Pilot Program for Long-Term Observation and Study of Ecosystems in the United States

Report of a Second Conference on Long-Term Ecological Measurements

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PREFACE

This report describes a pilot project for long-term observation and study of ecological systems in the United States. It includes a plan for the organization, development, and administration of the project, as well as a proposed system for the selection, storage, and retrieval of observational data.

The report stems from two recent conferences supported by the National Science Foundation (NSF) and attended by scientists representing many areas of ecology. The first of these meetings was held in March 1977 to discuss the feasibility and desirability of long-term ecological monitoring. At that conference it was concluded that such a program could be of great value not only to ecological research but to the management of biological resources as well. Those attending recommended that an ad hoc group of ecologists be established by the NSF's Biological Research Resources Program to develop a plan for an initial pilot project. The ad hoc group met in February 1978, and its conclusions are presented in this report.

The pilot project plan devised by the Ad Hoc committee outlines monitoring strategies encompassing a range of terrestrial, fresh water, and marine ecosystems. For each of these general target areas, which are discussed separately in the body of this report, a grouping of sample sites was chosen. The idea was to select the minimum number of monitoring sites, not an exclusive set, that would provide a representative cross section of the major ecosystems in the United States. In considering the types of measurements that would be needed in these ecosystems, the emphasis was again on choosing a relatively small number of variables believed to hold maximum potential for long-term applicability and utility of results.

As convenor of both conferences, I would like to thank all of those who attended for their time and dedication to this planning effort. Intense discussion and late hours were the rule at both meetings, for the issues were difficult and crucial. The participants devoted considerable time to the development of the reports, at the expense of their individual professional activities. Members of the ecological scientific community and those concerned with the management of biological resources are indebted to them and to the NSF's Program in Biological Research Resources.

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INTRODUCTION

Need for Research

All ecosystems undergo long-term changes, some of which may be cyclic, others undirectional. Some may be due to natural climatic variation, geological events, and biological processes; others to subtle long-term anthropogenic influences. At present, few research strategies are available to determine which changes are cyclic and which are undirectional or to distinguish anthropogenically induced changes from natural ones. These and other central ecological issues make clear the need for long-term quantitative data for both theoretical and practical purposes.

The value of long-term study is exemplified by the classic papers of John Lund, engaged in research at the British Freshwater Biological Association's Windermere Laboratory in the English Lake District. His long-range efforts led to important insights about diatoms, short-lived organisms which at first might seem to require only short-term examination.

Longer-lived organisms, which dominate many ecosystems and influence or control the rates of production and cycling of minerals in many habitats, require even longer studies.

Yet most research has emphasized the short-term. No one would suggest a study of Drosophila involving only 21/2 generations, yet the 2-year term of research support typically available in the United States encourages just such an approach. American science seems peculiarly lacking in long-term research. Of the 15 chapters on long-term studies in David Lack's Population Studies of Birds, none was based on research by Americans. Too- much research seems to appear out of a temporal and spatial vacuum, lacking the context which can make results most meaningful. Clearly, for the benefit of American science as well as of science in general, the situation demands attention. This need is becoming all the more important now that man is bringing subtle, long-term pressures on natural populations, communities, ecosystems, and the earth's entire biogeochemistry.

A few long-term studies have been initiated in North America, such as the measurement programs of the Canadian Freshwater Institute, Winnipeg, Manitoba, and the Hubbard Brook Ecosystem Study, New Hampshire. Even after only a decade of measurements, these sites have become the focus of intensive activity and have attracted many energetic scientists. Such programs demonstrate that long-term measurements serve not only to test hypotheses, but also to generate new and important questions.

It is no easy task to design a long-term program. Looking back, one may see many poor examples of data collected for their own sake, of programs continued merely because they had been there for a long time, and of data almost worthwhile but incomplete and lacking the crucial piece of information to make the whole set meaningful. A central issue or a hypothesis to test or to guide the collection of data seems to have been missing.

