (1968, 1969) stability-time hypothesis predicts a decline in diversity along natural physiological stress gradients. If this hypothesis can be extrapolated to the particular case of a pollution gradient, several changes in diversity can be expected as the degree of environmental disruption increases. The total number of species should decrease because of the elimination of sensitive species with narrow ecological requirements. Tolerant or euryecious species should remain or colonize the stressed habitat and possibly increase greatly in abundance due to the absence of predators and competitors or because of natural adaptations to disrupted conditions. The reverse should occur following pollution abatement. Measures of diversity which seem most appropriate for detecting these changes include areal species richness and equitability indices which emphasize the degree of dominance exerted by the more abundant species.

Table 1. Relation Between Richness and Equitability in Four Hypothetical Collections.

Species	Number of Individuals Per Collection A	B	C	D
z	10	80	20	82
y	10	10	20	8
x	10	2	20	6
w	10	2	20	3
v	10	1	20	1
u	10	1		
t	10	1		
s	10	1		
r	10	1		
q	10	1		
Total individuals				
Relative diversity:	100	100	100	100
Richness	high	high	low	low
Equitability	high	low	high	low

INDICES

No attempt will be made to analyze the relative merits of all diversity indices. Those given here were used in the benthic examples discussed below and are representative of indices commonly used in pollution research.

Areal richness of the macrofaunal benthos is usually expressed as the number of species collected per unit area of bottom sampled. Hoare and Hiscock (1974), however, determined areal richness as the number of species found in each kelp (Laminaria hyperborea) holdfast.

The most popular diversity indices are derived from information theory. Shannon's equation (H') and Brillouin's equation (H) provide a measure of the uncertainty of species identification of an individual picked at random from a multispecies assemblage (Pielou 1969). That uncertainty is dependent on both richness and equitability, so H and H' provide an integrated measure of both components of diversity. Pielou (1969) gave statistical criteria for deciding whether H' or H is the more appropriate index for any given sample. In practice the choice makes little difference because the diversity patterns indicated by the two equations are virtually identical (Boesch 1971; Rex 1973). Equations provided by (Lloyd, Zar, and Karr 1968) facilitate the calculation of H and H'.

$$H' = \frac{C}{N}\left(N \log N - \sum_{1=1}^{S} n_i \log n_i\right) \text{ Shannon Equation}$$

$$H = \frac{C}{N}\left(\log N! - \sum_{i=1}^{S} \log n_i!\right) \text{ Brillouin Equation}$$

Where N=total number of individuals for all species

n_i=number of individuals belonging to the i^{th} species

S=number of species

C=a constant dependent on the logarithmic base. For base 10, C=1.0; for e, C-2.302585; for 2, C-3.32198

Pielou's (1969) index of equitability (J') is the ratio of observed H' to the maximum possible H' for the observed number of species and individuals.

$$J' = H' \text{ obs}/H' \text{ max} = H' \text{ obs}/\log S$$

Simpson's (1949) index of diversity gives the probability that two individuals drawn at random from a multispecies population will belong to the same species. Theoretically, that probability should be sensitive to both richness and equitability. However, unless equitability is very great, Simpson's index is in effect a measure of dominance concentration. That is also true for the information-theoretic indices. At a given level of dominance, common species have a great influence on the value of H' or H than on Simpson's index and the most abundant species have a greater influence on Simpson's index. If equitability is low, as it usually is in marine assemblages, rare species have little effect on the value of either Simpson's or the information-theoretic indices. The complement of Simpson's index (1-S.I.) is positively related to diversity (McIntosh 1967):

$$1\text{-S.I.} = 1 - \sum_{i=1}^{S} \frac{n_i(n_i-1)}{N(N-1)}$$

Wade, Antonio, and Mahon (1972) expressed dominance concentration as simply the percent of all individuals in a sample which belonged to the most abundant species.

EXAMPLES

These examples have been selected to provide an empirical test of the hypothesis that areal richness and equitability of macrofaunal benthic assemblages will decrease along spatial or temporal pollution gradients. Data from nine source publication have been summarized to give diversity index values at three levels of pollutional impact (Table 2). Estimates of benthic diversity are dependent on the type and size of the sampling device, the screen size used to sieve the sediments, the number of replicates pooled to form a collection, and the scope of the taxonomic analysis. Because of variations in sampling designs, comparison of results from the nine investigations is based on the pattern of change along the stress gradients rather than actual index values.

