the role of ecology in the federal government

report of the committee on ecological research

council on environmental quality and
federal council for science and technology

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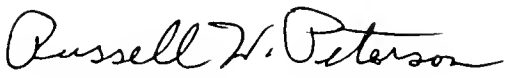
This report is the first assessment to be made of the extent and status of the ecological research being carried out by Federal agencies. It was prepared by an Ad Hoc Committee on Ecological Research, chartered jointly by the Council on Environmental Quality and the Federal Council for Science and Technology.

At the time the committee was convened and charged with the preparation of this report, Dr. Edward E. David was Chairman of FCST and Russell E. Train was Chairman of CEQ. We are indebted to them for inspiring and directing this important effort.

We invite your careful consideration of the content of the report as well as of the significance of the discipline of ecology to the solution of many urgent national and international problems and the accomplishment of individual and societal goals.



Russell W. Peterson
Chairman
Council on Environmental Quality

H. Guyford Stever
Chairman
Federal Council for Science and Technology

Foreword

Ecology as a science has come of age. From its beginning over one hundred years ago to the present, ecologists have asked basic questions: Why do plants and animals live where they do? How do they adjust to one another and to the changing forces in their environment? The relevance of ecological knowledge to the needs of people has long been recognized, and scientists with significant ecological concerns, e.g., "agronomists," "horticulturists," and "foresters," have made major contributions to meeting the food and fiber needs of the peoples of the world. In fact, in one sense the first farmers of civilization were applied ecologists, as they observed the relationship of plants to surrounding soil, water, light, and climatic conditions and determined the best means of cultivation to assure good production to meet human needs.

In recent years a dramatic growth in environmental awareness by people from all walks of life has given focus to additional sets of ecological questions: How do we maintain a high quality of life with the growth of our human population threatening the basic natural support systems of the world? How can the effects of technology as it impinges on natural ecosystems be directed constructively to provide value to our society?

Our welfare, and perhaps our survival, depends upon finding solutions to a myraid of ecological and environmental problems. There are very few simple solutions or "technological fixes" possible in the ecological world. Whereas most of the emphasis of ecological study in the past was descriptive, today we are extending our activities to assess further the effects of our actions on the ecosystems of which we are a part. This necessitates adding a predictive capability to the earlier descriptive base of ecology, while still pursuing the many unanswered basic questions. For example, current environmental impact assessment procedures call for descriptions of existing ecosystems and their functioning, as well as predictions of any long and short-term changes in these systems which are anticipated as a direct or indirect result of the construction or operation of a particular project.

In the National Environmental Policy Act of 1969 the role of the Federal government and the concomitant obligations are formalized as national policy.

> "Sec. 101. (a) The Congress, recognizing the profound impact of man's activity on the interrelations of all components of the natural environment, particularly the profound influences of population growth, high-density urbanization, industrial expansion, resource exploitation, and new and expanding technological advances and recognizing further the critical importance of restoring and maintaining environmental quality to the overall welfare and development of man, declares that it is the continuing policy of the Federal Government, in cooperation with State and local governments, and other concerned public and private organizations, to use all prac-

ticable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."

It is this sense of responsibility which led to the original charter for this report.

Much of this contemporary concern with environmental issues, as reflected in NEPA, has created an enlarged requirement for ecological knowledge and the work of ecologists. Unfortunately, as a result there has been a blurring of the terms "ecological" and "environmental." Ecology is a science. It is concerned with the organization and function of whole living organisms as they relate to each other and to their environment. An expansion of this description appears on pages (29-34) of the report, which extends the ecological concept to include human participation in ecosystems.

Clearly the scope of ecological science is very large. Basic ecological research may cover living systems as large as many thousands of square miles, such as biome studies of the artic, grasslands, or desert; to as small and discrete as the interior of a single cell, studied in viral ecology. In its applied aspects ecology may help us to know, for example, the relationships between human populations, atmospheric pollutants and disease or ways to increase the annual yield of fish from the sea.

The purview of ecological issues in this report was not meant to nor could it include the total scope of ecology. It is a first cut attempt to sift through the immense array of issues and identify clear and pressing matters believed to be crucial at a particular point in time. Likewise the listing of ecological R&D by Federal agencies is not intended to represent a definition of the limits of ecology, but is a preliminary categorization for the purposes of this pioneer report.

The title of this report is "The Role of the Federal Government in Ecological Research," and the sources of impetus for activity at the Federal level in the coordination and support of ecological research, both descriptive and applied, are varied. Part of the rationale for Federal involvement relates to the nature of ecology itself. It has become evident that ecological regimes, ecosystem boundaries and ecological impacts or problems do not correlate with existing patterns of ownership or with political and institutional frameworks. Not only do ecological concerns often cover more than one local or State jurisdiction (for example, in connection with pollution in an entire watershed, or land use for a region), but they often involve more than one nation. Recently needs have arisen for ecological research and planning on an international or global level in regard to such matters as atmospheric contamination, pollution of the oceans, energy resources, and use of natural resources such as marine mammals and fisheries.

In addition, the study of ecological processes often involves time spans and funding requirements which fall outside the practical or reasonable area of responsibility of an individual industry, planning commission, or other non-Federal entity. The Federal government can often enter creative partnership arrangements with the private sector, or with State or local governments to focus on ecological problems.

Numerous laws and guidelines set forth initially at the national level in response to a new national ecological and environmental awareness are creating demands for new types of ecological research and data. There is an urgent need for input of useable ecological information into the deliberations which lead to any new legislation concerning environment. Once new legislation is passed, the Federal government has the responsibility to insure that data systems and other tools which are necessary to respond to legislative requirements are available through either non-Federal mechanisms or Federal as necessary. For example, the current project-by-project approach to environmental impact assessment does not allow for considerations of cumulative impact of multiple projects or actions in a given geographic area. In the near future such large-scope evaluations may well need to be addressed at the Federal level. The Federal government may also need to provide support to insure that educational systems are stimulated and equipped to train people in ecology and related disciplines.

In recent years there has been growing concern over the future utilization of natural resources. Especially significant is the fact that a large percentage of these natural resources in question are to be found on Federal lands, e.g. national parks and national forests. Consequently there exists a great need for ecological input into policymaking concerning the use of Federal land and the nature of ecological and environmental programs conducted at the Federal level.

At the present time efforts to include biologists and ecologists in environmental problem-solving efforts are suffering from differences in training and conceptual approaches between the biological and engineering communities. More generally, there are communication barriers among entities at all levels of the environmental planning process, e.g. State and Federal agencies, private industry, consultants, academia, and the general public. One future role of the Federal government might be to encourage the construction of more effective communication and exchange of basic ecological information among all potential users of the information.

As an initial attempt to address the role of the Federal government in ecological research and applications, this report was jointly chartered by the Council on Environmental Quality and the Federal Council for Science and Technology. It is the work of an *ad hoc* committee of distinguished individuals representing a large variety of Federal agencies with various missions but all in some way concerned with the environment and with natural organisms, as well as non-governmental consultants. The Ad Hoc Committee on Ecological Research was requested to identify the national needs for ecology; to assess the present state of our capabilities and efforts to meet the needs; and to recommend long and short-range Federal actions to provide the ecological knowledge and know-how basic to achieving national goals. The assessment of current efforts was to include a survey of present ecological research and development by the Federal government. A corollary purpose emerging from the Committee's effort was to provide some focus to the diverse activities and specialized fields included in the Federal effort in ecology, both to promote better coordination, understanding and utilization of what is presently underway, and to facilitate identification of future needs.

The report falls into three major sections, each addressing major issues and problems in ecological research.

The first part of the report contains the six principal findings on national needs for improving ecological understanding and its application. From an analysis of these have emerged the 12 recommendations of the Ad Hoc Committee specific actions. Included in this part also is the charge to the Committee by the FCST and CEQ.

The second part is a discussion of basic concepts in ecology and a brief highlighting of human progress and problems in relationship to ecosystems and resources.

Finally there is a categorization of present Federal agency involvement in ecological research. This listing allows an estimate of much of the scope and detail of what Federal ecologists have considered important. It reflects as well as the considerable history of basic and applied effort directed by Federal agencies toward the need for knowledge and problem solving in response to issues raised in the second part of the report.

The report was reviewed by member and observer agencies of the Federal Council for Science and Technology and discussed at plenary session. The FCST approved publication of the report, although several agencies expressed reservations about the first recommendation, to establish a National Ecological Service. The report is being published as originally developed by the Ad Hoc Committee, and its recommendations will be carefully considered within the Federal establishment. Suggestions are welcome from any part of the public or private sectors related to the recommendations of this report or to the need for any further analysis of ecological research and issues as follow-up to this pioneering effort.

Chairman's Preface

There has been a dramatic change in public attitudes about the environment and a sudden awareness of the interdependencies of man and other living organisms within the last five years. This change was prefaced by both deterioration of the Nation's environment and increased knowledge about this environment. It is accentuated by a growing realization of the limits of resources, land, and water.

The science of ecology, which studies dynamics of landscapes, organisms including man, and environment factors, can help solve and prevent many environmental problems. Use of the principles and findings of this science is basic to environmentally responsible action. While classical ecology is a little over a century old, its role in synthesizing and integrating man's activities with natural systems is relatively new. This developing discipline has been asked to provide evaluations and predictions for systems of extreme complexity within a short time-frame. The national need to build additional capability in ecology thus becomes increasingly evident. Therefore, it is important and timely to review the present and future roles of ecology in the Federal Government. Recognizing this fact, the Council on Environmental Quality and the Federal Council for Science and Technology established the Ad Hoc Committee on Ecological Research to advise and to provide expert guidance to the Federal Government on:

1. Identification of national needs for ecological knowledge and capability;
2. Assessment of our present ecological knowledge and capabilities and the current status of our efforts to meet these needs;
3. Development of recommendations for short- and long-term national programs of ecological knowledge and capabilities basic to achieving our national goals;
4. Coordinating interagency ecological research activities; and
5. Strengthening the ecological basis for regulatory action for land, air, water and renewable resource management and for land use decisions.

The Committee, composed of representatives of all Federal agencies that have ecological programs, and outstanding ecological consultants from the academic community, conducted its assignment with a view to how ecology can contribute to national policies and goals, as well as solving national problems. Findings and recommendations were made to assist in achieving our present and proposed acts and policies on environmental needs; clean air and water, health, sufficient energy and raw materials, land use, and environmental quality.

There is an urgency to implement these recommendations because environmental problems that require ecological knowledge for their solutions continue to mount. In addition, natural areas required for ecological research continue to be disturbed and eliminated. Ecology, being a science of complex systems, involves many disciplines, and requires long lead times. The Nation needs the help this science is prepared to give. But the Nation must organize its agencies, individuals, organizations, and resources to assist in the obtaining of these solutions.

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The Committee expresses appreciation to former Chairman Russell E. Train of the Council on Environmental Quality, and former Chairman Edward E. David of the Federal Council for Science and Technology for envisoning the key role that ecology can play in solving the Nation's environmental problems and in soliciting this study from the ecological fraternity.

Dale W. Jenkins
Chairman
Ad Hoc Committee on
Ecological Research

Contents

CHAPTER I
Summary and Recommendations

1. THE CHALLENGE

An overworked metaphor states that spaceship earth embraces two worlds inhabited by man. One world is the biosphere of air, water, land and biota including the human species that has evolved over millions of years. The second is the world of urban and political institutions with the technology necessary to engineer an environment suitable for human habitation and obedient to man's purposes. Many of technological society's dilemmas arise from the conflicting demands of these two finite worlds. Civilization is both a collaboration and a conflict between natural and technological processes. Advanced civilization and developed nations become more, not less, dependent on resources and the web of processes that constitute natural ecosystems. As a consequence, developed nations utilize much more resources *per capita* than other nations and generate more waste and more pollution.

Our current American society has evolved from an agrarian society developing in a frontier environment with high esteem for personal and state freedom. The industrial revolution, occurring at the time the country was established, made feasible mass production of desired materials. This led to an economic growth period that was accompanied by a degree of depersonalization. Changes in social institutions, environmental deterioration, and other problems followed. We are now in a transition period to a more service-oriented economy emphasizing quality of life and individualization. Projections of population size and of *per capita* demands for goods and services during the last third of this century argue that we build for a nation with yet another 100 million people. Food, fiber, energy, shelter, transportation, and education must be planned to avert serious and prolonged deterioration in the quality of life. This essential planning for the best use of resources, environments, biota, and space for human satisfaction must be based on ecological knowledge. There is an inherent tendency of high energy, fuel-powered societies to *overshoot;* i.e., develop too much of the material "good things" at the expense of the quality of human life. Ecological considerations should not be viewed as mere constraints on productivity or on the fulfillment of human aspirations, but rather as the basis for achieving harmony between societal demands and the stability of the natural world. The challenge is to synthesize pertinent scientific knowledge, to ascertain and fill the gaps in this body of information, and to apply the understanding gained to solving problems of the human condition. Ecology offers an intellectual framework with great potential for helping to meet these challenges.

1. ECOLOGY AND NATIONAL POLICY

As we approach our Nation's third century, we are facing the rethinking and redirection of national goals. There is recognition of the finite nature of resource availability and of the environment's capability to accommodate continued unlimited growth. There is also increasing awareness of our reliance on a healthy environment, and growing recognition of the profound impact of man's activity on all components of the environment.

Recognizing the critical importance of "restoring and maintaining environmental quality for the overall welfare and development of man," the Congress of the United States has declared a National Environmental Policy with the purposes "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." Further, the Congress pledged in the policy "to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans." (P.L. 91-190, Section 101a)

A major thrust of this Act, together with other recent legislation on energy, land use, health, clean air and water pollution, ocean dumping, coastal zones, rare and endangered species, etc., is to insure that ecological principles and environmental factors enter into decision-making at all levels of government activity. Consequently, ecological and environmental considerations have become an important component of the missions of all Federal agencies and they must necessarily receive adequate consideration by other segments of society.

Ecology is the body of knowledge and the scientific discipline which underlies resource management and efforts to achieve environmental quality in much the same way that physics underlies engineering. Application of ecological principles is fundamental to achieving national goals in areas such as health, land use planning, energy, continued productivity of renewable resources, and urban growth with environmental quality. Achievement of national environmental goals requires a high level of basic knowledge of ecologiccial processes and understanding of ecological principles, supported by proficient capability to apply this understanding practically.

Development and maintenance of a high level of ecological understanding and capability is basic to achieving these national environmental goals.

Consequently, the nation must enhance the ecological knowledge and capabilities through an intensified effort by both the private and public segments of society.

In the following section, an agenda is proposed for Federal action to develop the necessary ecological capability, to acquire the required ecological information, and to apply it effectively for appropriate Federal programs.

3. SUMMARY OF FINDINGS AND RECOMMENDATIONS

The Committee has developed findings and recommendations which are presented here in summary form. The recommendations are discussed further in Section III. The findings are based on information in Section V.

Finding A

Ecological research activities are scattered throughout many agencies of the Federal Government with little overall coordination, direction, or definition of priorities. Large volumes of survey, monitoring, and research information of ecological value are gathered by Federal agencies, but with limited or specialized use, generally primarily by the collecting agency. These data, together with non-Federal information, constitute resources of enormous value if selected, focused, analyzed, and integrated for applicability to specific environmental problems, to strengthening the ecological basis for regulatory actions in land, water, air, and resource management and to mitigation of environmental impacts. Without a Federal focus, response to problems which require ecological information or capability will continue to be fragmented, costly, redundant, and reflexive rather than strategic, efficient, and contributory to national goals and productivity.

Synthesis and application of ecological information to the constructive realization of diverse societal goals and Federal missions is essential to maintain the resource base and quality of life in the Nation.

Recommendations

1. **Establish a National Ecological Service which would serve as an operational focus in the Federal Government for programs of ecological significance.[1] It would be integrative in purpose and would be primarily analytical in function. The principal functions of the Ecological Service would be to:**
   a. **Define ecological problems relevant to achieving national goals and critical to human welfare.**
   b. **Assemble, analyze, and synthesize ecological information and present it in operational form.**
   c. **Conduct selected research to fill critical needs.**

Finding B

The national interest can be advanced by more adequate application to Federal Government policy and operations of ecological knowledge, principles, and capability for the beneficial management for man of the Nation's biosphere. Management of renewable resources, while presently based partly on ecological principles, must be improved by using advanced ecological methodology and regional ecosystem approaches. The greatest need for advanced ecological research is in forecasting ecological effects of technological and sociological developments; i.e., determining "environmental impact." Forecasting ecological effects requires knowledge of the living and non-living components of the Nation's ecosystems and the ability to perform manipulative

[1] Several member agencies of the Federal Council for Science and Technology do not endorse this recommendation of the Ad Hoc Committee on Ecological Research.

experiments on selected ecosystems so as to measure ecosystem responses. Investigations into responses by individual species to specific perturbations in their environment are essential to comprehensive prediction about the whole.

Based on the ability to predict is the ability to plan more scientifically, and knowing how much societal development can be accommodated without destroying the vitality of ecosystems.

Recommendations

2-a. Develop improved capabilities for ecological research, including advances in conceptual frameworks, systems science, experimental design, and mathematical models. Augment these tools with basic ecological inventory data. Goals are to develop predictive capabilities of the effects of technological and sociological influences on the environment and to improve ecosystems management.

b. Support Federal involvement in research programs which strengthen the development of ecology as a discipline, in universities, Federal laboratories, and State activities.

3-a. Assign highest priority to ecological research programs that:

(1) Gather information on the composition and functioning of ecosystems.

(2) Help predict the ecological effects of technological developments.

(3) Serve to minimize or mitigate ecological impacts of man's disturbances, and restore damaged ecosystems to productive status.

(4) Develop means to improve management of renewable natural resources.

(5) Strengthen ecologists' capabilities to apply their expertise and knowledge to solving relevant environmental problems.

b. Implement this recommendation by support of Federal programs which utilize ecological research to achieve agency goals.