Yet ideas have a lifetime, and programs developed specifically to test a single idea may have little utility in the long run. Some studies with more general rationales seem to have made possible the identification of important issues which may be missed in more highly structured projects. Moreover, in many instances, studies started for one reason have proven to be more valuable for quite another reason.

The participants at two Conferences on Long-Term Ecological Measurements have attempted to grapple with these issues. The first conference considered the feasibility, rationale, and content of such a program. In addition, an attempt was made to set down some guidelines regarding measurements needed over the long term.

The second conference considered how a program in long-term ecological measurements might be implemented. This report represents the conclusions of the second conference, and it is meant to serve as a guide for setting up a pilot program involving a variety of representative ecosystems and with the cooperation of several agencies and groups of scientists.

Organization of This Report

The report is divided into two parts. The first addresses some general considerations applicable to all sites. It begins with an overview, followed by a general management plan that describes a method for moving from the present state of affairs to a well-structured pilot program. Next, a plan for data collection, storage, and retrieval is presented, leading to a discussion of those measurements that are desirable at the beginning of a program of long-term monitoring at any site.

The second part focuses in turn on terrestrial, fresh water, and marine habitats; it addresses the selection of sites, integration of activities among sites, and the specific phenomena that seem important to measure. Each of these sections includes a sample group of sites thought to represent a minimum number acceptable for a pilot study. The report is intentionally specific in naming sites in order to highlight the needs and potentials of such a program. The sites selected are meant to represent a possible sample, but not an exclusive one.

Part I. GENERAL CONSIDERATIONS

Overview and Recommendations

Long-term studies may be carried out by individuals or by institutions. A skilled scientist who has the desire to engage in long-term research seems a likely candidate for such a program, which requires precise measurements, accurate records, and the motivation to seek insights from observations.

Mechanisms should be developed to promote longer studies by such scientists. These mechanisms might include: (1) funding projects designed for longer periods than are now typical in ecological programs and (2) providing individual scientists with small sums to do inexpensive, long-term studies needing infrequent measurements which could be performed along with other research activities.

But increasing the potential for individuals to carry out long-term studies is clearly not enough, for some long-term records that are needed can not be obtained through individuals alone. Some records must be longer than one person's career.

Many kinds of institutions can participate in long-term measurements useful to central scientific issues in ecology. Some Federal agencies are already involved in such projects aimed at environmental problems. Wherever possible, these agencies should seek the cooperation and advice of ecologists involved in fundamental research. Better communication should be established so that the data developed in such Federal programs are made available to the scientific community. Moreover, existing data sets seem sometimes obscure, and the design of information systems could profit by feedback from scientists not directly in the Federal service.

The kind of cooperative research illustrated by the relationship between the Forest Service and the academic community at Andrews Forest, Oregon, and Hubbard Brook. New Hampshire, should be promoted elsewhere and serve as an example to other agencies.

There is a definite need for new types of programs for long-term ecological measurements. Many kinds of institutions and many possible mechanisms are available for the establishment of such programs. Whenever possible. the selection of institutions should be based upon a record of productive and useful short-term research.

Because little is known about the natural, temporal behavior of completely undisturbed ecosystems, it is important to identify a few pristine ecosystems where crucial parameters could be monitored. A pilot program should include some such sites. The sites selected would be those subject to only minimal influence by human activity, and at the same time least likely to suffer natural catastrophes. Interest in such pristine sites, however, does not imply a disinterest in sites subject to known perturbations.

The selection of other sites would depend on their representativeness for major ecosystems and populations, the interest shown in them by active scientists, their importance to major ecological issues, and their availability for long-term monitoring.