Hoare and Hiscock (1974) investigated the effects of a bromine extraction works on the kelp (Laminaria hyperborea) holdfast community in Amlwch Bay, United Kingdom. A halogenated, acidic (pH 4) effluent was discharged into the bay at a rate of 90 million liters/hr. Species richness of the holdfast macrofaunal community increased with distance from the outfall. Samples collected 920-1100 m along the coast from the outfall contained 54-70 species, holdfasts 250-560 m from the outfall contained 39-53 species, and 30 species were found 55 m from the outfall (Table 2).

The Elizabeth River, Virginia has been subjected to a variety of pollutants including industrial and domestic wastes, oil spills, heavy metals, and pesticides. Boesch (1973) examined macrobenthic diversity in the Elizabeth River and comparable muddy-sand habitats in adjacent areas of Hampton Roads. In the absence of pollution, Boesch (1973) believed that biotic conditions in these two areas would have been very similar. However, areal richness, equitability, and information-theoretical diversity were all substantially reduced in the Elizabeth River (Table 2).

Los Angeles Harbor receives effluents from sewage, cannery, storm drain, and industrial outfalls. Reish's (1959) data for surveys conducted in 1954 indicate a decline in all aspects of diversity along a stress gradient from the relatively clean outer harbor and outer reaches of the main channel (Reish's stations 4a, 22 and 26) through the main channel (stations 40, 41, 29, and 48a) to the heavily polluted Consolidated Slip (stations 49, 50, and 51) (Table 2). Reish (1959) considered the outer harbor benthic assemblage to be healthy and characterized by the presence of the polychaetes Tharyx parvus and Cossura candida; the main channel to be semi-healthy and characterized by Polydora paucibranchiata, Dorvillea articulata, and Cirriformia luxuriosa; and the Consolidated Slip to be very polluted and characterized by Capitella capitata or completely abiotic conditions. In 1968 the oxygen-depleting fraction of oil refinery effluents was eliminated and in 1970 Reish (1971) repeated his survey of the Consolidated Slip. The three indicator species for the semi-healthy zone were found at the previously heavily polluted stations. Indices for all aspects of diversity were substantially greater than in 1954 (Table 2).

Kingston Harbor, Jamaica, is also subjected to multiple forms of pollution from sewage, industrial, agricultural, and other sources (Wade, Antonio, and Mahon 1972). The most severe stress results from an accumulation of organic wastes on the bottom. Dissolved oxygen concentration decreases continuously along a transect through the three major basins of the Harbor (outer harbor, inner harbor, and upper basin). The results of Wade et al. (1972) can be summarized by comparing benthic diversity in these three basins in 1968 and 1971 (Table 2). In 1968 a small portion of the upper basin was abiotic, but most of the basin was occupied by an assemblage of 11 species strongly dominated by Spiochaetopterus oculatus which accounted for 96.4% of all individuals (96.4%N). In 1971 the entire upper basin was abiotic. Thirty-five species dominated by Chaetopterus variopedatus (47.4%N) existed in the inner harbor in 1968. C. variopedatus had disappeared by 1971 when the inner harbor contained a Spiochaetopterus (43.6%N) assemblage of 13 species. A very diverse assemblage of 97 species with no strong dominant (max n_i = 13.9%N) was present in the outer harbor in 1968. Although Wade et al. (1972) concluded that conditions in the outer harbor remained unchanged in 1971, richness decreased to 36 species and dominance increased (max n_i = 26.0%N). Both spatial and temporal patterns of richness and dominance in the Kingston Harbor benthos were consistent with the hypothesis of an inverse relationship between diversity and pollution.

Table 2. Diversity of Macrofaunal Benthic Assemblages Along Pollution Gradients.