4-a. Utilize naturally bounded regional systems of landscape as units for research planning and management, rather than artificial or political subdivisions.

b. Implement this recommendation by integrating in the least disruptive manner with presently established agency regions, while adapting political units to regional ecosystem units.

Finding C

There is a primary, operational demand for forecasting ecological effects of technological and sociological developments; i.e., determining environmental impact. Predictive ecological evaluation of environmental effects applied during the earliest planning stages of technological developments, resource utilization, environmental modification, human settlements, and other human activities *can avoid or minimize* detrimental ecosystem alteration and project delays. This would enable more economical and effective implementation of the spirit of Title 1 of NEPA, with less stress on agencies and their resources.

Environmental impact statements can be greatly improved and facilitated by including quantitative evaluation of ecological impacts; i.e., effects on the present ecosystem, more quantitative prediction of ecosystem change, ecological costs and benefits, post-impact evaluation of predicted impacts, and identification of problems amenable to solution by additional ecological research.

Recommendations

5. **Revise agency guidelines for environmental impact assessment in accordance with CEQ guidelines (Federal Register, Aug. 2, 1973) to require that consideration of and research on environmental effects of projects commence at the outset in planning technological developments, resource utilization, environmental modification, construction of human settlements, and other human activities.**
6. **Prepare environmental impact statements with high priority consideration to:**
    a. **Maximum practicable use of quantitative analysis, prediction, and evaluation of ecological impacts;**
    b. **Post-impact evaluation of predicted impacts and unpredicted consequences on a selective basis; and**
    c. **Identification and initiation of research of problems amenable to solution by additional ecological research.**

Finding D

Ecological research requires two kinds of protected research areas, which are the workbenches of ecologists. One type includes undisturbed natural areas for use as baselines or benchmarks, as experimental controls, and as a bank for irreplaceable ecologic and genetic diversity. Adequate representation of all natural ecosystems needs to be in such a system. The second type of protected research area includes sites that are reliably managed for manipulative ecological processes following known human impact. The two types of areas are complementary, and both are urgently required for scientific investigation of human impact on ecosystems.

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Recommendations

7. **Complete the existing National System of Natural Areas, with full representation of major ecosystems, to provide sites for studies of naturally functioning systems that can serve as ecological reference points for baseline monitoring, and as controls for experimental research. Utilize existing Federal lands to the maximum extent possible. Classify the natural areas into a useful system.**

8. **Complete the National System of Ecological Research Areas to provide sites for manipulative experiments, management testing, and observations of the results of human impact. Utilize existing Federal lands to the maximum extent.**

Finding E

There is also a need for ecological research of intensively managed and heavily used urban ecosystems. This is a joint finding by this Committee and the CEQ-OST Committee on Environmental Health. Although neither committee studied the problem in detail, it was agreed that this is an area with little knowledge but great need.

There is a great need to determine the "carrying capacity" of the land for human populations and their many demands on land. Most studies are of a single use, and can identify the maximum yield or capacity under optimum management for meeting a particular demand. Yet meeting of one need affects all others, directly or indirectly. Evaluation of carrying capacity should include consideration of diversity, stability, and environmental quality, together with ecosystem needs to meet human demands. Conservation of energy and materials requires additional innovative research and implementation. Methods should be evolved for reducing stress on ecosystems, while enhancing their capability to meet human demands and to support wild species.

Recommendations

9. **Assign high priority to research on the ecology of intensively managed and used, man-dominated urban ecosystems, so as to establish threshold values for ecosystem stress. Detailed ecological research requirements and applications should be determined in a separate study by appropriate experts.**

10. **Investigate the techniques for developing means of long-range ecological planning geared to establishing a "carrying capacity" for human activities.**

Finding F

There are very few broadly trained professional ecologists and particularly few who are capable of applying ecological knowledge to environmental problems. Ecological education in universities needs to be augmented and reoriented to be effective in producing broadly trained professional ecologists capable of meeting national needs. These people should be competent natural scientists, while also being skilled in the social sciences and humanities.

The talents of ecologists employed by the Federal Government are not generally used as effectively as possible. There is no Civil Service classification for ecologists. The existing jobs requiring ecologists are usually filled with personnel who lack adequate ecological training.

Recommendations

11. **Ecological education should be augmented by providing a specific core curriculum, and research training grants for practical work on high priority environmental problems.**

12. **Federal agencies should hire professional ecologists where needed and not substitute other specialists who lack full ecological training. The Civil Service Commission should establish a classification for ecology and set standards to assure adequate capability.**

CHAPTER II
Scope of the Report

1. The Committee

The Ad Hoc Committee on Ecological Research was composed of members from the various Federal agencies with ecological research programs, observers, and ecological consultants from the academic community. The membership of the Committee is shown in the Appendix. The terms of reference for the Committee and messages from Chairman Train and Dr. Edward David are presented in this introductory section.

The Committee first defined the scope of ecology for the purposes of this assignment and reviewed the ecological research programs and funding of the Federal Government including those programs contracted to other organizations. Agency ecological research programs and funding are summarized in Chapter V. The Committee recognized the importance of the ecological research programs of state and other non-Federal governments, industry, and of other private organizations, but review of these programs was outside the purview of the Committee's activities.

The major problem areas requiring ecological research were identified and the types of ecological research required to help solve these problems were listed in the matrix of Tables 2-4 for fiscal years 1971 to 1973. Each agency identified its major research emphasis in ecology and the outstanding needs to accomplish assigned missions.

Three panels of the Committee were formed to: (a) review and analyze present ecological research programs and specific and immediate needs for ecology, (b) analyze short-term needs and problems and recommend a national program particularly in relation to the purposes of the National Environmental Policy Act of 1969, and (c) study and recommend a national long-term policy or program in ecology.

The present report is the first interagency evaluation of Federal ecological research programs. The presentation of findings and recommendations is responsive to the broad mandate and assignments given to the Committee.

2. Mandate and Terms of Reference

The mandate to this Committee was specified in the original charge to the Committee from the Council on Environmental Quality and Federal Council for Science and Technology, supplemented by statements by Dr. Edward David, Chairman, FCST and Chairman Russell Train, CEQ. These three documents follow.

ORIGINAL CEQ-FCST TERMS OF REFERENCE

A number of Federal programs depend on understanding the functioning of ecosystems and the ways in which their functioning is affected by man's activities, deliberate or inadvertent. There is a need to focus Federal programs on important and urgent ecological problems in order to assure that such programs are adequate and to prevent duplication. The Committee will concentrate on issues of concern to agencies responsible for environmental management and regulation. The Committee will concentrate on natural systems, rather than intensively managed land, water and urban areas.

This Ad Hoc CEQ-FCST Committee on Ecological Research should provide recommendations to the Chairmen to the Federal Council for Science and Technology and the Council on Environmental Quality in the following areas:

1. Means of interagency coordination where required.
2. Strengthening of the ecological basis for regulatory actions, for land and water management, and for land use allocation.
3. Development of a long-range research program with the objective of strengthening the science of ecology and its predictive capability.

This committee should prepare an inventory of the research and development needs and opportunities of the Federal agencies and departments and the justification for these needs. It should indicate which are being satisfied by industry (recognizing there has been little incentive for support of ecology in the private sector), which are supported by the agencies of government, and which are unsatisfied. The committee should suggest an interim research and development program, appropriately distributed among the departments and agencies, to meet these and other opportunities. The committee will be terminated upon submission of a final report.

Members

Department of Agriculture
Department of Commerce
Department of Defense
Department of Health, Education, and Welfare
Department of the Interior
Department of Transportation
Atomic Energy Commission
Council on Environmental Quality
Environmental Protection Agency
Federal Council for Science and Technology
National Aeronautics and Space Administration
National Science Foundation
Office of Management and Budget
Smithsonian Institution

Summary and Extension of Remarks of Dr. Edward E. David to the FCST-CEQ Ad Hoc Committee on Ecological Research

I would like to express my appreciation for the opportunity to meet with your Committee on February 25, 1972, and present you with my general

views on the Committee as you evaluate and develop a Federal R&D program in the field of ecology.

First, I would like the Committee to provide me with an early draft outlining the structure of the discipline "Ecology." By first defining the discipline, the Committee then has a framework upon which to evaluate the current research and to project the research needs of the future.

The Committee should look briefly at the current research and identify the gaps and duplications of the current Federal program. This exercise should be only to the extent necessary to provide a foundation for the more important activities of the committee.

The Committee must address and define the categories of problems, the solutions for which will depend heavily upon the acquisition and transfer of basic ecological knowledge. One such major problem is the current difficulty to project the short-term as well as the long-term cumulative ecological effects that could result from planned major action in the context of the National Environmental Policy Act of 1969. Many Federal agencies have expressed concern over the lack of ecological information and the translating of the available information into a form that allows for an assessment of the potential significant environmental impacts that could derive from major problems.

The Committee should develop a set of major priority problems and identify those areas of ecological research which should be encouraged to provide the knowledge required for solutions to those problems. To accomplish this a set of major research objectives needs to be developed. From these goals and objectives, a priority list of research needed should be developed. Organizational recommendations are important but secondary to the identification of research areas.

The Committee should also examine the transferability of the knowledge gained from ecological research. We need to develop a set of criteria for the conversion of knowledge gained into a mold that would facilitate its use in problem solving.

The Committee should examine the area of information gathering, storage, retrieval and dissemination. Considering the fact that the field of ecology is rapidly developing into a major supportative science, it behooves the Committee to reassess the traditional mechanisms for disseminating ecological knowledge in order to determine whether the prevailing information delivery systems are adequate for the delivery of ecological information to project planners.

In conclusion, let me reiterate the view that I expressed during my meeting with you. It is all too easy for committees to recommend that more and more research be done. The Committee on Ecological Research must guard against making such recommendations without first providing careful and explicit justifications in support of those recommendations. I look forward to maintaining a close liason with the Committee and anticipate that its recommendations will be of great assistance in designing a Federal program for the support of ecological research which is supportive of the National Environmental Policy Act

of 1969 and the President's goals and policies for environmental enhancement.

Statement of Chairman Russell E. Train to the CEQ-FCST Ad Hoc Committee on Ecological Research

This is to express my personal appreciation, as well as that of this council, for the work this Committee is doing and to indicate the importance which I attach to this work and the directions I believe it should take.

The past several years have seen a great increase in environmental awareness and concern, and with it the growing recognition that we must take into account the impact of our activities on the environment. Ecologists have been saying this for many years. However, it is only recently that the general public and the Government have awakened to the fact. One result is the enactment of the National Environmental Policy Act of 1969 (NEPA), the main thrust of which is to assure that environmental considerations receive adequate attention at all levels of Government planning, decision making, and action. The environmental impact statements required by NEPA created within Government an almost instant need for ecological understanding—and it has become ever more clear that our present ecological knowledge and capabilities are grossly inadequate.

Ecology is basic to environmentally responsible action. I use ecology here in the scientific sense of the body of information, knowledge, and the scientific discipline which underlies management and use of the environment in the same way that physics underlies engineering. However, ecology has become so academically and politically stylish that it has become a catch-all term, frequently applied to anything vaguely dealing with the environment. One result is that we do not have a clear understanding of where we stand in terms of ecological knowledge, nor where we must go. This situation can pose several serious problems:

> First and most important, without clear guidance we may not obtain the ecological foundation necessary to achieve our national environmental goals.
>
> Second, without clearer definition of "ecology," we may foreclose our options for obtaining the necessary information. If the Federal budget lumps a wide variety of items under the heading of "ecology," it will give Congress and the Office of Management and Budget a grossly inflated idea of the amount of real ecological research that is being undertaken, and may make it exceedingly difficult to obtain recognition and authorization for the additional real ecological research which is required.
>
> Third, recognizing that our ecological capabilities are currently limited, if we do not have a clear idea of where we now stand or where we need to go, we run the risk of ill using the scarce resources we have.

This is where the mission of this Committee on Ecological Research is so important. The basic objective of the Committee is to advise and

provide expert guidance to the Federal Government. Specifically, this mission involves:

1. Identification of national needs for ecology;
2. Assessment of our present ecological knowledge and capabilities, and the current status of our efforts to meet these needs.
3. Development of recommendations for a short and long term national program of ecological research, designed to provide the ecological knowledge and capabilities basic to achieving our national goals.

I anticipate that your report will have five direct audiences, each with its associated potential for guidance and other impacts: (1) Dr. David and myself; (2) The Federal agencies; (3) The Office of Management and Budget; (4) Congress and the Public; and (5) the Nation's universities.

Ecology is an area where the Federal Government is not strong. Consequently, I attach particular importance to the contributions to this Committee of the non-governmental participants. This is an area where we particularly need the critical scientific analysis and expertise of the scientific and academic community, working with the Government participants, to assure that the Committee's recommendations address themselves to *ecological* research, and that research is justified in terms of supporting our endeavors to achieve national environmental goals and policies.

In conclusion, I wish to emphasize my strong and continuing personal interest in your work and my gratitude for your efforts to assist with a national problem of great importance.

3. Definition of Ecology and Scope of Report

Ecology as used by this Committee involves biological components and their interrelationships to each other and to the environment. Ecology is the scientific discipline and body of knowledge which underlies management and use of the environment in the same way that physics underlies engineering.

The focus in ecological research has been shifting gradually from the study of species and populations of species to include study of entire ecosystems. Thus ecology is no longer a division of biology, but deals with totality and patterns of relationships between man and other organisms and the environment. The systems approach requires recognition of interactions at different integrative levels not only among biological organisms but also between biota and the physical and chemical factors in the environment. Inevitably, these interactions have impact on the social milieu of our society.

There is a trend toward increasing ecological and supportive environmental research to help resolve the serious ecological and environmental problems facing us. Federal agencies are now recognizing that an understanding of ecological systems offers the only rational basis for managing renewable resources, maintaining life support systems on Earth, and assessing and helping to predict

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probabilities of the effects of man's activities and technology. Implementation of the National Environmental Policy Act has given new visibility to the usefulness of and the necessity for information resulting from ecological research. Every mission agency with a requirement for ecological research needs its research product as a basis for managing its mission as well as for preparing environmental impact statements.

A number of Federal programs depend on understanding the functions of ecosystems and the ways in which these functions are affected by man's activities, both deliberate or inadvertent. There is a need to focus Federal programs on important and urgent ecological problems to assure that such programs are adequate and to prevent duplication of effort. The Committee concentrated on those issues, agencies, and programs concerned with environmental management and regulation, emphasizing naturally and moderately managed systems rather than intensively managed land, water, or urban areas. The analyses of the Committee do, however, apply to all ecosystems, including those with large human populations. Research on the ecology of intensively managed systems, such as monocultural cropping systems, tree farming, fish hatcheries, poultry farms, and feedlots, is included only to the extent that it contributes to basic ecology or that the products and by-products have impacts when they enter natural or moderately managed ecosystems.

Federal Government research programs involving the effects of environment and pollutants on man were not studied by this Committee, since that area is the responsibility of a separate committee on Environmental Health Research, organized under the Council on Environmental Quality and the Office of Science and Technology. This report does not include human health related ecology, except for some disease vectors and nuisance pests. Social and behavioral interactions among human beings are also excluded, but they merit special review in a separate study. Urban ecology is recognized as being extremely important, but it also requires detailed study by qualified experts in that field.

In analyzing funding levels, capital investments in ecological research facilities are not included, nor are costs of building and operating ship support, launch vehicles, satellites, and aircraft. International support of ecological research is included if agency funds were expended. Funding is reported by the primary agency receiving Federal funds to prevent duplication. Federal funds given to state and municipal governments, to universities, and other organizations for ecological research are included.

4. Supportive Research, Surveys and Monitoring

Although supportive environmental studies and extensive non-research or routine surveys contribute significantly to ecology, they are not included as ecological research in this study. Non-research surveys or monitoring programs include those on meterology, weather, physical oceanography, soils, hydrology, topography, geodetics, timber, agriculture, soil conservation, economics, pollution, and many others. The Federal environmental research programs have been

reviewed, and the findings are published in a separate report[1] which also summarizes research on pollution affecting the environment.

The Committee recognizes that our collective ability to conduct ecological research depends on our success in acquiring prerequisite data on nonliving aspects of ecosystems. Measurements of the physical and chemical characteristics of terrestrial and aquatic environments, as well as of atmosphere which circulates over both, are fundamentally important as a foundation for development of ecological perceptions and knowledge. Several agencies have very substantial research and monitoring programs of an environmental supportive nature.

The Department of Commerce has recorded cyclic variations in total atmospheric concentrations of carbon dioxide. This factor is an essential component in understanding global cycles in photosynthetic activities. Similarly, an understanding of biological productivity cycles in marine ecosystems is achievable only through the interpretation of physical, chemical, and biological data of the ocean. Environmental studies are included in this report when they are made in relation to biological organisms.

Similarly, the Corps of Engineers conducts supportive research in the fields of sedimentation, reservoir and lake management, estuarine and coastal environments, and interrelationships in regional ecosystems in order to develop design criteria and operational technology. While this research does not directly include biological organisms, it is of importance to studies on productivity of fisheries. Information gained is used to estimate the effects of engineering works in order to alleviate deleterious effects and to aid in productivity of fish and wildlife.

Acquiring requisite environmental data from monitoring and collection facilities is expensive both in direct investments and in manpower. Inadequate support for such activities would present major obstacles in advancing our knowledge of ecosystems and in solving pressing environmental problems.

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[1] Environmental Quality Research and Development - A Review and Analysis of Federal Programs, August, 1971, Executive Office of the President, Office of Science and Technology, pp. 137.

CHAPTER III
Detailed Recommendations

Recommendation 1

Establish a National Ecological Service which would serve as an operational focus in the Federal Government for programs of ecological significance. It would be integrative in purpose and would be primarily analytical in function.

The principal functions of the Ecological Service would be to:

a) *Define ecological problems* relevant to achieving national goals and critical to human welfare.

b) *Assemble, analyze, and synthesize* ecological information and present it in operational form.

c) *Conduct selected research* to fill critical needs.