In the process of selecting the study sites described in Part II of this report, conference participants gave priority to:

1. Sites where productive and useful short-term research has already been conducted.

2. Sites representative of major ecosystems and populations.

3. Sites considered important to major ecological issues.

4. Sites in which active scientists have shown interest.

5. Sites protected and accessible for research purposes.

6. Pristine ecosystems where crucial variables can be monitored.

7. Sites that are not pristine, but are unaffected by undesirable impacts and meet the other criteria.

It is essential that measurement programs, like all projects funded by the National Science Foundation, be subject to periodic review. Such careful review, combined with judicious selection of sites and a selection of measurements and their priority, would increase the likelihood of success, utility, and importance of these programs.

Long-term measurement programs should not compete for funds with short-term research projects, nor should they be interpreted as mechanisms for all-encompassing analyses of entire ecosystems. The concern of the programs suggested here is to select factors essential to major ecological issues. While the time scale is large, and while in the long run such programs should exist in many locations, the present need is to determine the minimal level of monitoring necessary.

The problem of what to measure suggests the importance of certain kinds of ecological specimens not now collected or stored but which could prove extremely valuable. These would include, for example, some inexpensive-to-collect and small-sized samples of insects; representative tissues of major vegetation and vertebrates; and samples of the air, water, and soil.

Museums and other repositories should be encouraged to hold such collections; this function should not be the responsibility of ecological monitoring stations. These collections would help to deal with the unforeseen: it is difficult to project what will be needed in the future, but experience shows that frustration can come from the lack of some crucial past measurements of tissues, air, water, and soil (e.g., the concentration of CO_2 in the atmosphere or mercury in fish 100 years ago).

A modest collection a few samples collected at infrequent intervals-could be invaluable if the time and site of collection were recorded. Care must be taken in the selection of methods for long-term study. Generally, measurements should provide data to:

1. Identify unidirectional and cyclic changes.

2. Detect time lags in the ecosystem's response to outside influences.

3. Test ecological theories concerning stability, diversity, community structuring, and system development.

4. Act as sensitive indicators of ecological change.

Measurement techniques should also have the following characteristics:

1. Simplicity and reliability--so that studies made at different sites or times or by different investigators may be compared with confidence.

2. Stability-i.e., unlikely to change drastically over a period of decades or subject to rigorous intercomparison when techniques change.

PROGRAM DEVELOPMENT AND MANAGEMENT WORKING GROUP

The first and second conferences on Long-Term Ecological Monitoring defined the need for such a program, proposed a network of sites, formulated measurement protocol, and provided guidelines for implementation of a pilot monitoring project. Much remains to be done, however, and it is necessary to establish an interim Working Group to provide continuity between the conference reports and the actual implementation of the proposed monitoring program.

The Working Group will have the difficult task of translating what is essentially a scientific plan for long-term measurements into an operational plan that can be implemented. Initiation of the interim management plan will require development of guidelines for institutions wishing to participate, assessment of specific site potentials for long-term measurements, and agreement on the ranking and priority of variables to be measured, refinement of the management plan, and establishment of appropriate groups to define and oversee policy for the program itself. In addition, the Working Group will need to be concerned with the sources and levels of financial support required for implementation of the operational plan.

To carry out these and related functions, the Working Group will need expertise of a nature somewhat different from that represented at the first and second conferences. At the same time, although it will be using the conference reports as its basis for planning, the Working Group will need to include a representative selection of the conference participants in order to preserve the basic goals and philosophy set forth by the conferences. It is suggested that the Working Group include ecologists with knowledge of all the habitats represented in the scientific plan, namely terrestrial, fresh water, wetland, and marine ecosystems. The group should also include members who have the following attributes: (1) strong management capability; (2) knowledge and experience in institutional relationships, particularly the relationships among government agencies and between government agencies and universities or research institutions; (3) data system expertise; and (4) knowledge of ongoing environmental monitoring programs (e.g., National Weather Service, United States Geological Survey, and the like).

The Working Group will need financial resources for staff support, i.e., a secretariat, and for consultants to solve specific problems. It will need to maintain close liaison with sponsoring agencies.