STRESS/LOCATION		INDEX	NONE/ MINOR	MODERATE	MORE SEVERE	REFERENCE
			DEGREE OF IMPACT			
Bromine Plant Effluent Amlwch Bay, UK		S	61.0	46.0	30	Hoare & Hiscock (1974)
Multiple Elizabeth River, VA		S	40.0	20.1		Boesch (1973)
		H'	3.96	2.69		
		J'	0.75	0.64		
Multiple Los Angeles Harbor, CA	1954	S	13.9	7.0	0.2	Reish (1959, 1971)
		H	0.63	0.38	0	
		1-S.I	0.57	0.40	0	
	1970	S.			6.67	
		H			0.64	
		1-S.I			0.73	
Multiple Kingston Harbor, Jamaica	1968	S	97	35	11	Wade *et al.* (1972)
		%Dominant	13.9	47.4	96.4	
	1971	S	36	13	0	
		%Dominant	26.0	43.6	-	
Sewage Outfall Kiel Bay, F.R.G.		S	15.0	17.0	10.0	Anger (1975)
		H'	2.87	1.50	0.85	
		1-S.I.	0.71	0.52	0.29	
Thermal Effluent York River, VA	Feb. 1964	S	53	41	17	Warinner & Brehmer (1966)
		H'	1.05	0.98	1.14	
		1-S.I.	0.76	0.89	0.94	
	Aug. 1963	S	11	6	2	
		H'	0.82	0.64	0.10	
		1-S.I.	0.81	0.75	0.11	
Thermal Effluent Indian River, DE		S	12.0	10.5	5.2	Logan & Maurer (1975)
		H'	1.92	2.51	1.27	
		J'	0.54	0.74	0.60	
Dredging Goose Creek, N Y		S	10.5	9.2	4.5	Kaplan *et al.* (1975)
		H	1.03	2.05	0.54	
Oil Spill York River, VA		S	33.0	14		Bender *et al.* (1974)
		H'	3.02	3.28		
		J'	0.60	0.86		

Anger (1975) studies benthic diversity in Kiel Bay, Federal Republic of Germany, along a transect extending 2000 m offshore from an untreated sewage outfall. Diversity index values in Table 1 represent the means for samples collected from sand substrates in the relatively clean zone 1000-2000 m offshore, the semi-polluted zone (200-700 m), and the severely polluted zone (50-100 m). This is the first example in which equitability and areal richness did not follow the same pattern along the stress gradient. Both H' and the complement of Simpson's index decrease toward the outfall, but areal richness reached a slight maximum 300 m offshore. Anger (1975) attributed the anomalous richness pattern to an "edge effect" due to the appearance of species adapted to both clean and organically enriched sands in the semi-polluted zone.

The effects of a power plant thermal effluent on the macrobenthos of the York River estuary, Virginia were investigated by Warinner and Brehmer (1966). They made collections in August 1963 and February 1964 at three stations located 100 and 400 m directly offshore of the discharge canal and 400 m offshore a site several hundred meters above the canal. Bottom water temperatures indicated that sites closest to the canal were subject to the greatest thermal stress. During the summer the cooling waters apparently increased ambient temperature near or beyond the upper tolerance limit of many estuarine species. Areal richness followed the spatial-temporal stress gradient, but H' and the complement of Simpson's index reached their highest values at the site 100 m off the canal in February (Table 2). A comparison of diversity at stations furthest from and closest to the canal in February shows that richness decreased from 53 to 17 species while 1-S.I. and H' increased from 0.89 to 0.94 and 1.05 to 1.14, respectively. In this example H' values were determined primarily by the equitability pattern.

In a similar project (Logan and Maurer 1975) examined the effects of a thermal effluent in the Indian River estuary, Delaware. Data in Table 2 represent mean benthic diversity 100 m above the cooling water intake (no impact), 2.5 km below the discharge (moderate impact) and 1.5 km below the discharge (more severe impact). Again, areal richness followed the stress gradient, but H' and equitability (J') were higher 2.5 km below the discharge than at the control station.

In the summer of 1967 a channel 23 m wide x 2.1 m deep x 825 m long was dredged in Goose Creek, New York (Kaplan et al. 1975). Data in Table 2 represent mean benthic diversity before the dredging, one year after the dredging (moderate impact) and immediately after the dredging (more severe impact) at Kaplan's sand stations A through D. Both richness and information-theoretic diversity (H) were substantially reduced immediately after dredging. A year later richness had not recovered completely, but Brillouin's index H was twice as great as its predredge value.

Bender, Hyland, and Duncan (1974) examined the effects of an oil spill on a sand beach in the York River estuary, Virginia, by comparing benthic diversity two months after the spill with conditions at comparable control beaches. Richness was less, but equitability and information-theoretic diversity were greater in the assemblage on the oiled beach (Table 2).