Establishment of a National Ecological Service is recommended which would provide national ecological leadership for meshing the capabilities of the Federal agencies with other governmental, academic, and industrial organizations. A central operational focus for ecological research and related ecological programs is urgently needed in the Federal Government in order more effectively to address national problems affecting environment and resources.

This Service would also complete natural and research areas systems (Recommendations 7 and 8), and a data management system. These would help to implement the National Environmental Policy Act, clean air and water acts, and the proposed acts on land use policy and energy policy when enacted. Initially this Service could:

Evaluate and revise selected existing survey and inventory systems into a National Ecological Survey.

Evaluate existing and recommend revised monitoring programs for a national ecological monitoring program with meaningful biological and ecological indices.

Select, analyze, and integrate data for helping implement the National Environmental Policy Act and related acts. Priority should be given to high-impact areas such as coastal California, Long Island, and peninsular Florida.

a) A *National Ecological Survey* has many values and uses, the same as the important and extensively used Geological Survey. An Ecological Survey could carry out a long-term program to analyze impacts on

ecosystems in the United States, prepare baseline information, and understand the relationships of organisms with their surroundings. Alternative uses of the landscape could be evaluated using this information, and opportunities to optimize the productivity of various regions would be revealed. Fragile ecosystems could be identified and environmental quality values could be defined. An Ecological Survey could provide the baseline information required in nearly all land use decisions.

The survey strategy is a vital part of long-range planning for and application of ecological research. The distribution and abundance of plant and animal species, the detailed recorded knowledge of local ecosystems, and the identified resident expertise are recognized as essential to the preparation of many environmental impact statements and as guidelines for land use planning.

An Ecological Survey could be developed based on the data from the related supportive surveys, inventories, and monitoring programs conducted by various Federal, state, and other agencies. The Ecological Survey would utilize selected data from the surveys and compile them in an ecologically meaningful and useful system, particularly oriented to supply necessary data to help develop predictive capabilities. The Ecological Survey is not proposed to be a large new program, but would consist of ecologists and other specialists synthesizing and coordinating presently available selected data into more useable form. Ecologically important survey data needs would be identified, and these could be obtained by revising or adding to existing surveys or inventories.

There is a need to coordinate the many environmental surveys and inventories that have developed over the years, and the Ecological Survey is a logical place for this action to occur. Such a program would result in improved coordination between groups, reduce overlap, and might even reduce Federal expenditures.

b) Medical doctors have developed reasonably reliable techniques to measure general human and animal health. Using indicators such as pulse rate, blood pressure, temperature, and urine analysis, one can obtain a general indication of a person's health. Ecologists are just beginning to develop comparable indices for quantifying and predicting the health of ecosystems. A useful, though somewhat tedious, technique to indicate the "health" of rivers and streams has been developed based on the relative number of the various species of diatoms (one-celled plants) inhabiting a section of water. By knowing the range of species tolerance to pH, temperature, oxygen, etc., the health of the ecosystem can be diagnosed.

More such indicator techniques need to be developed, preferably with organisms at a higher level on the food chain because certain materials may be concentrated at each step in the chain. The "condition" of these organisms may also be less variable, requiring fewer samples. Birds could be valuable in this regard because they are not only high in the food chain and occupy a diverse range of terrestrial and aquatic habitats, but they are often sensitive to slight ecological changes.

The Committee recommends research to devise meaningful ecological

indices, including appropriate fundamental investigations to substantiate the indicator value of particular biological organisms.

The Federal government presently supports extensive biological and environmental monitoring programs on a national scale. These are not presently coordinated or integrated to be of constructive ecological value. It is recommended that a national ecological monitoring program be established which would bring together data from the pertinent existing biological, agricultural, environmental, pollutant, and other survey and monitoring programs. The new function would be coordination, integration, and analysis of the data to produce a national ecological monitoring program. Data from important study, baseline, and monitoring sites (e.g., biome study areas) as well as from impact areas near cities, industries, and river mouths would be included.

c) Requirements for ecological data have intensified in recent years, and the Committee is concerned about lack of provision for effective ecological data systems. There have been many expressions of need for regional and national ecological data systems.

Results of ecological research are needed at an early stage in planning so that sound management decisions can be made. Preparers of environmental impact statements would draw on national or regional data storage centers, and data impact statements could also contribute to the data bank. Eventually the data bank would be used to construct an "ecological characterization" of specific regions.

Computerized environmental data storage and retrieval programs are in existence, but inadequate provision is made for ecological interpretation and utilization of data. One cannot at this time program a computer to supply answers to broad environmental problems.

It is recommended that existing systems of environmental data storage and retrieval, such as those at Oak Ridge National Laboratory, the Environmental Protection Agency, and the National Library of Medicine, be evaluated and the best available subsystems selected. It is probably not desirable to initiate a completely new data management system.

The *National Ecological Service* could be a logical organization to help coordinate and implement the other recommendations of this Committee.

Recommendation 2

a. **Develop improved capabilities for ecological research, including advances in conceptual frameworks, systems science, experimental design, and mathematical models. Augment these tools with basic ecological inventory data. Goals are to develop predictive capabilities of the effects of technological and sociological influences on the environment and to improve ecosystems management.**

b. **Support Federal involvement in research programs which strengthen the development of ecology as a discipline, in universities, Federal laboratories, and State activities.**

Advanced capability means strengthening ecology in terms of highly trained manpower; suitable facilities; leadership, coordination, and integration; and information transfer mechanisms to move the scientific results into the decision making process. It also means further development of techniques for field research, statistically valid field sampling, biological and chemical assays, field scale instrumentation, and computer modelling. It includes use of protected natural areas and research areas, and data on plant and animal distribution and abundance. There is need for refinement of ecological principles and transferability of theories of cause-and-effect relationships from one area to another.

There are different integrative levels involved in studying ecosystems. They cannot be understood solely by the reductionist method.

Systems science provides the methodology for study and management of complex ecosystems. Parts of systems science were born in the field of ecology, but now ecology has much to gain from advances in systems analysis methods developed in other disciplines.

Only recently have systems analysis techniques been available for handling large numbers of interdependent factors, with complex feedback processes. System models reveal slow response patterns to various stresses and to manipulations of ecosystems or their components. Ecological computer simulation models have the potential to aid in formulating and validating ecological policies, and helping managers and decision makers to anticipate probable future consequences of alternative courses of action.

It is necessary to combine information from ecosystems studies with engineering, economic, social, and political information in order to gain valid predictive capability; for man's technical, economic, social, and political activities have much to do with the future of the biosphere.

Business and industry have not supported ecology as they have chemistry and physics, but that condition is likely to change as ecological impacts of technological change become a factor in industrial decision making. By stressing the need for greater research capabilities in ecology to serve industry, universities should be able to obtain substantial support in the form of endowed chairs, environmental center funds, fellowships, and facilities grants. Advanced ecological research capability obviously could be useful to industries concerned with minerals extraction, plant siting, waste management, responsibility for environmental effects of products, and market opportunities in maintenance and improvement of the environment.

Advanced technical capability in ecology promises more effective ecological research and more effective ecological action.

Recommendation 3

a. **Assign highest priority to ecological research programs that:**

   (1) **Gather information on the composition and functioning of ecosystems.**

(2) **Help predict the ecological effects of technological developments.**

(3) **Serve to minimize or mitigate ecological impacts of man's disturbances, and restore damaged ecosystems to productive status.**

(4) **Develop means to improve management of renewable natural resources.**

(5) **Strengthen ecologists' capabilities to apply their expertise and knowledge to solving relevant environmental problems.**

b. **Implement this recommendation by support of Federal programs which utilize ecological research to achieve agency goals.**

Ecological research is concerned with at least two categories of ecological problems, current and future, for which there is, at present, no adequate methodology for evaluating the societal-ecological trade-offs. Current problems of the first category are, for example, the demands of large urban concentrations on the supporting land and water areas. In the second category are new ecological problems resulting from technological advances to meet future demands for food, fiber, power, and amenities. The complexity of these problems requires a systems approach with the capability of simulating the consequences of various courses of public policy and action.

Achieving significant results in these areas requires concentration on selected aspects of ecological research such as:

1. Obtain accurate, quantitative data on plant and animal distributions, populations, communities, and whole ecosystems to provide needed baselines and trends.
2. Develop standardized measurement methods and improved instrumentation and sensors.
3. Accelerate ecological research in areas where rapid and drastic environmental changes have led to change or depletion of species.
4. Use integrated multidisciplinary team approaches to understand complex ecosystems.
5. Use techniques of modern systems science for data utilization.
6. Improve ability to predict probabilities for the future from ecological information.

Some specific ecological problems and areas needing research are:

1. Terrestrial Ecosystems

a. Interactions among terrestrial and aquatic ecosystems within a drainage basin or other physiographic area including forest, grassland, cropland, wetland, natural and man-made aquatic and urban ecosystems.

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b. Impact of alternative patterns of land and water use on (1) production of commodities and amenities, (2) quality of the environment, and (3) public access to benefits.

c. Impact of alternative patterns and intensities of recreational use on parks, wilderness, and natural areas, other public and private lands, and on public health.

d. Impact and amelioration of non-point source water pollution due to runoff from urban and rural land.

e. Impact of toxicants on populations and ecosystems, including long-term effects on reproduction, genetic constitution, and tumor formation.

f. Ecological impact of alternative patterns and intensities of development of electrical power resources.

g. Impact of alternative patterns of use and disposal of biodegradable wastes (e.g., feedlot wastes, city sludge).

h. Global monitoring of terrestrial and aquatic ecosystems and the impact of man's activities on them.

i. Impact of weather modifications on ecosystems.

j. Tropical forest ecosystems including impact of alternative patterns and intensities of human activity.

k. Fish and wildlife habitat.

l. Impact of alternative methods of pest control in natural and managed ecosystems.

2. Fresh Water and Marine Ecosystems

a. Impact of man's activities on wetlands ecosystems.

b. Ecology of marine mammals, especially whale populations and the impact of present and prospective whaling.

c. Systems studies of marine and estuarine fish species, especially those of present or potential food importance.

d. Managed systems for production of fish and shellfish.

e. Ecology of ocean dwelling zones.

f. Integrated ecosystems studies of lakes to provide bases for management of water quality.

g. Fate and effect of oil in the ocean.

Recommendation 4

a. **Utilize naturally bounded regional systems of landscape as units for research planning and management, rather than artificial or political subdivisions.**

b. **Implement this recommendation by integrating in the least disruptive manner with presently established**

agency regions, while adapting political units to regional ecosystems units.

Regional approaches to ecosystems research, planning, and management are necessary because traditional political units are seldom congruent with natural ecosystems. Often the boundaries of political units were determined without regard to the natural systems of landscape (e.g., they occur along lines of latitude or longitude). Some political boundaries are determined by streams, rivers, or estuaries. As the need to manage watersheds or estuaries arises, so does the requirement for a regional grouping of political units. Regional ecosystems studies allow transferability of data and findings within the region or to similar regions and are the most useful units for ecological studies.

Recommendation 5

Revise agency guidelines for environmental impact assessment in accordance with CEQ quidelines (Federal Register, Aug. 2, 1973) to require that consideration of and research on environmental effects of projects commence at the outset in planning technological developments, resource utilization, environmental modification, construction of human settlements, and other human activities.

Potential ecological consequences of Federal projects should be investigated in the earliest planning stages to obviate costly delays resulting under the present system of *post facto* adjudication of challenges. Court decisions are as likely to be determined on technicalities as on the merits of cases. Advance attention to the ecological consequences of planned actions should result in sounder decisions and the conservation both of public funds and natural resources.

Major technological developments, such as the breeder reactor or fusion power, have lead times of over 20 years for development and initial production. The time to begin considering potential ecological impacts is during early development. If evaluation were done in the early phases it could decrease the need for separate costly impact statements about each power plant being installed. Ecological advice and consultation is needed in long-range planning of major technological developments, renewable and nonrenewable resource utilization, major environmental modifications, agricultural developments, human settlements, transportation facilities, and waste disposal systems.

As project plans are reviewed, the lessons learned from unfavorable court actions could more readily be incorporated into similar projects in the planning stage than they are under the present system. Implementation of this strategy now should lessen court challenges in the future.

There is a need for planning for ultimate total resource use related to projected total demand on the fixed amount of existent space and useable natural resources. This will impinge on and require compromises of environmental quality. Meaningful priorities should be established to meet these requirements of man and whatever floral and faunal species he needs to share this planet with him when sustained survival is realistically threatened.

Despite three years of experience with the National Environmental Policy Act, no Federal agency has developed a "feedback" procedure so it can quantify the types of problems being encountered in preparing impact statements. This relatively simple procedure of screening their impact statements for "unknowns" would allow agencies to substantiate their need for research in specific areas and would lend credibility to the results. It would be of great value if all agencies periodically review their impact statements and compile a list of ecological difficulties encountered from gathering preparatory data through preparing the final impact statement and implementing the proposed activity.

Recommendation 6

Prepare environmental impact statements with high priority consideration to:

a. **Maximum practicable use of quantitative analysis, prediction, and evaluation of ecological impacts;**

b. **Post-impact evaluation of predicted impacts and unpredicted consequences on a selective basis; and**

c. **Identification and initiation of research of problems amenable to solution by additional ecological research.**

Agencies should publish follow-ups concerning their predictions of environmental impact. Federal agencies should (a) estimate the kind and amount of environmental impact they believe their activity will cause, (b) provide information to decision makers to permit weighing of environmental costs against activity benefits, and (c) if the activity is terminated, estimate how long it will take the disturbed ecosystem to recover or succeed to another "useful" condition. Agencies should, after project implementation, follow-up and evaluate actual impact.

Agencies should develop a mechanism to inspect their impact statements for ecological problems amenable to research. This action will require the aid of ecologists to translate environmental problems into the proper types of research categories so a systematic approach may be made in solving the problem.

A number of benefits could accrue from these activities. The reliability of agency predictions could be validated. Accurate predictions would indicate that agencies have "adequate" environmental information; widely missed predictions would indicate that the agency needs to conduct additional research and perhaps their proposed activities need to be delayed until adequate data becomes available. At present, once an activity is initiated no matter what its resulting impact is, the activity often continues.

Recommendation 7

Complete the existing National System of Natural Areas, with full representation of major ecosystems, to provide sites for studies of naturally functioning systems that can serve as ecological reference points for baseline monitoring, and as controls for experimental research. Utilize existing Federal lands to the maximum extent possible. Classify the natural areas into a useful system.

Natural areas are important as reference points or as baseline controls against which man-caused changes can be measured. These areas are required as controls for manipulative research experiments and management testing. Such areas are of value for studying the structure and function of natural ecosystems. They are of value in the preservation of biotic communities, of rare and endangered species of plants and animals, and of gene pools, and research methods for their protection. Natural areas are of educational and training value. They may also contribute directly to environmental quality by serving as ecological buffers to modulate the environment and support diversity.

Natural areas should be protected as much as possible from human intervention and pollution. The areas should be of suitable size to allow cycling of materials within the system. Species diversity should be maintained and collecting and destructive research prohibited. Some management may be required to maintain the desired ecosystem status or successional stages.

Recommendation 8

Complete the National System of Ecological Research Areas to provide sites for manipulative experiments, management testing, and observations of the results of human impact. Utilize existing Federal lands to the maximum extent.

The purpose of ecological research areas is to develop techniques for qualitative and quantitative continuous assessment of the ecological impact of man's activities and technology, and to serve as living demonstrations of effective ecosystems management.

In ecological research, emphasis is placed on quantitative studies of ecosystems with special attention given to the study of interactions among the components. These insights are frequently gained most efficiently by imposing a stress on the ecosystem experimentally. Quantitative research on entire ecosystems must be based on the observed response of landscape units exposed to experimental manipulation. The experimental unit may consist of an entire watershed or body of water. By measuring the ecological response of the unit of inputs of man-caused disturbances, valuable empirical data can be collected for management use.

Availability of landscape units of suitable size for experimentation is central to the ecosystem experimental approach. In addition, these ecosystems should be representative of much larger units so that information gained may be extrapolated with greater confidence throughout the region.

Ecological research areas should be in locations where the area and experiments will be little altered by inadvertent releases of pollutants or by uncontrolled human activity. They may be areas which are relatively unmodified or greatly modified or polluted. They should be of sufficient size so materials which cycle (e.g., nutrients and pollutants) can do so largely within the system. Many potential areas exist within the public lands and some are already reserved for research. A suitable network of such research ecosystems should be designated in appropriate areas.

At present a system of National Environmental Research Parks has been established on certain federally operated facilities. It is recommended that these form the basis for the National System of Ecological Research Areas.

Recommendation 9

Assign high priority to research on the ecology of intensively managed and used, man-dominated urban ecosystems, so as to establish threshold values for ecosystem stress. Detailed ecological research requirements and applications should be determined in a separate study by appropriate experts.

The Committee agreed that ecological study of urban ecosystems is important and urgently needed. This area was not reviewed by this Committee or the CEQ-OST Committee on Environmental Health Research; however, both Committees recommend that the subject be reviewed by experts in this specialized field.

Recommendation 10

Investigate the techniques for developing means of long-range ecological planning geared to establishing a "carrying capacity" for human activities.

The influence, both positive and negative, of man on his environment is a function of population size and life style. In recent years industrial man has come to recognize this his activities depend on a finite resource base. Because this resource base for food, housing, recreation, industry, tranportation, material wealth and many other activities is so diverse and widely dispersed, appreciation of the limited capacity of the earth to sustain an expanding human population with escalating aspirations of wealth has come slowly. Pastoral man has long understood and adjusted to the grazing capacity that sustained his herds.

Comprehensive management of resources for urban development, as well as for population planning, require better prediction of per capita requirements. For example, ecologists have suggested that the minimal area for each person in the United States to sustain the present life style may be approximately 5 acres; the present ratio averages 10 acres per person.

Analysis of ecological carrying capacity as a tool for evaluating environmental impact and accommodating appropriate population growth is required. Such analytical and predictive ability can be fostered in the Ecological Service as well as by agencies sponsoring ecological investigations in support of their missions. The concept of carrying capacity developed for animal husbandry should be extended to management of land for human activity.

Recommendation 11

Ecological education should be augmented by providing a specific core curriculum, and research training grants for practical work on high priority environmental problems.

The Committee has found a shortage of professional ecologists trained in ecosystem research and systems approaches. This is true in part, because the number of graduate programs in ecology is relatively

small. Over the last five years, however, student interest in ecological training has increased concurrent with the rising public concern over ecological problems. The recent termination of Federal support of research training grants has been particularly harsh on students with field research projects and it is easier now to conduct graduate research within the confines of the campus. Academic institutions could produce more ecologists and other relevant environmental scientists with research training grants which permit students to study real problems. Such field research can be interdisciplinary and could be cooperative with industry or local government, thus more effectively linking intellectual resources with socially relevant issues. This activity is most meaningful at the graduate and continuing education levels.

Ecological awareness has increased in all age groups, but ecological knowledge has been restricted. In spite of an information explosion, especially in environmental activist literature, well-planned, accurate, and well-documented ecological curriculum materials are generally inadequate at all educational levels. Because ecology is a relatively young, dynamic, and evolving science, the curricula tend to be as varied as the instructors. It is, therefore, timely to specify a core curriculum in ecology for various educational levels in context with other relevant subjects.

Ecologists have been given many new definitions and have been wrongly considered to be specialists in pollution or the environment. In addition there are many concerned environmentalists and "instant" ecologists without proper ecological education. To further add to this complexity, wide differences exist within the ranks of professional ecologists. Some are statistically oriented, and some use a non-quantitative natural history approach. Others utilize a firm taxonomic base while some ignore species and utilize biomass or total productivity to indicate conditions. Hence some ecologists are suitable for certain situations and others are not. It is important that a common knowledge base or core curriculum be developed within the various universities so ecologists (like medical doctors) can be "general practitioners" first and specialists second.

Recommendation 12

Federal agencies should hire professional ecologists where needed and not substitute other specialists who lack full ecological training. The Civil Service Commission should establish a classification for ecology and set standards to assure adequate capability.

Federal agencies have problems in employing ecologists in planning and research roles because ecology, as such, is not listed as a field of science in the Civil Service Commission's list for the Biological and Agricultural Sciences. This omission makes determination of manpower needs in ecology very difficult. While line jobs can be filled by ecologists who are enlisted in botany, forestry, fishery and wildlife biology, or zoology, a staff position as "ecologist" could be more easily justified and would be more appropriate. The Civil Service Commission should be requested to add "ecology" as a field of science and to establish appropriate professional standards to assure proper training and experience.

CHAPTER IV
Ecology as a Scientific Discipline

1. Scope of Ecology

Ecology is the study of whole organisms and their relationships to each other and to the environment. Ecology has developed out of the discipline of biology, and environmental biology remains as a most important disciplinary core. Environmental studies that do not involve organisms are not ecology. Yet, environmental studies within the biosphere, that portion of the earth where life is concentrated, are ecologically incomplete without including living entities and their effects. Ecological research has become increasingly interdisciplinary rather than a subdiscipline of biology. Included may be elements of geology, oceanography, climatology, radiology, physics, and biochemistry as well as aspects of health sciences, sociology, psychology, and other behavioral sciences that may not be thought of as strictly biology.

The levels of biological organization with which ecology deals are shown in Table 1 with an indication of the characteristics of each level and the ecological speciality with which it is concerned. Although the emphasis in modern ecology is on understanding sets of major processes, or even the totality of relationships within ecosystems, ecosystem research at all levels of organization is required to provide information on components of the system and synthesis of these components and the processes which link them. Such an understanding of ecosystems provides a basis for rational management of most renewable natural resources.

Table 1: Levels of Ecological Organization

Individual	The fundamental biological sytem; an organism	Physiological and psychological response to environmental change or stress. *"Physiological ecology"*
Population	The set of individuals of the same species an ecosystem	Regulation of population size and density by biotic and abiotic factors. *"Population ecology"*
Community	A naturally occurring or man-modified assemblage of	Interactions between populations of different species in a community,

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	organisms of various colocated species	e.g., behavioral and biochemical aspects of plant-herbivore interactions; competition, predation. *"Community ecology"*
Ecosystem	A geographically delimited assemblage of coadapted communities, and the nonliving portion of earth it occupies	As an ecosystem (e.g., a lake) is the smallest relatively self-contained ecological system, it is the logical unit for system dynamics, and study of perturbations to ecosystem function and changes in one system which affect another. Major terrestrial ecosystems (e.g., grasslands of western North America) are called "biomes." Their study constitutes *"Ecosystem ecology."*
Biosphere	All organisms and all parts of the earth they occupy and modify including oceans, soils, and atmosphere	*The all-inclusive system is often too large to examine. Biogeochemical studies of the migration and distribution of biogenic elements may require a biosphere system.*

2. Energy Flow and Cycling of Matter in Ecosystems

An organism, unlike a non-living natural entity, requires for its maintenance a continuous input of energy and continuous exchange of molecules with its environment. The plants, animals, and bacteria which live together in an ecosystem all ultimately derive the energy they require from the solar radiation that impinges on the surface of the system. The myriad species of an ecosystem can be grouped into a small number of trophic categories on the basis of the manner in which each derives its energy-*producers, consumers* (first-, second-, third-order) and *decomposers.*

The preponderant amount of available chemical energy in an ecosystem is in the organic matter of the producer level. Succeeding levels of herbivores and carnivores in a food web have approximately one-seventh as much living matter as the preceding level. Respiration losses from each level, and the inevitable losses in transformation of compounds removed from the preceding level, cause this sharp decrease in energy content as the trophic pyramid is ascended. Since the size of individuals tends to increase as the pyramid is ascended, population size drops markedly.

Organisms which decompose organic material are relatively inefficient in utilizing the energy that they release for body construction, yet they dissipate a large fraction of the chemical energy

stored by the producers. Decomposers play a vital role in the recycling of matter within an ecosystem by reducing the energy-rich compounds of feces and the dead bodies and remains of plants and animals to simple molecules that producers can reutilize.

Chemical elements tend to circulate in the biosphere in characteristic paths from environment to organisms and back to the environment. These paths are variously called "inorganic-organic cycles" or "biogeochemical cycles." Of the nearly 100 elements known to occur in nature, we have found some 30 to 40 are required by living organisms. Some of these elements (e.g., carbon, hydrogen, oxygen, and nitrogen) are needed in large amounts; others in lesser or even balance than others, and materials are returned to the environment as rapidly as they are removed. Some cycles are unevenly balanced and portions of the nutrients may become lost or bound in sediments or in organisms and thus are not available to the ecosystem.

Man's activities have accelerated the movement of many materials, e.g., phosphate, into lakes. Fortunately some cycles, such as carbon, have so many compensating mechanisms that man has successfully used them but done little to alter them. Application of radionuclide tags has facilitated quantitative studies of ecological food webs and pathways of both nutrients and toxicants in the environment.

3. Species Composition of Ecosystem

The numerous species found at each level in a food chain are competing for energy and nutrients. Which of the competing species will be the numerical dominant in an ecosystem is, to varying degrees, determined by the food-selection characteristics of the animals of the next higher trophic level. That is, the second-order consumers can often determine the dominance at the herbivore level and the herbivores determine dominance at the plant level. Granted that the numerical dominance among competing species is determined, in part, by the selective feeding behavior of the next higher trophic level, then consumers of the highest levels must both directly and indirectly influence the composition of the entire ecosystem.

This fact may provide mechanisms by which man can regulate the great living mass of the producer and herbivore levels by manipulating the smaller populations of larger individuals at the top levels. There is evidence, for example, that the predatory fish of a lake (such as trout or bass) may influence the algal populations through their direct effect on the plankton-eating fish and their indirect effect on the animal plankton that feed by sweeping algae from the water. Changes in fish stocks may have aggravated eutrophication problems in some lakes, but proper manipulation of these fish stocks may also be a means to alleviate these same problems.

In some natural terrestrial ecosystems herbivores play an important role in determining the abundance, spatial distribution, and temporal patterning of the competing species of producers. This is equally true for large grazers on a prairie or for insects in an evergreen tropical forest. Insect herbivores are themselves subject to an often highly selective attack by predatory insects. The stability of predatory insect population with complex behavior depends on the spatio-temporal

patterns of distribution for the herbivore populations upon which it preys. "Clean" monoculture for field or forest crops may become ecologically unstable because the populations of grazing animals, particularly insects that can be supported by the extensive food source, usually lack the predatory control that exists in a more heterogeneous system. A hopeful approach to the regulation of agricultural pests is the development of pest management systems which integrate chemical, biological, and cultural practices including genetic selection, mixed crop plantings, predator introductions, biodegradable pesticides, attractants, repellants, and hormonal chemicals.

4. Human Ecology

Human ecology is primarily concerned with the effect of the living and nonliving environment on man. His responses to this environment may be physiological, psychological, or behavioral. Urban ecology is the study of human settlements, the habitat of man. Evidence is accumulating that people respond to crowding, to architectural design, and to other aspects of their urban environment in important ways. For example, the necessity to destroy portions of the Pruitt-Igo housing complex in St. Louis seems directly attributable to a building design that failed to provide an appropriate degree of family privacy.

When men live in small groups as primitive cultivators, nomadic herders, or hunters, their ecological relationships are little different from those of many other animals of similar size and trophic demand. But the concentration of humans in urban societies is unique. While other large animals which are spatially packed move continuously over large areas to acquire food (e.g., bison herds), food must be imported to cities and wastes must be removed.

Providing nutrients thus becomes a vast, complex set of operations involving the importation of large quantities of food derived from distant crop lands, ranges, and fisheries. Industrial man uses fossil energy to increase the efficiency of conversion of solar energy to a desired food and to increase the yield of monocultural crops, herds and fisheries. Fossil energy is used to import fertilizers, prepare pesticides, and run heavy equipment for tilling and harvesting. But industrial man's use of selected, high-yield crops and livestock may so alter the original composition of the ecosystem that the system's very stability is threatened. Wherever these changes are excessive, the instability of the ecosystem becomes obvious, as those who lived in the "dust bowl" of the 1930's will remember. Improved management has, for the moment at least, reduced the sensitivity of prairie systems to such changes. But maintenance of productive systems on prairie sites exacts a high cost in fossil or nuclear energy.

5. Relating Ecological Values to Societal Needs

Evaluating trade-offs for alternative, often competing, uses of land is ecologically difficult because the market value of ecological effects, both acute and chronic, cannot be easily determined. Assessing ecological effects by traditional cost/benefit analysis is therefore not sufficient.

One method used to calculate the monetary value of natural ecosystems employs an "Energy based" technique. Basically money

and energy flow in opposite directions in society; i.e., money output is exchanged for energy input. Thus the ratio of Gross National Product to National Power Consumption can be used to "convert" calories to dollars. For the United States this is approximately 10,000 kilocalories per dollar. Using this conversion, the ecological work of an acre of forest has been calculated to be about $2,560 per year. Still to be determined is the proportion of this work which is essential to man as part of his life support system.

Another approach to economic evaluation of natural ecosystems involves assessing the work of nature in treating and recycling municipal wastes. Experiments at Penn State University indicate an acre of natural or seminatural vegetation can be an effective *tertiary* treatment mechanism. An acre of land can absorb about 1.3 million gallons of treated waste water per year, which is about the amount of waste water produced by 35 city people. If this waste were subjected to artificial treatment, it would cost about $1,400. Thus in addition to "growing a tree crop," an acre of land could be worth an additional $4,000 per acre for waste effluent disposal.

A useful method to determine ecological versus technological tradeoffs is to estimate per capita needs for land. It has been suggested that the minimum per capita acreage requirements for a quality environment based on present United States population and acreage is on the order of:

Food-producing land	1.5 acres
Fiber-producing land	1.0 acre
Natural use areas	2.0 acres
Urban-industrial areas	0.5 acre
Total	5.0 acres/capita to sustain the present quality of life.

Although more intensive culture can increase food yield per acre, additional requirements are generated to sustain the higher level of technology. This thesis needs to be tested because, if true, our present U.S. population can be more than doubled before depletion of life's amenities.

Associated with this calculation is the idea of some optimal proportion between natural and constructed environments. In order to develop a rational ecosystem management plan, the optimum ratio between natural and artificial ecosystems must be determined. Preliminary estimates suggest the ratio should be about 1:1 on an area basis for the United States as a whole but should differ between regions. If this concept is valid, then we are already overbalanced in some geographic areas. An acceptable ratio depends on the character of use and management, but it is clear that aggregation of people into urban centers also requires natural ecosystems somewhere to sustain the life support system.

6. Current Problems of Ecosystem Research and Management

In ecological research, emphasis is placed on holistic studies of ecosystems with special attention given to the processes of interaction among the components. These types of studies are needed to evaluate and predict the environmental impact of all types of development

projects. Quantitative research on entire ecosystems must be based on the observed response of large landscape units exposed to manipulation whether the manipulation is planned or not. The experimental unit may consist of an entire watershed. By measuring the ecological responses of the watershed to inputs from disturbances caused by man, empirical data can be collected and mathematical models can be developed and tested for their predictive ability and management value.

Availability of landscape units of suitable size for experimentation is central to holistic ecosystem experiments. Some of these experimental ecosystems should be in locations where they will be only slightly altered by inadvertent release of pollutants or by uncontrolled human activity. The experimental area should be of sufficient size so materials such as nutrients, radionuclides, or heavy metals which cycle can do so primarily within the ecosystem. In addition, these ecosystems should be representative of much larger units so information gained may be transferred with confidence throughout the region. Research techniques need to be developed to indicate the reliability of extrapolated data.

Recent findings have shown that holistic models of large systems based on scientific truths are difficult to assemble and will take years to construct. Models which show the relationships of various parts of the ecosystem and are not truly mathematical in flow relationships have more immediate value. It is, therefore, necessary to proceed at once with subsystem models that can be constructed with reasonable accuracy. Since so many of man's activities alter ecological systems, research is needed which emphasizes recovery rates or shows how changed conditions can be modified to support more useful ecosystems. One of our great needs is to learn how to rehabilitate damaged ecosystems, such as strip mined lands or aquatic areas, or to design ecosystem uses so the damage can be mitigated. This type of research would be valuable in planning physical or chemical changes in ecosystems whether surface waters, landscapes, or urban and industrial sites.

CHAPTER V
Federal Ecological Research Programs

1. Analysis of Programs

a. National Problem Areas Requiring Ecological Research

The most important national problem areas requiring ecological research have been categorized and are listed in the vertical axis in Tables 2-4. The types of ecological research required to help solve these problems are shown in the horizontal axis of the same tables. The resulting matrix for organizing support of ecological research shows the amount of Federal funds being expended in each category of research on each specific problem. This matrix makes it possible to compare and analyze the amounts of support given to each area. It was frequently difficult to categorize certain types of research since there was overlap in subject area and some subjective judgments were required. Additionally, because of rounding errors agency descriptions in Section 2 may not add to the tabular values.

The levels of Federal support of ecological research as defined by the Committee are $139.97 million for FY 1971, $157.69 million for FY 1972, and $182.28 million for FY 1973. Comparisons with previous years are not meaningful because different types of analyses and definitions were used.

Ecological research is being conducted on a wide variety of problem areas which require it. The ecological research (Table 3) supported in 1973 ($182.28 million) is analyzed in more detail to show a comparison of relative efforts. Ecological research is being used to help manage our natural resources and in helping solve problems caused by the activities of man including pollution and environmental change. Of the total 1973 research effort, 27 percent was spent on the effect of environmental change including air, water, and land use effects. For problems of evaluating whole ecosystems, 19.3 percent was spent on impact assessment, regional global consequences and predictions, and stability and interactions of ecosystems. The greatest amount of research (37.5 percent), was conducted on problems associated with regulating organisms including pest and disease management, biological production (food and fiber), exotic and rare species, and wildlife management. For problems arising from the activities of man, 8.7 percent was spent on ecological research on recreation needs, urbanization and urban planning, resource recycling and waste disposal, socio-economic trade-offs of alternative development projects, weather modification, and engineering construction and industrial siting.