DISCUSSION

The benthic examples demonstrate that richness and equitability do not always follow the same pattern along pollution gradients. No single index can provide an adequate analysis of all aspects of diversity. The information-theoretic indices were most strongly correlated with equitability patterns, but they are also sensitive to changes in richness and can produce equivocal results unless richness and equitability are analyzed independently of one another. A combination of two of the simplest indices - areal richness and the complement or reciprocal of Simpson's index of dominance concentration - seems most appropriate for pollution investigations.

In all except one of the examples, areal richness of macrobenthic assemblages declined as pollution increased. The results are consistent with predictions made on the basis of Sanders' (1968, 1969) stability-time hypothesis. The exception was Anger's (1975) study of the Kiel Bay sewage outfall where the highest number of species was found in areas of moderate pollution. That may not represent a discrepancy because moderate organic enrichment of sediments does not necessarily impose stress on benthic ecosystems. Areal richness is the most basic and easily interpretable concept of diversity. Data on spatial-temporal changes in the density of species can contribute to regulatory decisions, but such information is most useful if accompanied by an analysis of qualitative changes in species composition and the stress sensitivity of affected species. Bender, Hyland, and Duncan's (1974) study of the impact of an oil spill on the intertidal benthos provides a good model for the coordination of field and laboratory investigations. Having observed an apparent decline in benthic richness, they conducted oil toxicity experiments which demonstrated that species which remained on the oiled beach had a greater tolerance to oil than those species present only on the control beaches.

The complement of dominance concentration, equitability and information-theoretic indices often reached maximum values in areas of relatively high pollution and obvious stress. These indices should not be uncritically accepted as environmental quality criteria. Particular index values can certainly not be established as regulatory standards comparable to abiotic water quality parameters. Indices which are sensitive primarily to the equitability component of diversity can, however, be useful in pollution research if emphasis is placed on the interpretation of their ecological significance rather than simply on their statistical description. Many forms of pollution impose stresses which are unique in the evolutionary experience of marine communities. Equitability in assemblages exposed to such pollutants may increase because all species are adversely affected and none can establish structural dominance. Other forms of pollution create disrupted conditions to which opportunistic species have natural adaptive capabilities. Increases in dominance concentration due to population explosions of known pollution indicator organisms such as the polychaete, *Capitella capitata*, do suggest a degradation of the benthos. Alternatively, pollution may favor the development of communities with different diversity patterns which are not necessarily undesirable. Watling *et al.* (1974), for example, found the benthos in the vicinity of a sewage dump site to be strongly dominated by the bivalve, *Nucula proxima*. Because *N. proxima* is a deposit feeder which naturally inhabits organically-enriched substrates, they concluded that its great abundance did not reflect serious environmental damage.

Diversity indices should not be the sole biological criterion of stress. They do not provide an adequate summary of all aspects of community structure. In particular, they are not sensitive to changes in species composition or the total abundance of all species. For example, benthic areal richness recovered rapidly at a small dredging site in Yaquina Bay, Oregon (Table 3). Information-theoretic diversity and the complement of Simpson's index showed little change after dredging. Diversity patterns did not reflect the substantial effects of dredging on dominant species or the total density of the benthic assemblage. Qualitative and quantitative changes in species composition should be analyzed by numerical classificatory techniques (Boesch 1973; Haedrich 1975; Clifford and Stephenson 1975). Even a complete community structure analysis may be inadequate. Every attempt should be made to interpret structural alterations in terms of their functional significance and direct observation of functional parameters may be necessary. None of the authors of the papers discussed here restricted their research to diversity analysis.

The critical test of the efficacy of indices of diversity is whether they can discriminate relatively minor effects of pollution from natural variations. The benthic examples suggest that this is possible only when diversity is analyzed as part of more comprehensive investigations of population and community dynamics. Tables of index values certainly do not provide an adequate scientific basis for regulatory decisions.

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Table 3. Benthic Diversity, Dominance and Density at a Dredge Site in Yaquina Bay, Oregon (Swartz, unpublished data).

	PRE-DREDGE	POST-DREDGE	
	7 Oct 75	29 Oct 75	17 Nov 75
Diversity:			
$S/0.5m^2$	68	41	58
H'	1.01	0.99	1.14
1-S.I.	0.84	0.79	0.86
Dominant species $[100(n_i/N)]$:			
Owenia collaris	32.4	3.6	3.5
Anisogammarus pugettensis	0.1	42.2	1.7
Photis brevipes	12.2	3.6	30.7
Density:			
Total $N/0.5m^2$	3559	702	1215

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