TABLE 2. CEO-FCST COMMITTEE ON ECOLOGICAL RESEARCH

MATRIX FOR ORGANIZING SUPPORT OF ECOLOGICAL RESEARCH, FY 1971

($ in Millions)

PROBLEM AREAS REQUIRING ECOLOGICAL RESEARCH	1. Describing Ecosystems: A. Natural	1. Describing Ecosystems: B. Managed	1. Describing Ecosystems: C. Man-occupied	2. Functions and Relationships: A. Among organisms	2. Functions and Relationships: B. With environment	2. Functions and Relationships: C. Changes with time	2. Functions and Relationships: D. Synthesis, modeling or prediction	3. Management: A. Of environment	3. Management: B. Of organisms	3. Management: C. Of man's activities	4. Impact of man's activities: A. On environment (pollution)	4. Impact of man's activities: B. On organisms	4. Impact of man's activities: C. On man (other than health)		
I. EFFECTS OF ENVIRONMENTAL CHANGES															
a. AIR QUALITY EFFECTS															
1. POLLUTANT EMISSIONS	.02	.01	.06		.09	.16			2.51	.03			.47	1.36		4.77	
2. THERMAL ADDITIONS													.64			.64	
b. WATER QUALITY EFFECTS																	
1. EUTROPHICATION	.10				1.52	.46	.03	.07			1.40		.44			4.02	
2. THERMAL ADDITIONS	.06					.10		.11			.13		.20	1.85		2.45	34.65
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.66	.14	.01		.18	.42	.08	.12	.01	.29	.12		.11	.28		2.42	
4. POLLUTANT EMISSIONS	.32		.02		.02	1.79		1.40				1.40	.18	8.78		13.91	
c. LAND USE EFFECTS																	
1. NON-RENEWABLE RESOURCE EXTRACTION									.10	.01			.28	.05		.44	
2. RENEWABLE RESOURCE PRODUCTION	.10	.02			.15	.10	.10	.10	.05	.25						.87	
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.26	.13			.57	.43	.05	.85	.33	1.23	.61		.55	.12		5.13	
II. PROBLEMS OF EVALUATING WHOLE ECOSYSTEMS																	
a. IMPACT ASSESSMENT	5.79	.16			.58	3.74	.07	.39		.75			.04	2.72		13.24	
b. REGIONAL GLOBAL CONSEQUENCES AND PREDICTIONS	.10	.04				.10	.51									.24	23.67
c. STABILITY AND INTERACTIONS OF ECOSYSTEMS	2.31	.71	.05		1.97	2.40		.60	.73	.72			.05	.14		10.19	
III. PROBLEMS ASSOCIATED WITH REGULATING ORGANISMS																	
a. PEST AND DISEASE MANAGEMENT	.31	.64	.30		4.06	.91		.08	1.64	8.42	.50		2.01	.53		19.40	
b. BIOLOGICAL PRODUCTION (FOOD, FIBER)	4.95	.20		13.95	4.74	2.54	.25	.41	.34	3.58			.34	.12		31.42	58.05
c. EXOTICS AND RARE SPECIES	.12				.03	.02			.23 .03	.54				.20		1.17	
d. WILDLIFE MANAGEMENT	.22	1.57	.20		.16	.14	.41		.65	2.56	.15					6.06	
IV. PROBLEMS ARISING FROM ACTIVITIES OF MAN																	
a. RECREATIONAL NEEDS		.01	.09		.01				.09	2.48	.11		.34	.12	.31	3.56	
b. URBANIZATION AND URBAN PLANNING			.01		.01			.02	.03	.01	.06		.02	.03	.29	.48	
c. RESOURCE RECYCLING AND WASTE DISPOSAL		.02	.02		.08	.02			.12	.11	.32		.76		.10	1.55	
d. SOCIO-ECONOMIC TRADE-OFFS OF ALTERNATIVE DEVELOPMENT PROJECTS						.04		.01					.18		.53	.76	9.24
e. WEATHER MODIFICATION									.23							.23	
f. ENGINEERING CONSTRUCTION AND INDUSTRIAL SITING	.90							.23	1.52				.01			2.66	
V. DEVELOPMENT OF ECOLOGICAL RESEARCH																	
a. DEVELOPMENT OF ECOLOGICAL PRINCIPLES	2.50	.05	.33		2.11	3.77	.48	.62	.04	2.96			.06	.10	.08	13.10	14.36
b. RELATION TO OTHER SCIENCES	.50				.03	.07	.63	.03								1.26	
	17.22	3.70	1.09	13.95	16.31	17.27	2.61	5.04	.23	8.42	23.94	3.40	1.40	6.68	16.40	1.31	$139.97
		22.01				55.18					35.99				25.79		

TABLE 3. CEQ-FCST COMMITTEE ON ECOLOGICAL RESEARCH

MATRIX FOR ORGANIZING SUPPORT OF ECOLOGICAL RESEARCH, FY 1972

($ in Millions)

PROBLEM AREAS REQUIRING ECOLOGICAL RESEARCH	1. Describing Ecosystems: A. Natural	B. Managed	C. Man-occupied	2. Functions and Relationships: A. Among organisms	B. With environment	C. Changes with time	D. Synthesis, modeling or prediction	3. Management: A. Of environment	B. Of organisms	C. Of man's activities	4. Impact of man's activities: A. On environment (pollution)	B. On organisms	C. On man (other than health)		
I. EFFECTS OF ENVIRONMENTAL CHANGES															
a. AIR QUALITY EFFECTS															
1. POLLUTANT EMISSIONS	.01	.01	.12	.03	.10	.01		1.91	.05	.10		.46	1.84		4.64
2. THERMAL ADDITIONS						.05						.14			.19
b. WATER QUALITY EFFECTS															
1. EUTROPHICATION	.09			1.32	.53	.03	.15			1.10		.08			3.30
2. THERMAL ADDITIONS	.08			.15	.13		.20					.36	2.59		3.51
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.94	.01	.26	.30	.52	.10		.45	.26	.13		.30	.28		3.55 40.43
4. POLLUTANT EMISSIONS	.04		.08	.06	1.76		1.73	.07		.18	1.70	1.40	9.76		16.78
c. LAND USE EFFECTS															
1. NON-RENEWABLE RESOURCE EXTRACTION		.02						.13	.01			.58	.53		1.27
2. RENEWABLE RESOURCE PRODUCTION	.05	.02		.70	.25	.20	.75	.05	.35						2.38
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.24	.11	.18	.71	.50	.05	.43	.09	1.57	.76		.58	.19		5.41
II. PROBLEMS OF EVALUATING WHOLE ECOSYSTEMS															
a. IMPACT ASSESSMENT	7.92	.14		.60	4.23	.07	.60	.01	1.04			.04	2.96		17.61
b. REGIONAL GLOBAL CONSEQUENCES AND PREDICTIONS	.20	.04			.10		.86								1.20 31.04
c. STABILITY AND INTERACTIONS OF ECOSYSTEMS	1.32	.93	.05	2.67	3.40	.64	2.32	.02	.74			.05	.09		12.23
III. PROBLEMS ASSOCIATED WITH REGULATING ORGANISMS															
a. PEST AND DISEASE MANAGEMENT	.31	.73	.30	3.14	1.27	.13	.05	1.64	7.65	.52		2.24	1.27		19.25
b. BIOLOGICAL PRODUCTION (FOOD, FIBER)	5.48	.05		.95 5.00	3.22		.35	.29	3.22			.36	.10		32.05 58.94
c. EXOTICS AND RARE SPECIES	.11			.01	.05	.05		.28 .03	.44				.20		1.17
d. WILDLIFE MANAGEMENT	.25	1.59	.20	.02	.16	.30		.65	3.15	.15					6.47
IV. PROBLEMS ARISING FROM ACTIVITIES OF MAN															
a. RECREATIONAL NEEDS		.01	.21	.24				.12	2.58	.22		.12	.14	.22	3.86
b. URBANIZATION AND URBAN PLANNING			.09				.55	.09	.01	.01		.03	.08	.28	1.14
c. RESOURCE RECYCLING AND WASTE DISPOSAL		.02	.01	.03	.04		.25	.27	.74	.04		.64		.10	2.14 12.44
d. SOCIO-ECONOMIC TRADE-OFFS OF ALTERNATIVE DEVELOPMENT PROJECTS								.01						.42	.43
e. WEATHER MODIFICATION				.05				.29				.01	.02	.01	.38
f. ENGINEERING CONSTRUCTION AND INDUSTRIAL SITING	1.62						.43	2.37				.05	.02		4.45
V DEVELOPMENT OF ECOLOGICAL RESEARCH															
a. DEVELOPMENT OF ECOLOGICAL PRINCIPLES	2.21	.07	.36	2.31	3.40	.34	1.31	.04	2.99			.05	.11		13.19 14.24
b. RELATION TO OTHER SCIENCES	.13		.01	.26	.20	.35	.10								1.05
	21.01	3.75	1.87	13.95 17.60	19.86	2.27	10.16	.28	8.53	24.80	3.21	1.70	7.49	20.18	1.03 $157.69
		26.63			63.84				36.84					30.40	

TABLE 4. CEQ-FCST COMMITTEE ON ECOLOGICAL RESEARCH

MATRIX FOR ORGANIZING SUPPORT OF ECOLOGICAL RESEARCH, FY 1973

($ in Millions)

PROBLEM AREAS REQUIRING ECOLOGICAL RESEARCH	1. Describing Ecosystems: A. Natural	B. Managed	C. Man-Occupied	2. Functions and Relationships: A. Among Organisms	B. With Environment	C. Changes with Time	D. Synthesis, Modeling or Prediction	3. Management: A. Of Environment	B. Of Organisms	C. Of Man's Activities	4. Impact of Man's Activities: A. On Environment (Pollution)	B. On Organisms	C. On Man (Other than Health)		
I. EFFECTS OF ENVIRONMENTAL CHANGES															
a. AIR QUALITY EFFECTS	.18														
1. POLLUTANT EMISSIONS	.01	.01	.18		.04	.10	.02	.05	1.92	.07	.10		.55	1.91		5.14	
2. THERMAL ADDITIONS								.02	.03				.11	.02		.18	
b. WATER QUALITY EFFECTS																	
1. EUTROPHICATION	.03				1.32	.49		.31	.05	.10	.10	1.10	.13	.15		3.73	
2. THERMAL ADDITIONS	.10		.25		.06	.15		.29	.05	.10			.37	3.83		5.20	44.57
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.78	.01			.32	.47	.08		.63	.34	.24		.44	.39		3.70	
4. POLLUTANT EMISSIONS			.18		.23	2.02		1.74			.15		2.44	11.34		18.10	
c. LAND USE EFFECTS	.03					.05			.03							.11	
1. NON-RENEWABLE RESOURCE EXTRACTION	.04								.17	.01	.05		.14	.10		.51	
2. RENEWABLE RESOURCE PRODUCTION		.03			.50	.50	.50	1.00	.08	.35	.05		.13	.05		3.19	
3. MANAGEMENT AND CONSERVATION OF ECOSYSTEMS	.37	.09	.18		.79	.40	.04	.18	.09	1.23	.70	.23	.79	.29		5.01	
II. PROBLEMS OF EVALUATING WHOLE ECOSYSTEMS																	
a. IMPACT ASSESSMENT	9.12	.24			.58	4.21	.07	.56		.82			.79	3.15		19.54	35.23
b. REGIONAL GLOBAL CONSEQUENCES AND PREDICTIONS	.30	.04			.20			1.00								1.54	
c. STABILITY AND INTERACTIONS OF ECOSYSTEMS	1.31	.62	1.64		2.48	2.39	.86	3.20	.03	.75			.13	.14		14.15	
III. PROBLEMS ASSOCIATED WITH REGULATING ORGANISMS																	
a. PEST AND DISEASE MANAGEMENT	.31	.95	.30		4.16	1.16	.23	.75	1.55	8.47	.50		2.26	1.04		21.68	
b. BIOLOGICAL PRODUCTION (FOOD FIBER)	8.55			15.60	5.60	3.62	.10	.74	.23	3.53			.35	.12		38.44	68.28
c. EXOTICS AND RARE SPECIES	.10				.01	.05	.05	.29	.07	.46				.20		1.23	
d. WILDLIFE MANAGEMENT	.27	1.60	.20		.38	.12	.15	.06	.65	3.35	.15					6.93	
IV. PROBLEMS ARISING FROM ACTIVITIES OF MAN																	
a. RECREATIONAL NEEDS		.01	.23		.01				.12	2.76	.17		.13	.15	.35	3.93	
b. URBANIZATION AND URBAN PLANNING	.05		.17					1.00	.13	.01	.01		.08	.23	.32	2.00	
c. RESOURCE RECYCLING AND WASTE DISPOSAL		.02	.07			.09	.01	.30	.42	.93	.10		.80		.10	2.84	15.89
d. SOCIO-ECONOMIC TRADE-OFFS OF ALTERNATIVE DEVELOPMENT PROJECTS								.20	.20						.60	1.00	
e. WEATHER MODIFICATION						.05			.31				.02	.30	.01	.42	
f. ENGINEERING CONSTRUCTION AND INDUSTRIAL SITING	1.00		.05			.10		.25	4.03				.18	.90		5.70	
V. DEVELOPMENT OF ECOLOGICAL RESEARCH																	
a. DEVELOPMENT OF ECOLOGICAL PRINCIPLES	2.78	.06	.35		2.36	3.34	.70	1.72	.04	2.93	.05		.15	.21		14.69	18.01
b. RELATION TO OTHER SCIENCES	.10				.10	1.32	1.00	.80								3.32	
	25.48	3.68	3.80	15.60	19.14	20.87	3.81	14.36	10.83	26.21	2.37	1.33	9.99	23.43	1.38	$182.28	
	32.96				73.78				39.41				36.13				

For development of ecological research in 1973, 9.9 percent of the budget was spent. This included development of ecological principles (8 percent or $14.69 million) and $3.32 million for relation of ecological research to other sciences.

b. Types of Ecological Research

An analysis of the types of ecological research being conducted on problem areas (Table 3) shows that of the $182.28 million spent in FY 1973, 18.1 percent was on describing ecosystems including natural, managed and man-occupied ecosystems. A relatively large amount (40.5 percent) was spent on functions and relationships, including among organisms, with environment, changes with time, and on synthesis, modeling or prediction. The amount spent on synthesis, modeling or prediction was 8.0 percent or $14.36 million. For management, 21.6 percent was spent on research for management of environment, of organisms, and of man's activities. Research on the impact of man's activities was 20 percent including impact on environment (pollution), on organisms, and on man (other than health).

In the analysis of types of ecological research, all of the different categories increased without any unusual increase in any one category. The categories, management of environment and of organisms, showed the least amount of increase.

The problem area with the greatest amount of increase was problems arising from activities of man, which showed a 70 percent increase from $9.24 million in FY 1971 to $15.89 million in FY 1973. The most significant increase within this area was in the ecology of urbanization and urban planning.

The area, problems of evaluating whole ecosystems, showed a 48 percent increase from $23.67 million in FY 1971 to $35.23 million in FY 1973; the category of impact assessment increased most. These increases are associated with the emphasis in "mission" agencies to comply with the National Environmental Policy Act, which requires preparation of Environmental Impact Statements, and with increased concern in this area. The category of regional global consequences and predictions increased from $0.24 million in FY 1971 to $1.30 million in FY 1973 due primarily to the establishment of a $1.00 million project in synthesis modeling or prediction.

In the area of problems associated with regulating organisms, the increase in 1973 over 1971 was less than 20 percent. However, this problem area still received more than a third of all funds for ecological research.

Ecological research is widely scattered throughout the various Federal agencies and bureaus. It is usually conducted to meet specific mission requirements in each bureau. Some of the research has been continuing for decades while other research is new or just being initiated. Coordination between the agencies and bureaus is very difficult under these conditions. Assurance that older research projects are still needed and relevant, and that the best ecological research methods are being used is difficult to ascertain. With such a large number of problem areas split between a large number of agencies and bureaus there is bound to be some overlap or replication.

While the present analysis at the program level shows bureaus working in the same general areas, a detailed project and task analysis is required to determine true duplication. In an area as complex as ecological research such replication may be valuable if the results are accurately compared.

2. Agency Activities in Ecological Research

Department of Agriculture

Agriculture needs ecological information for the management of renewable resources in order to maximize sustained yields of selected products. Production of food, fiber, feed crops, and timber have high priority. Other research areas include habitats for wildlife and livestock, recreation, amenities and services for rural living, flood control, and preservation of natural areas with unusual qualities.

Ecological research programs are multidisciplinary and largely problem-oriented with major emphasis on pest and disease management; development of alternatives to pesticides; improved biological production of food, timber, and fiber; and conservation of soil, water, vegetation, and ecosystems. Research is conducted on recycling and waste management and on the effects of pollution on forests, crops, and horticultural plants.

Atomic Energy Commission

The ecological research program includes terrestrial and aquatic studies on baselines and interrelations of organisms and populations with their environment, especially to predict the fate and effects of all relatively long-lived radionuclides within ecosystems. This work includes research on pathways, rates of movement, and distribution of radioactive substances in the natural environment and in man's food chain. Also included are studies on thermal additions and pollutant emissions, ecosystem analysis, and the capacity of the environment to absorb pollutants.

Department of Defense

Studies are conducted primarily with environmental and ecological modifications brought about by engineering construction. Research is conducted on the stability of ecosystems and the effects of pollutant emissions on organisms and the environment.

Ecological research is conducted on pest management, including the impact of alternative methods of pest management. Ecological studies are conducted on vector diseases of man and animals in nature. The Army Quartermaster Corps has conducted biome studies in tropical forests of Thailand and Panama.

Corps of Engineers

Research includes studies on impact assessment, management and conservation of ecosystems, engineering construction to control the environment, and industrial siting. Studies are made to determine the impact that these activities have on organisms and on the environment and the effects that operation and maintenance of completed projects have on ecosystems. Methods are developed for aquatic weed control, waste disposal, and management of pollution associated with dredging, thermal effects, and eutrophication.

Environmental Protection Agency

The Environmental Protection Agency's ecological research program deals primarily with the interaction of air and/or water pollutants with selected aquatic and terrestrial organisms. Effort is devoted to environmental transport paths and the fate of pollutants with their concomittant effects on biota of importance to man. Research may also be directed toward development of scientific information which will establish criteria upon which specific environmental quality standards may be based. In some cases, management strategy for restoration of environmental damage may be based on ecological research. Economic effects related to ecological damage and scientific observations of regionally or locally polluted areas may receive in-depth examination. Aspects of ecological research are embodied in three program areas: (1) ecological effects, (2) transport processes, and (3) environmental studies.

Department of Health, Education, and Welfare

Man-occupied ecosystems are described, and functions and relationships between man, his environment, and its management are investigated. Studies evaluate the impact of man's activities on man (e.g., psychological stresses, social values, and life styles of frequent interaction in high population density areas) and the relationship between animals and with their environment. Research includes the ecology of vectors of certain zoonoses (animal diseases communicable to man) and the metabolism of pesticides and other chemical compounds in biological systems.

Department of the Interior

The Department of the Interior conducts research on the effects of air, water, and food pollutants on natural, aquatic, and terrestrial ecosystems and on representative species within such systems. Processes (e.g., eutrophication) and pathways by which pollutants may pass through food webs and sometimes accumulate in organisms in hazardous amounts are of special concern.

Research is conducted on conservation and management of natural ecosystems in order to stabilize them and to maintain their quality of productivity. Research is carried out on the impact of extraction of fossil fuels, minerals, and other nonrenewable resources on the ecosystems within which they occur, the sites where extracted materials are processed, or the corridors over which they are transported.

The impact of irrigation and augmented precipitation on natural and managed ecosystems is also studied. Research is conducted to improve management of wildlife, fish, and their habitats.

An important and urgently needed area of research is the impact of man's activities on the ecosystems in National Parks and other areas to which there is public access for recreational use.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration conducts research, including its present Earth Resources Technology Satellite program, on the remote sensing of selected environmental parameters. A portion of this research is directed toward characterization of ecosystems including species composition and productivity. An

important component of the Federal ecology research program is development of techniques for remote sensing observations to measure the impact of pests, diseases, drought, cold, floods, water logging, man's activities, and other sources of stress.

National Science Foundation

The National Science Foundation is a principal source of research support on problems of evaluating whole ecosystems and developing ecological principles. Support for the development of ecology as a discipline is offered in ecosystem analysis, biological oceanography, limnology, paleoecology, ecological energetics and physiological processes, and biogeochemistry. Research is supported for application of ecology to management and policy issues of the coastal zone, semi-primitive regions, urban-rural environments, as well as to land use, waste management and trace contaminant problems. Research funds are granted primarily to academic institutions for a wide variety of fundamental research and to academic, non-profit and profit institutions for applied ecological research programs involving critical problems requiring ecological principles for solution. Areas identified for current and future emphasis are: (1) ecology of upwelling zones, (2) aquatic ecosystems integration, (3) biological control, (4) mathematical modeling of ecological systems, and (5) evaluation of ecological principles as they may apply to urban ecosystems. Increasing emphasis is placed on research which seeks integrated concepts and experimental manipulation of the dynamics of large ecosystems or biomes.

Smithsonian Institution

The ecological research program includes studies on the composition of and interactions among organisms in complex ecosystems, both aquatic and terrestrial. Distribution and abundance of plant and animal species and their relationships to the environment are studied to provide baseline data. Studies are conducted on natural regulatory systems including species behavior, territoriality, and competition. Special studies are carried out on light and radiation effects on plants. Detailed tropical and deciduous forest biome studies are conducted. Various analyses of the effects of man's activities on plants, animals, and ecosystems are in progress. Natural areas are defined, quantitatively evaluated, and recommended for preservation. A watch is kept on short-lived ecological phenomena such as population explosions and kills by major oil spills and toxic materials.

Department of Transportation

Ecological research develops technology to minimize air, water, and other forms of pollution resulting from transportation systems and activities and studies vegetation management to prevent erosion and to improve and stabilize roadsides. Effects of deicing salt on vegetation and water quality are studied to prevent or ameliorate such effects. The Coast Guard studies the biological effects of oil pollution and spills and the responses of mussels and algae to petrochemical as possible biological indicators of oil pollution. The biological effects of noise on living organisms are also being studied.

Department of State

The Agency for International Development supports research on the ecology and behavior of various organisms to serve as the basis for developing operational programs to control predators (e.g., the vampire bat), animal and disease vectors, and nuisance vegetation.

Ecological studies are conducted to increase the biological production capabilities of food and fiber in developing countries through management of the environment (e.g., irrigation, fertilization) and organisms (e.g., rotation, grazing, disease control, population regulation).

3. Funding Levels

The ecological research funds expended in various Federal agencies are shown in Table 5. The major increases in funding from FY 1971 to FY 1973 have been in the Department of Commerce, National Science Foundation, Environmental Protection Agency, Corps of Engineers, Smithsonian Institution, and the National Aeronautics and Space Administration. The Department of Defense and Department of Transportation have also initiated modest programs.

TABLE 5. ECOLOGICAL RESEARCH FUNDS IN VARIOUS FEDERAL AGENCIES

Agency	Research Funds ($ million)		
	FY 1971	FY 1972	FY 1973
DOC	$28.33	$31.87	$40.45
NSF	19.54	23.69	34.29
USDA	33.87	33.92	32.48
DOI	21.21	22.02	22.92
EPA	14.94	17.67	18.40
CE	6.13	10.03	11.90
AEC	9.21	9.58	10.06
SI	2.15	2.80	3.95
State	2.37	2.80	3.95
NASA	1.05	0.93	2.21
DHEW	1.03	1.03	1.03
DOD	0.14	0.60	0.96
DOT	——	0.57	0.65
TOTAL	$139.97	$157.69	$182.28

4. Ecological Research Programs by Problem Areas

The following summary narrative descriptions of Federal ecological research programs are organized under the important national problem areas requiring ecological research as shown in the vertical axes of Tables 1-3: I. Effects of Environmental Changes, II. Problems of Evaluating Whole Ecosystems, III. Problems Associated with Regulating Organisms, IV. Problems Arising from Activities of Man, V. Development of Ecological Research. The funding level of each Federal agency program is shown for Fiscal Years 1971, 1972, and 1973. The funds are shown as millions of dollars to two decimal places.

I. Effects of Environmental Changes

a. Air Quality Effects

1. Pollutant Emissions

National Aeronautics and Space Administration—Remote sensing is used to determine the concentration and spatial and vertical distribution of aerosols and gases and to delineate and quantify the effects of these aerosols and gases on the environment and on the organisms which are exposed to these pollutants.

1971	1972	1973
$0.03	$0.03	$0.23

National Science Foundation—University-based research is supported to describe the effects of air pollutants in man-occupied ecosystems, interactions with other environmental constituents, and the management of ecosystems by manipulating either environmental parameters or man's activities. Ecological consequences of alternative abatement strategies are analyzed.

1971	1972	1973
$0.51	$0.50	$0.40

Department of Agriculture—Major pollutants such as sulfur dioxide, fluorides, ozone, hydrogen chloride, and other oxidants and particulates affect tree species and associated plant and animal life in rural forests as well as in densely populated urban areas. Radioactive emissions and fire are also involved. The impact of these pollutants on organisms and ecosystems is studied in research on the sources and concentrations of damaging air pollutants and the frequency of damage. Current research is directed toward methodology and instrumentation for detection and analysis. The tolerance of organisms to one or more pollutants, the selection of resistant varieties, and the methods of protecting plants and animals from pollutants, are also under study.

1971	1972	1973
$0.27	$0.27	$0.29

Environmental Protection Agency—Investigations of the effects of major air pollutants on crops and vegetation are conducted to provide information for establishing secondary ambient air quality standards.

Specific studies of the effects of nitrogen oxides, sulfur oxides, hydrocarbons, and other oxidants are conducted on representative terrestrial ecosystems.

Ecological research on effects of air pollution includes: (1) determination of the effects of air pollutants on biotic (crops, vegetation) and abiotic (soil, water, natural and man-made materials) components of the environment and (2) assessment of the effectiveness of control measures through monitoring of selected ecosystems.

1971	1972	1973
$1.34	$1.91	$1.96

2. Thermal Additions

National Science Foundation—Research efforts have emphasized synthesis and predictive modeling of thermal discharges into the atmosphere (e.g., from power plant heat exchangers), and the local ecological responses.

1971	1972	1973
$0.64	$0.19	$0.12

b. Water Quality Effects

1. Eutrophication

Environmental Protection Agency—Eutrophication and remedial lake restoration research is conducted to develop eutrophication controls and restoration procedures for the lakes and ponds of North America. Specific objectives include: (1) development of an understanding of the eutrophication process with emphasis on the role of plant nutrients in aquatic systems, nutrient cycling between sediments and biota and nutrient effects on plant growth; (2) development and demonstration of technology to control and reverse eutrophication processes; and (3) development of methods for monitoring eutrophication conditions and for predicting the impact of nutrient sources on the eutrophication of natural waters.

1971	1972	1973
$2.80	$0.20	$0.20

Department of the Interior—The Geological Survey conducts studies to: (1) develop an understanding of the eutrophication process with emphasis on the role of plant nutrients in aquatic systems nutrient cycling among water, sediments, and biota and nutrient effects on plant growth; (2) develop technology to control and

reverse eutrophication processes; and to (3) develop methods for monitoring eutrophication conditions and for predicting the impact of nutrient sources on the eutrophication of natural waters.

1971	1972	1973
$0.46	$0.41	$0.44

National Science Foundation—Current research on eutrophication supported by NSF grants includes competitive growth responses of various algae to nutrient enrichment in both field and laboratory studies, responses of lake and river ecosystems to enrichment, and the relevance of these findings for the management of enriched aquatic systems.

1971	1972	1973
$0.50	$0.35	$0.82

2. Thermal Additions

Department of the Interior—The ecological effects of thermal additions to water are studied by the Bureau of Sports Fisheries and Wildlife to provide information on natural productivity of fish in freshwater systems and to determine the effects of environmental variables and contaminants on the fishery resource. Included are studies of life histories, population dynamics, and environmental requirements of principal fishes and the food organisms on which they depend for each of the ecosystems covered. Further studies by the Office of Water Resources Branch and the Geological Survey deal with the interrelationships between organisms and their hydrologic environment including thermal additions to this environment.

1971	1972	1973
$0.48	$0.81	$0.96

Environmental Protection Agency—Ecological studies are conducted on thermal additions to water to determine their effects on the reproduction and life cycles of aquatic organisms in fresh and marine waters. The objective is to improve the basis for developing and implementing thermal standards.

1971	1972	1973
$1.00	$1.50	$2.00

Atomic Energy Commission—The effects of thermal additions on biological processes and organisms are being studied by the national laboratories and extramural organizations. Thermal effects on invertebrates and salmonid fishes are being examined. These include thermal death patterns, relationships between stress and fatigue and thermal tolerance, resistance to heat or cold shock, relations between thermal inactivation of organisms and predation on them by fish or other organisms, and sensing of heat or cold by fishes. The effect of heat on organisms entrained in the cooling water of power plants is being examined as they pass through such systems. The Savannah River Laboratory is studying the effects of added heat on the fate of radionuclides in a cooling pond and the effects on organisms in flowing streams. The effects of heat on disease in fishes and the synergistic effects of temperature, pollutants, and disease are being examined.

1971	1972	1973
$0.57	$0.76	$1.19

National Science Foundation—Grant research stresses ecological responses to additions of hot water (e.g., from power plants) in terms of energy flux, food chain alternations, and growth rate changes in local aquatic environments with a warmer environment or a seasonal pulse.

1971	1972	1973
$0.23	$0.19	$0.70

Corps of Engineers—Civil works study of thermal effects on rivers, bays, and lakes includes monitoring of temperature regimes, thermal stratification, and water quality. This is done prior to and after impoundment to determine the project's effect on the ecological balance and the natural processes of the immediate and downstream environments. Thermal stratification investigations have evaluated the use of air diffuser systems or submerged wires on temperatures in stratified lakes and the effects of temperature variations on water quality, ecosystem components, and sedimentation. Mathematical and physical models and remote sensing techniques are being developed for predicting the ecological impacts of physical, geological, and chemical oceanographic parameters.

1971	1972	1973
$0.06	$0.24	$0.35

3. Management and Conservation of Ecosystems

Department of Commerce—The Manned Undersea Science and Technology Program contributes to basic research in the marine ecosystem by providing the capability for undersea research and developing the technology to allow direct observation and analysis of the undersea environment. This work is accomplished primarily through the use of undersea laboratories and manned research submersibles.

1971	1972	1973
$ 0	$0.13	$0.27

Department of the Interior—Research is conducted on the management and conservation of ecosystems, both as a goal in itself and as an accessory function to a broader mission. The Bureau of Outdoor Recreation studies potential new recreation areas, including wild and scenic river additions whose ecology must be evaluated before decisions are made regarding their use. The Geological Survey performs research on stresses related to water based ecosystems; the Office of Water Resources Research supports a number of individual research projects dealing with areas similar to those studied by the Survey. The Bureau of Sport Fisheries and Wildlife, the Bureau of Land Management, and the National Park Service are all charged with specific responsibilities in ecosystem preservation and management.

1971	1972	1973
$1.22	$.145	$1.48

Smithsonian Institution—The management and conservation of an estuarine ecosystem is being studied in the Rhode River estuary in Chesapeake Bay. The subestuary is being described and measured biologically, chemically, and physically. Interrelationships are being studied and a model is being developed. The movement of biocides, fertilizers, and sediment introduced from the watershed is being measured in relation to preservation and conservation. Ecological studies on marine coastal and coral reefs are being conducted in Panama and in other areas.

1971	1972	1973
$0.10	$0.15	$0.30

Department of Agriculture—Disturbance or manipulation of ecosystems sometimes causes changes in water quality. The changes may be in bedload or suspended sediment, chemical composition, or temperature of streams or lakes. Research includes analysis of water quality as affected by changes in forests because of removal of vegetation, road-building, and mining. Research is devising ecosystem conservation and management methods to prevent erosion and siltation, to rehabilitate surface-mined areas, and to minimize adverse effects of disturbances such as fire and roadbuilding. Basic to these studies is an understanding of the interrelationships among plants, soil, and water in a wide variety of ecosystems.

1971	1972	1973
$0.59	$0.87	$0.71

4. Pollutant Emissions

Environmental Protection Agency.—Programs on aquatic systems are conducted to determine the effects of pollutants such as temperature, pesticides, and heavy metals on fresh water and marine fish, invertebrates, and their food chain organisms. Specific objectives include determining (1) the effects of organic chemicals, heavy metals, petroleum and petroleum by-products on marine life; (2) safe levels of pesticides and pesticide derivatives in estuarine and coastal waters; and (3) temperature and dissolved oxygen requirements for marine life. Acute and chronic effects of pollutants on the various life stages of the organisms are being determined in order to specify safe levels of the pollutants involved.

1971	1972	1973
$9.80	$11.38	$11.43

National Aeronautics and Space Administration—Remote sensing is employed to identify and define the spatial distribution and dynamics of pollutants. The acquired data are used to analyze the effects of waste products on bodies of water and their ecology. Specific attention is directed toward industrial effluents; oil seeps, slicks, and spills; water pollution distribution and dispersion; sediments in coastal areas and estuaries; and benthic responses to fertilization and mining chemicals.

1971	1972	1973
$0.04	$0.04	$0.04

Atomic Energy Commission—Water pollution emissions are being studied with regard to their effects on biological processes and on organisms. The fates and effects of intermediate and long-lived radionuclides are studied in natural systems. Some important nonradioactive nutrients such as nitrogen and phosphorous are also included. Research on fallout and reactor effluent radionuclide cycling and accumulation in the biota is being conducted in a wide variety of aquatic ecosystems important to man. The combined effects of radiation, temperature, and chemical pollution in surface waters modified by man are being studied. The effects of temperature modification and chemical additions from a nuclear power plant on the organisms in a shallow subtropical marine bay constitute another area of study.

1971	1972	1973
$2.31	$2.20	$2.53

Department of Transportation—The Coast Guard is studying the physiological responses of mussels and algae to petrochemicals as a possible biological indicator of oil pollution. The fate and behavior of oil on beaches of San Francisco Bay are being studied. Current knowledge is being assessed to determine the potential for using biodegradation processes in cleaning up oil spills in the marine environment and to define specific study areas.

The Federal Highway Administration is studying the effects of highway deicing chemicals on roadside vegetation and aquatic life and the transport of chemicals by surface runoff and groundwater.

1971	1972	1973
$ 0	$.22	$0.15

Department of the Interior—Water pollutants are studied to develop criteria for setting water quality standards for the propagation of marine and estuarine fishes, invertebrates and their food chain organisms, and wildlife. The objective is to develop criteria for safe levels of pesticides and pesticide derivatives in estuaries and coastal waters. The effects of organic chemicals, heavy metals, petroleum, and petroleum by-products on estuarine and marine life are being investigated.

The Geological Survey is studying the effects of pollutants on ecosystems in certain geographic areas as part

of a broader effort to outline the biophysical parameters of the area.

1971	1972	1973
$1.41	$1.37	$1.54

National Science Foundation—Primary effort is focused on sources, routes, and distribution patterns of toxic materials in the ecosystem, particularly heavy metals, such as lead from automobile exhausts. An increased effort reflects studies on trace contaminants in the environment, including cadmium, mercury, molydbenum, and nitrate. Analysis of pathways, rates and target populations are the basis for examining ecological response and management alternatives.

1971	1972	1973
$0.50	$1.72	$2.45

c. Land Use Effects

1. Nonrenewable Resource Extraction

Department of the Interior—Environmental and ecological impacts related to resource extraction and use are evaluated. The effects of acid mine drainage and oil pollution on fish and the impact of resource exploitation and transportation on fish and wildlife of northern areas are studied.

1971	1972	1973
$0.05	$0.05	$0.05

Department of Agriculture—Serious land disturbances often result from mining, extraction of gas and oil, and exploration for mineral and petroleum resources. Vegetation is disturbed or destroyed, and soil is often destroyed leaving only sterile spoil banks. Methods are developed for repairing and restoring land affected by extraction of nonrenewable resources. This requires an understanding of the character of altered sites, the processes of primary and secondary plant succession, and methods of accelerating growth of plant cover. Development also includes studies that will lead to revised methods of mining to reduce unfavorable impacts and to cut post-mining costs and rehabilitation expenses.

1971	1972	1973
$0.17	$0.22	$0.22

National Science Foundation—An important goal of the integrated research projects on terrestrial biomes of the International Biological Program IBP has been to provide a method of systems evaluation of land-use practices in the production of renewable resources which can then be simulated in computer models. In the grasslands biome, for example, this subject is a major concern.

1971	1972	1973
$0.55	$1.96	$2.68

Department of Commerce—The objective of the Fire Weather Service is to help protect life, conserve natural resources, and aid in stabilizing the economy of the timber industry. Basic information provided includes temperature, wind, humidity, timber brush moisture, precipitation, and thunderstorm activity on an intensified local scale in those managed ecosystems with a fire hazard. Research to improve the understanding of basic processes is included.

1971	1972	1973
$0.02	$0.02	$0.02

National Science Foundation.—Grant research emphasizes ecological consequences of alternative development activities and land-allocation techniques. Requirements for open space, water and other resources consequent upon increases in population and consumption patterns are examined. Improved methods for guiding, planning and development, such as application of remote sensing or computer models and game theory are supported. Utilization of ecological information in land allocation and resource extraction is applied to land-planning research.

1971	1972	1973
$0.2	$0.96	$0.20

2. Renewable Resource Production

Department of the Interior.—Fish and wildlife population management studies are conducted by the Bureau of Sport Fisheries and Wildlife, and plant ecology research is conducted by the National Park Service. These studies are designed to maintain a sound level of renewable resources in the areas administered by these organizations.

1971	1972	1973
$0.32	$0.42	$0.43

Corps of Engineers.—Studies are made of dredging operations conducted to remove sedimentation deposits which would hinder ship operations. The Corps has completed studies in the Great Lakes and other regions related to disposal of dredge spoil by developing disposal areas for polluted spoil and experimenting with creation of new marshlands with unpolluted spoils. This work is important in mitigating detrimental impacts on ecosystems and providing suitable conditions for creation of new ecosystems. Techniques are being developed for measuring the impact of normal sedimentary processes in order to enhance downstream ecosystems.

1971	1972	1973
$0.27	$0.38	$0.50

National Science Foundation.—Research grants consider new evaluation techniques for examining impact of man's activities on other biota, incorporation of ecological information into technology assessments, and role of ecological understanding in citizen participation in evaluating environmental impacts.

1971	1972	1973
$0.07	$0.27	$0.25

Department of Transportation.—The Federal Highway Administration is conducting an ecological research program involving 17 studies to determine vegetation management practices and materials that will produce a more viable roadside ecology in order to preserve highway banks, prevent erosion, and present a more aesthetic appearance.

1971	1972	1973
$0	$0.31	$0.33

Environmental Protection Agency.—Research in this area explores and develops strategies and mechanisms for local and regional use in environmental management. The holistic approach taken toward the study of these systems ensures that the total effects of environmental policy are considered. Ecosystem research is directed toward understanding the relationships between environmental problems and the totality of society, including its environmental, social, economic, and institutional systems, and the means by which environmental policy and technology

can be designed to conform with and effectively utilize these systems.

1971	1972	1973
$0	$0.15	$0.23

National Aeronautics and Space Administration.—Remote sensing is used in studying the present patterns of land use. Detection of ecological and environmental changes occurring in the present pattern of land usage is employed in developing long-range regional land use and resource management policies.

1971	1972	1973
$0.04	$0.04	$0.38

Smithsonian Institution.—Ecological studies are being made of an estuarine watershed ecosystem on Chesapeake Bay with regard to land use effects, runoff into the estuary, and information for proper management and conservation of an area with natural forest, regrowth vegetation, and some managed land. Ecological studies in Panama and other regions describe the effects of land use on plant and animal populations, relating these effects to management and conservation practices. The ecosystems are described, and their functions, relationships, and the impact of man's activities (especially species loss and replacement) are studied.

1971	1972	1973
$0.10	$0.20	$0.30

3. Management and Conservation of Ecosystems

National Science Foundation.—All of the IBP biome studies pay attention to problems of the management of ecosystems so as to optimize the resource-use while conserving the integrity of the ecosystem. This is a particular concern of the biomes in regions of great physico-chemical stress, such as desert and tundra.

1971	1972	1973
$0.17	$0.43	$0.75

Department of Agriculture.—The use of land for the production of food, forage, and fiber causes change in natural ecosystems. These changes can be minimal.

Under some systems of forest management, under intensive agricultural cropping, they can be profound. Research is conducted to understand the functioning of ecosystems so management practices can be devised that will have as little environmental impact as poossible. This research involves studies of the relationships of plants and animals to the factors of their environment, both in nature and under management. The knowledge gained from such studies is used to assess the effects of alternative management practices.

1971	1972	1973
$4.21	$3.58	$2.57

II. Problems of Evaluating Whole Ecosystems

a. Impact Assessment

National Science Foundation.—Small research grants consider evaluation techniques for examining the impact of man's activities on other biota.

1971	1972	1973
$0	$0.07	$0.20

Department of Commerce.—Major efforts are designed to evaluate the consequences of environmental modifications of marine ecosystems. Particular emphasis is placed on the effects of dredging, filling, effluent discharges, and construction in freshwater and marine areas. Draft impact statements for the National Environmental Policy Act by other government agencies are analyzed.

1971	1972	1973
$2.22	$3.82	$4.82

Atomic Energy Commission.—Research with broad implications concerning impacts of pollution on the functions of whole ecosystems is supported. Most of this work concerns terrestrial ecosystems, but some marine and freshwater systems are included. Impact assessment is being made with regard to the structure of relatively undisturbed natural ecosystems. Components of species populations are being described before and after nuclear detonations.

The effects of high-level radioactive sources on plants and trees of irradiated forests and the effects of low levels of gamma radiation on reproductive and other

demographic functions of field populations of vertebrate animals are being studied.

1971	1972	1973
$4.52	$4.79	$4.78

Department of Agriculture.—Research programs include work on assessment of impacts of natural and man-made disturbances and manipulations on ecosystems. Included are studies of effects on vegetation used by domestic animals and wildlife, of alternative timber harvesting systems, of fire and impacts of insects and diseases. The impacts of chemical agents introduced into, moving through, and accumulating in ecosystems are also under study.

1971	1972	1973
$1.95	$2.22	$2.13

Smithsonian Institution.—Research is being carried out in many parts of the world on the floral and faunal composition of areas being impacted by human activities. The changes in species composition, species replacement, and loss of rare and endangered species are being studied. Research is concentrated in marine shallow waters and estuaries, coral reefs, and tropical and deciduous forests. Baseline studies are being conducted and museum specimens of organisms are being analyzed for toxic metals as a means for showing the impact of man.

1971	1972	1973
$0	$0.10	$0.10

Department of the Interior.—The Department of the Interior, in common with other Federal agencies, is required by law to make a full assessment of the environmental impacts of proposed major activities and actions. Studies related to such assessments are undertaken or funded by the Department and are reviewed by other specialized organizations where appropriate. Basic studies are also made on ecosystems and toxic substances or harmful activities that may pose a threat to their continued health or survival of these systems.

1971	1972	1973
$1.92	$2.22	$2.00

Corps of Engineers.—Fundamental ecological research is directed toward developing environmental impact statements and methodology to mitigate adverse effects on the local fisheries.

Studies include evaluation of effects due to changes in the salinity levels and pH of water in estuaries; use of remote sensing to define ecological sensitive areas; controlling water flow to eliminate significant changes in nutrient levels, temperatures, and pH factors; and development of techniques for measuring heat exchange and photosynthesis on physical models in order to improve ecological predictions.

1971	1972	1973
$2.63	$4.30	$5.11

b. Regional Global Consequences and Predictions

National Science Foundation.—Activity is concentrated on synthesis and predictive modeling of large ecological systems in response to environmental changes such as variations in carbon dioxide levels, air pollution, or widespread drought. Assessment of ocean pollution-concentration along major transects has been recently completed for evaluation of effects upon biological resources.

1971	1972	1973
$0	$0.86	$1.00

Department of Agruculture.—Research includes studies that contribute to man's ability to predict regional or global consequences of his actions. Included is research on impacts of man's activities on major forest, range, and desert ecosystems. For example, the conifer forest and muskeg or taiga of Alaska are being intensively studied for the first time. Taiga occupies millions of acres in northern latitudes around the world and is extremely sensitive to disturbance. Other ecosystems being studied include the deserts of the Sonoran Province and the alpine tundra.

1971	1972	1973
$0.04	$0.04	$0.04

Smithsonian Institution.—The world distribution and abundance of certain biological organisms are very important in evaluating whole ecosystem changes, particularly the consequences of man's activities. Baseline data on species composition and abundance are being collected which are essential in studying

consequences and for predicting changes in marine, freshwater, and terrestrial habitats. Ecological studies are being carried out in many areas, particularly in tropical regions. Predictive studies are being conducted, such as the potential ecological effects on construction of a sea-level Panama Canal.

1971	1972	1973
$0.20	$0.30	$0.50

c. Stability and Interactions of Ecosystems

Department of Commerce.—The objectives of the Marine Ecosystem Analysis (MESA) program are to describe, understand, and monitor the physical, chemical, and biological processes of marine environments; to provide information and expertise required for effective management of marine areas and the rational use of their associated resources; and to analyze the alterations. Emphasis is directed to physical/chemical and biological baseline descriptions; desriptions of sediment deposition and transport; effects of stress from environmental alterations on marine ecosystems, with particular emphasis on the living resources; and descriptions of the source and fate of pollutants.

1971	1972	1973
$0	$0	$1.50

Department of Defense.—Studies are carried out on the evaluation of specific ecosystems of interest to the military. Studies are completed on tropical evergreen and semideciduous forest.

1971	1972	1973
$0	$0.08	$0.48

Health, Education and Welfare.—Health Services and Mental Health Administration supports grant research on stimuli (visual, tactile, auditory, food, water, light, photoperiod, etc) affecting or determining competition, aggression, tolerance, peck order, and habitat among various vertebrate animal species.

1971	1972	1973
$0.03	$0.03	$0.03

Atomic Energy Commission.—Research conducted at Oak Ridge National Laboratory concerns the

interaction between two types of ecosystems, a terrestrial forested watershed and a stream running through the watershed.

1971	1972	1973
$0.33	$0.37	$0.37

Department of the Interior.—Ecological research on stability and interactions is carried on by the Bureau of Sport Fisheries and Wildlife, the National Park Service and (to a limited extent) by the Geological Survey as a support function to their primary missions.

1971	1972	1973
$1.45	$1.40	$1.39

Smithsonian Institution.—One of the major activities of the National Museum of Natural History and the Smithsonian Tropical Research Institute is the description of biota of ecosystems and areas through time. This work includes the abundance and distribution of flora and fauna and changes in species, distribution, and abundance with time. The functions and relationships of organisms with the environment involve detailed studies on effects of climate, solar radiation, toxic materials, and other factors on species. The relationships between organisms in the ecosystem are being studied in Panama and at Chesapeake Bay with regard to their importance in ecosystem function and stability. Relationships involving social patterns, food relationships, pollination, and seed dispersal are being studied.

1971	1972	1973
$0.80	$1.00	$1.30

Department of Agriculture.—Research is carried out to define and quantify the interactions of plants and animals with their environments and with each other. A system of Natural Areas serves as a baseline on which the functioning of undisturbed ecosystems is studied. Research on the structure and functioning of forest, range, and desert ecosystems (in cooperation with the International Biological Program) is also included. Similar studies are underway on ecosystems that have been manipulated in various ways. The ecological relationships developed here can then be used as inputs for research on management systems.

1971	1972	1973
$3.24	$3.66	$3.48

National Science Foundation.—The principal research effort has sought to establish the role of diversity of biota in ecological systems, determine rates and trends of succession (e.g., from fire or abandoned land), and assess functional relationships among the major part of the biome studies of the International Biological Program, for which the NSF is the head agency.

Large, integrated research efforts funded by the Foundation have been studying the composition of, and interactions within, ecosystems to gain an understanding of their stability in the face of various land management practices. Grasslands, desert, Eastern decidious forest, Western coniferous forest, and arctic tundra are the biomes included. The approach has been to develop mathematical models of the structure and dynamics of these ecosystems that can simulate the effects of diverse land-use practices.

1971	1972	1973
$4.17	$5.60	$5.40

National Aeronautics and Space Administration.—Multispectral airborne and spaceborne photographic and electrical techniques are employed to investigate the relationship between organisms and their environment in oceanic, coastal, and terrestrial ecosystems. Included are studies to identify plant and animal communities, to detect elemental deficiencies and diseases, to identify environmental parameters (marine and soil), to identify pollutants and their effects, and to determine the important interactions among these parameters.

1971	1972	1973
$0.20	$0.20	$0.24

III. Problems Associated with Regulating Organisms

a. Pest and Disease Management

Department of Defense.—Ecological research is conducted on pest management, including the impact of alternative methods of pest management in tropical ecosystems.

1971	1972	1973
$0	$0.40	$0

Department of Health, Education and Welfare.—The Communicable Disease Center research

program includes research on ecology of the vectors of certain zoonoses, especially in relation to their dispersal by man's activities. Biological control; mosquito, bird, and mammal bionomics; and ecology of parasites are studied.

1971	1972	1973
$1.00	$1.00	$1.00

Department of State.—Research is conducted in several developing countries for the control of rats, bats, and noxious birds. Studies include population dynamics, control systems in relation to environmental factors, and developing and testing alternative control methods. Laboratory and field research is conducted on mass rearing and releasing of sterile male tsetse flies to determine the feasibility of control and eradication. Research is designed to find simple, effective, and nonpolluting methods of controlling weeds and nuisance vegetation in developing countries, especially in tropical regions.

1971	1972	1973
$2.37	$2.98	$2.98

Atomic Energy Commission.—In pest control research, irradiation or chemicals are used to produce sterile organisms or organisms carrying lethal reproductive factors. Studies of the genetic mechanisms which sustain lethal factors for several generations and of the mechanisms by which natural pest populations may be controlled are being conducted in Puerto Rico, and Latin America on such pests as the South American fruit fly, the Mediterranean fruit fly, and the sugar cane borer.

1971	1972	1973
$0.22	$0.23	$0.16

Department of the Interior.—The Bureau of Sport Fisheries and Wildlife is charged with the responsibility of managing waterfowl and other migratory birds, game fishes, endangered species, and wildlife populations in general. The purpose of the research is to gain information for the protection, management, and possible enhancement of these animal resources.

1971	1972	1973
$1.91	$1.97	$2.04

National Aeronautics and Space Administration.—Controlled laboratory and field experiments are conducted and uncontrolled field sites are investigated to determine the effects of stress conditions on plant growth. The data are correlated with the remotely sensed signatures from airborne and spaceborne sensors. Investigations are carried out to determine the effects of insects, pathogens, and other damaging agents on vegetation.

1971	1972	1973
$0.31	$0.31	$0.31

Department of Agriculture.—Ecological research on pest organisms is oriented toward determining the economic, social, and ecological impacts of destructive agents on forests and agroecosystems. Emphasis is on development of an ecological understanding of the relationships between host and environmental systems and the occurrence of destructive pest populations. Based on sound ecological understanding, alternative strategies are being developed for managing pests to increase multiple resource values and to improve productivity while minimizing the adverse effects on environmental quality.

1971	1972	1973
$11.81	$11.17	$10.87

National Science Foundation.—Grants support research activities which relate to the development of strategies for pest management that will minimize the use of toxic chemicals. These fall chiefly into two categories:

(1) physiological and biochemical studies of insect hormones and pheromones;

(2) ecological studies of pest organisms (mainly insects) in natural or modified ecosystems. By far the greatest share of the funding increase in FY 73 is for the support of integrated research projects on the pest complexes of six major crops. Additional support for this effort is provided by USDA and EPA.

1971	1972	1973
$1.24	$0.64	$3.79

Environmental Protection Agency.—As a result of the use of pesticides in the environment, which results

in disruption of ecological balances, the Environmental Protection Agency sponsors research on development of alternative methods of pest controls aimed toward reduction of dependence upon pesticide chemicals, especially in commercial agricultural uses. Development of new control strategies based upon ecological relationships is under study in cooperation with other Federal agencies. The main emphasis is upon understanding the intricate insect population interrelationships of dynamics found in several major crop ecosystems in which quantities of pesticides are used. Integrated use is being made of prey-predator relationships, insect pheromones, specific pathogens such as viruses, trap crops, and predictive modeling technology.

1971	1972	1973
$0	$0.80	$1.80

b. Biological Production (Food and Fiber)

Department of Commerce.—Research programs include basic stock assessment; population dynamics; food chain studies; interrelationships of species including fish, shellfish, marine mammals, and marine plants. Ecological studies are conducted on anadromous fishes, and basic research necessary for development of a meaningful aquacultural program.

1971	1972	1973
$26.09	$27.90	$33.74

Department of the Interior.—The Office of Water Resources Research supports studies in the application of water resources to enhance production of food and fiber. Similar research is carried out by the Bureau of Reclamation, which is charged with the task of increasing productivity from agricultural land, and the Bureau of Land Management, which has the responsibility of optimizing output from Federal lands under its jurisdiction. Supporting research of a more basic nature is performed by the Geological Survey. Projects range from studies on the role of phreatophytes in the hydrologic components of ecosystems to research on the ecological impact of the removal of nitrogen from agricultural wastewater.

1971	1972	1973
$1.09	$1.26	$1.26

National Aeronautics and Space Administration.—The relationships between fish populations and related environmental features such as temperature, salinity, currents, chlorophyll, etc., are determined through remote sensing. Data on fish slick oil are collected and identified both chemically and spectrally to aid in locating and identifying pelagic fish stocks. Sea surface temperature and chlorophyll concentration are measured to determine relationships between these and the fish populations.

1971	1972	1973
$0.06	$0.06	$0.07

Department of Agriculture.—Production can be improved by the development of better plant and animal resources and the technology to use them. Research emphasis is on genetic development and breeding for the improvement of varieties of high yielding, high quality crops and forest trees, ornamentals, and types of animals that are adapted to a wide range of agroecosystems. Development of improved plant and animal nutrition technology, improved irrigation principles and practices, and efficient and safe biological and chemical methods for controlling weeds, diseases, insects, nematodes, and other pests of crops and animals are emphasized. Research is also underway on the development and management of integrated crop, forest, and livestock production practices that are compatible with high yielding, high quality agroecosystems and a quality environment.

1971	1972	1973
$2.89	$260	$1.65

National Science Foundation.—Support is provided for metabolic and ecological studies of the basic biological processes in food and fiber production.

1971	1972	1973
$1.30	$0.10	$0.50

c. Exotics and Rare Species

Department of the Interior.—The Bureau of Sport Fisheries and Wildlife is charged with the responsibility of protecting certain rare and endangered species. Ecological field studies of many endangered species at field stations located in Florida, Arizona, South Dakota, California, Hawaii, and Puerto

Rico are related to population status and habitat requirements.

1971	1972	1973
$0.64	$0.54	$0.56

Smithsonian Institution.—The National Museum of Natural History has detailed information on the distribution and abundance of rare and exotic species from various ecosystems and is the major repository of specimens supporting this information. The National Zoo is involved in rearing and maintaining many rare and exotic species. The National Museum and the Ecology Program are making lists of the rare and endangered species of plants for the Pacific Basin and the United States and studying the reasons for rarity and endangerment.

1971	1972	1973
$0.20	$0.20	$0.25

Department of Agriculture.—Exotic species may be resistant to disease and insect attacks which ruin native species of the same genus. Resistant exotics may be crossbred with native species to produce resistant hybrids or, if suitable, can be substituted for the native species. Plants are being tested for adaptation to special purposes including shelterbelts in the Great Plains, Christmas trees, timber, and ornamentals for urban planting. Selected species must thus be adapted to the soil and climate of an area and resistant to indigenous insects and disease.

1971	1972	1973
$0.31	$0.37	$0.42

National Science Foundation.—Occasional grants are supported to examine ecology of rare, endangered or imported species.

1971	1972	1973
$0.07	$0.06	0

d. Wildlife management

Department of Agriculture.—The two principal means of managing wildlife populations are regulation of hunting and fishing and manipulation of wildlife and fish habitats. Research includes work on manipulation of vegetation that provides food and

cover for wildlife and fish. Different species of animals find optimum habitat conditions at different stages of plant succession. Research identifies these optimums, and the normal variations about them, and provides the scientific basis for deliberately managing fish and wildlife. Some research is especially designed to determine the interrelationships between wildlife habitats and management for products such as timber. There is new emphasis on habitats for non-game species.

1971	1972	1973
$1.76	$1.87	$2.16

National Aeronautics and Space Administration.—Remote sensing and surface measurements are used for surveying and assessing wildlife habitats and population dynamics. Radar and telemetric techniques are used in studying migratory routes and the impact of land use and cultural pressures on wild animals and on animal behavior in relation to their migrations and territories. Decreases in funding represent a phasing out of an animal tracking program.

1971	1972	1973
$0.33	$0.21	$0.07

Department of the Interior.—The Bureau of Sport Fisheries and Wildlife studies the determination of habitat requirements and relationships between habitats and physical factors such as precipitation or pollution, population trends on forest-wildlife and pesticide-wildlife relationships, species distribution and life history, and control of animal damage.

1971	1972	1973
$3.97	$4.34	$4.50

Smithsonian Institution.—The wildlife management program of the Smithsonian is limited to describing wildlife species and populations in natural ecosystems, such as Panama and Chesapeake Bay, and special studies in Africa. Studies of functions and relationships of the wildlife with the environment are mainly by the National Zoo and Tropical Research Institute. Studies on social behavior and organization of vertebrates in Panama and Africa are of importance in wildlife management.

1971	1972	1973
$ 0	$0.05	$0.10

IV. Problems Arising from Activities of Man

a. Recreational Needs

National Science Foundation.—The research activity examines ecological relations of man-occupied ecosystems and his pollution effects in areas used for recreation. Urban open-space, coastal areas and selected semi-primitive environments are emphasized. Methods for evaluating trade-offs among competing uses for recreational areas and ecological values are being developed.

1971	1972	1973
$1.21	$1.31	$1.56

Department of Agriculture.—Much of America's outdoor recreation is based on ecosystems that provide opportunities for physical activity, such as hiking or fishing, or are attractive environments. Research includes studies that determine ways of managing ecosystems so they remain useful and attractive while being occupied. Biological "carrying capacities" for specific uses in specific ecosystems are determined. Methods of managing people's use of dispersed areas, such as backcountry and wilderness, are devised. Techniques for designing, constructing and managing intensive-use sites are developed. Research also develops improved varieties of plants for use in parks, playgrounds, and other recreation areas that are heavily used and must be intensively managed.

1971	1972	1973
$1.97	$2.26	$2.03

b. Urbanization and Urban Planning

Environmental Protection Agency.—Research involves understanding the basic forms of growth and change in urban and regional systems, developing and evaluating comprehensive models for assessment of the impact of environmental policy decisions, and identifying institutional forms which might be channeled to achieve environemntal quality goals.

1971	1972	1973
$ 0	$0.53	$0.58

Department of the Interior.—Ecological studies are being performed by the Geological Survey using the San Francisco Bay Region as a pilot model. Related research is performed by the National Park Service in

its attempts to provide urban populations with outdoor recreational activities.

1971	1972	1973
$0.29	$0.28	$0.32

National Aeronautics and Space Administration.—Remote sensing data and the corresponding ground truth information are employed to determine the utility of applying remotely sensed information on land use patterns and other surface characteristics to the planning for recreational needs and urban development.

1971	1972	1973
$ 0	0	$0.11

Department of Agriculture.—Urbanization alters the ecology of specific sites and influences that of adjacent undeveloped areas. Research contributes to improved guidelines for regional and urban planning to minimize adverse consequences of urban expansion. One example is the detailed analysis of potential new residential and commercial growth in the rural Nicasio Valley of California. Projected developments were analyzed against a variety of ecological criteria and conditions, and the most ecologically and aesthetically sound approach was outlined. Other research includes problems such as alteration of water regimes, erosion and siltation due to construction, ecology of residual open spaces and parks, nongame wildlife habitats in urban and suburban areas, and ecology of shrubs for modification of man's urban environment.

1971	1972	8 1973
$0.14	$0.17	$0.17

National Science Foundation.—Research emphasis is on synthesis and predictive modeling of ecological relationships in rapidly urbanizing areas as a partial basis for improved planning. Increase is due to the research for urban management. The urbanization process is analyzed in order to specify ecological data needs and synthesis requirements. Ecological responses to transportation networks, distribution of utilities, siting of residential and industrial siting and open space requirements are studied. Methods for coupling ecological principles to the regional planning process are being developed.

1971	1972	1973
$0.05	$0.16	$0.83

c. Resource Recycling and Waste Disposal

Department of Agriculture.—Agricultural production often results in large quantities of plant and animal wastes. Research emphasis is currently placed on efficiently recycling these wastes in order to prevent pollution hazards. Land application is a major recycling technique for municipal as well as for agricultural wastes. The land can also be used as a renovating system for some wastes, primarily liquid. Research is directed toward developing guidelines for land application that do not create pollution problems and that preserve the integrity of the soil for plant growth. Another recycling technique involves treatment to convert plant and animal wastes into useable animal feed. A third approach is the conversion of wastes into other useable products, such as single cell protein or methane gas.

1971	1972	1973
$1.04	$1.07	$1.35

National Science Foundation.—Research examines ecological food chains for their possible role in recycling carbon and nutrients from municipal wastes and for their response to toxic materials released in waste disposal. The capacity of ecosystems to absorb wastes, such as liquid sewage effluents spread on forests or swamps, is also examined.

1971	1972	1973
$0.35	$0.96	$1.33

Department of the Interior.—The Bureau of Mines views many types of urban and agricultural wastes as potential raw material to supplement other resources. Research is supported on the separation and recycling of raw and incinerated urban wastes with recovery of glass and metals and the use of these wastes and feed lot wastes as a source of oil and gas.

1971	1972	1973
$0.16	$0.12	$0.15

d. Socioeconomic Trade-offs of Alternative Development Projects

National Science Foundation.—Research emphasis is on ecological component of methodology for

assessing alternative policies, management practices, or development projects.

1971	1972	1973
$0.19	$0.01	$0.40

Department of the Interior.—Research on socioeconomic trade-offs of alternative development projects is carried on by all elements of the Department of the Interior in connection with the Department's responsibilities under the National Environmental Policy Act.

1971	1972	1973
$0.53	$0.42	$0.60

e. Weather Modification

National Science Foundation.—The ecological implications of weather modification being studied include food chain effects of seeding agents and shifts in biota as a consequence of relocation of climatic boundaries.

1971	1972	1973
$ 0	$0.03	$0.05

Department of Agriculture.—Trees and shrubs can be used effectively for modifying and improving man's immediate environment. Research is directed toward designing and evaluating the effectiveness of protective tree plantings of various shapes, widths, densities, and species composition in achieving desirable environmental changes. Experimentation in selecting and testing of trees with increased tolerance to the climate and soils where such plantings are needed is an integral part of this program. Other research efforts are directed toward developing practices for maintaining the health and vigor and prolonging the effective life of trees in shelterbelt plantings.

1971	1972	1973
$0.04	$0.05	$0.05

Department of the Interior.—Research on the ecological impacts of weather modification is supported by the Bureau of Reclamation in connection with its Upper Colorado Snowpack Augmentation Program and precipitation augmentation program in the Great Plains. A much smaller effort of this type is supported

by the Bureau of Land Management in a program to determine the value of artificially induced rainfall in combating forest fires in Alaska.

1971	1972	1973
$0.23	$0.30	$0.32

f. Engineering Construction and Industrial Siting

Department of Defense.—Ecological studies are conducted to determine the ecological impacts of military construction.

1971	1972	1973
$ 0	$0.04	$0.30

Department of Transportation.—The Federal Highway Administration is developing a prediction method for forecasting water quality changes in streams due to highway construction in drainage basins. Studies are being conducted on the evaluation and control of water quality and the adverse effects of highway construction on aquatic life. Erosion control during highway construction is being studied and analyzed in order to decrease stream sedimentation and damage to areas affected by drainage from construction sites.

1971	1972	1973
$ 0	$0.04	$0.17

Department of the Interior.—Most of the ecologically related research being performed in this area is being supported by the Bureau of Reclamation in connection with proposed dams, irrigation systems, and similar public works in the west. The Geological Survey conducts research on the geologic and hydrologic components of planning of structures (e.g., warm oil pipelines in Alaska).

1971	1972	1973
$ 0	$0.09	$0.06

National Science Foundation.—Research activity considers impact of construction on ecological systems and the resulting changes in the environment. These studies include coastal construction as well as urban industrial development.

1971	1972	1973
$0.03	$0.03	$0.07

Corps of Engineers.—Findings developed in impact assessment studies are applied to problems of engineering construction and industrial siting. The studies include demonstration programs on scaled physical models and prototypes to determine the validity of the findings and their effectiveness in resolving the problem.

1971	1972	1973
$2.63	$4.30	$5.10

V. Development of Ecological Research

a. Development of Ecological Principles

Atomic Energy Commission.—Research is on understanding basic functional processes, synthesizing data, and modeling for predictive purposes. This research is concerned with deciphering the normal operations and functions of natural systems not yet subjected to significant disruptions from ordinary pollutants or from radionuclides. Projects are concerned with energetics of natural populations of freshwater macroconsumers, structure and function in lake metabolism, energy transfer between invertebrates and vertebrates of a stream, control of productivity and population characteristics in aquatic communities and marine food chains.

1971	1972	1973
$1.24	$1.24	$1.34

Department of the Interior.—The Fish and Wildlife Service supports research in connection with its primary missions of sound management of animal populations under its jurisdiction and in basic studies by the Office of Water Resources Research, the Geological Survey and the National Park Service.

1971	1972	1973
$0.51	$0.50	$0.53

Smithsonian Institution.—Taxonomic, behavioral, and ecological research on natural ecosystems results in development of fundamental principles on ecosystem stability and fragility, and on species or population changes and modifications. This type of research is being carried out in many parts of the world, especially in the tropics. Various studies on speciation, mimicry, habits of predation and parasitism, and feeding relationships between organisms are

delineating fundamental ecological principles on ecosystem structure and function.

1971	1972	1973
$0.80	$0.80	$1.00

National Science Foundation.—The principal objective of the Foundation's support for ecological research is the development of ecological principles. Problems of ecological regulation within communities and ecosystems of oceans, freshwaters, and on land receive major attention. Ecophysiology, biogeochemistry, micrometeorology, soil ecology, and paleoecology are also supported. A significant fraction of the support listed is provided in the integrated studies of oceanographic, terrestrial (biomes), and crop-pest ecosystems.

1971	1972	1973
$7.14	$7.19	$8.71

National Aeronautics and Space Administration.—Remotely sensed data on atmospheric surface characteristics are employed in the development of ecological models. The models and the remotely sensed data are being investigated to determine their ability to contribute to environmental and resource management.

1971	1972	1973
$0.04	$0.04	$0.39

Department of Agriculture.—Current research emphasizes the relationships between population dynamics of plants and animals in natural and managed ecosystems and their yields and quality. The efficiencies of photosynthesis and soil and water utilization as affected by plant spacing are being investigated. The ultimate objective is to maximize the productivity and quality of animals, crops, and agroecosystems per unit area while still maintaining environmental quality.

1971	1972	1973
$3.44	$3.49	$3.32

b. Relation to Other Sciences

National Science Foundation.—Research emphasizes environmental sciences by relating ecological

functions to hydrologic cycles, soil processes, or atmospheric and oceanic events. Increases reflect development of problem-focused research requiring interdisciplinary team efforts on societally relevant problems.

1971	1972	1973
$1.26	$1.05	$3.32

APPENDIX
Committee Members and Consultants[1]

MEMBERS

Dr. Dale W. Jenkins, Chairman
Director, Ecology Program
Smithsonian Institution
Washington, D.C.

Dr. Philip L. Johnson, Vice Chairman
Division Director, Environmental Systems and Resources/RANN
National Science Foundation
Washington, D.C.

Dr. Lee Talbot
Senior Scientist
Council on Environmental Quality
Washington, D.C.

Dr. Bill Caldwell
Technical Assistant
Office of Science and Technology
Washington, D.C.

Dr. William S. Osburn
Ecologist, Division of Biology and Medicine
Atomic Energy Commission
Washington, D.C.

Dr. Sidney R. Galler
Deputy Assistant Secretary for Environmental Affairs
Department of Commerce
Washington, D.C.

Dr. William Aron
Director, Office of Ecology and Environmental Conservation, NOAA
Department of Commerce
Washington, D.C.

Col. Herbert E. Bell
Acting Deputy Assistant Secretary for Environmental Quality
Department of Defense
Washington, D.C.

[1] Affiliations at time Committee was formed.

Major Donald J. Rogers
Director for Categorical Programs
Office of the Assistant Secretary of Defense
Department of Defense
Washington, D.C.

Mr. Martin Convisser
Director, Office of Environmental Quality
Department of Transportation
Washington, D.C.

Mr. Eugene Lehr
Chief, Research and Coordination
Department of Transportation
Washington, D.C.

Dr. John L. Buckley
Deputy Director, Office of Research
Environmental Protection Agency
Washington, D.C.

Dr. Kenneth J. Hood
Head, Terrestrial Ecology Section
Environmental Protection Agency
Washington, D.C.

Dr. Douglas H. K. Lee
National Institute of Environmental
Health Sciences
Department of Health, Education, and Welfare
Research Triangle Park, North Carolina

Dr. Arthur J. Zeizel
Environmental Scientist
Environmental Factors
Department of Housing and Urban Development
Washington, D.C.

Mr. Martin Prochnik
Deputy Science Advisor
Department of the Interior
Washington, D.C.

Dr. Arch B. Park
Chief, Earth Resources Survey
National Aeronautics and Space Administration
Washington, D.C.

Mr. Nathaniel B. Cohen
Director, Office of Policy Analysis
National Aeronautics and Space Administration
Washington, D.C.

Dr. John L. Brooks
Program Director, General Ecology
National Science Foundation
Washington, D.C.

Mr. Norman Ross
Budget Examiner
Natural Resources Programs Division
Office of Management and Budget
Washington, D.C.

Mr. Earl Darrah
Budget Examiner
Environmental Branch
Office of Management and Budget
Washington, D.C.

Dr. David Challinor
Assistant Secretary for Science
Smithsonian Institution
Washington, D.C.

Dr. Donald King
Science Specialist
Office of Science and Technology
Department of State
Washington, D.C.

Dr. T. C. Byerly
Assistant Director
Science and Education
U.S. Department of Agriculture
Washington, D.C.

Dr. C. Grant Ash
Chief, Environmental Resources Branch
Directorate of Civil Works
Office of the Chief of Engineers
Washington, D.C.

Mr. Louis A. Kaufman
Office of the Chief of Engineers
Corps of Engineers
Washington, D.C.

OBSERVERS

Mr. Richard A. Carpenter
Executive Director
Environmental Studies Board
National Academy of Sciences
Washington, D.C.

Mr. John Blodgett
Environmental Policy Division
Library of Congress
Washington, D.C.

CONSULTANTS

Dr. Stanley Auerbach
Director Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Dr. W. Frank Blair
Department of Zoology
University of Texas
Austin, Texas

Dr. John E. Cantlon
Provost
Michigan State University
East Lansing, Michigan

Dr. Charles F. Cooper
Director, Center for Regional
Environmental Studies
San Diego State College
San Diego, California

Dr. Frank B. Golley
Executive Director
Institute of Ecology
University of Georgia
Athens, Georgia

Dr. Arthur D. Hasler
Director, The Institute of Ecology
Madison, Wisconsin

Dr. Bostwick H. Ketchum
Associate Director
Woods Hole Oceanographic Insititution
Woods Hole, Massachusetts

Dr. Ruth Patrick
Chairman, Department of Limnology
Academy of Natural Sciences
Philadelphia, Pennsylvania

Dr. Robert B. Platt
Department of Biology
Emory University
Atlanta, Georgia

Dr. John F. Reed
College of Environmental Sciences
University of Wisconsin
Green Bay, Wisconsin

CONSULTANTS FOR PREPARATION OF FOREWORD

Dr. Carl A. Carlozzi
Carlozzi, Sinton and Vilkitis, Inc.
Amherst, Massachusetts

Dr. Larry E. Milliger
Greiner Environmental Sciences, Inc.
Baltimore, Maryland

Dr. Patricia J. Rand
Atlantic Richfield Company
Los Angeles, California

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