The general responsibility of the Working Group is largely defined in the narrative of the conference reports and in the comments above. In addition, it is especially important that the Working Group be charged with the responsibility to see that the Long-Term Ecological Monitoring Program be open and accessible to any interested person or group.

Responsibility for establishment of the Working Group should be focused in an organization that has or can establish effective liaison with Federal and state agencies and academic and private institutions interested and involved in monitoring and long-term ecological data acquisition. Ideally, this organization would not be a governmental agency but should have the experience and ability to coordinate a multifaceted activity such as that proposed in the development of the monitoring network and its management plan.

Suggested organizations include the American Institute of Biological Sciences, The Institute of Ecology-Holcomb Research Institute, and professional scientific organizations such as the Ecological Society of America. Funding for interim activities would be solicited from Federal agencies interested in becoming involved in the pilot network. The Working Group would initiate the Network Management Plan given below.

Network Management Plan

The management plan for the monitoring network considers activities at three levels (1) central policy and overview, (2) network coordination, and (3) site coordination. It also involves committees to advise on general science policy matters and on site management related to long-term ecological monitoring. While not a component of the management structure, the services of an appropriate national repository for scientific materials are essential to the effective operations of the network.

The relationships of the elements of the management plan are diagrammed in Figure 1. The proposed management structure is designed to permit expansion of the pilot network by the inclusion of additional monitoring sites or by the addition of "satellite sites" to pilot (intensive) regional sites.

Ecological Monitoring Council

The Ecological Monitoring Council is conceived as a central policy and overview group composed of representatives from the scientific community and from management. It should be structured to provide for both continuity and a degree of rotation among individual members and should include a nucleus of participants from the Working Group described above. Active participation by agencies and organizations involved in monitoring and ecological data acquisition is essential, as is the involvement of other interested groups who may also contribute to the program. The Senior Science Policy Committee should also be represented in the Council's membership and/or participate in its deliberations.

It is suggested that the Council include representatives of (1) organizations with land ownership/management functions, including the National Park Service, U.S. Department of Agriculture (Forest Service and Agricultural Research Service), Department of Energy, Organization of Tropical Studies, and university and state agency representatives; as well as (2) other interested agencies, including the National Science Foundation, Council for Environmental Quality, National Oceanic and Atmospheric Administration, and Environmental Protection Agency. Although this report focuses primarily on the United States, involvement of appropriate non-U.S. agencies, such as the Canadian Environmental Service, is also advisable.

The suggested responsibilities of the Council include: (1) establishing general policy regarding ecological monitoring and its long-term goals; (2) securing continuing financial support; (3) assisting network development (e.g., site acquisition, security, etc.); (4) establishing an Executive Board for administrative purposes and other committees or advisory groups as may be needed for the effective conduct and management of the network; and (5) selecting, appointing. and providing guidance to the Network Coordinator.

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                                        PILOT MONITORING NETWORK
                                SUGGESTED MANAGEMENT STRUCTURE

                                ECOLOGICAL MONITORING COUNCIL
                                                &
                                         EXECUTIVE BOARD
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NATIONAL _ _ _ _ _ _  NETWORK COORDINATOR_________SENIOR
SCIENCE REPOSITORY                             |                    POLICY COMMITTEE
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        SITE
SITE                                        SITE
  DIRECTOR/
DIRECTOR/                                 DIRECTOR/
COORDINATOR                                 COORDINATOR                  COORDINATOR
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FIGURE 1. A suggested management structure for the pilot monitoring network

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Network Coordinator

Effective management of the network will be the responsibility of the Network Coordinator, assisted by the Council, the Senior Science Policy Committee, and the Site Advisory Committee. In addition to the general responsibilities noted below, the Coordinator must provide for the efficient conduct of the monitoring program at all network sites with specific regard to quality control, security, and longevity. These responsibilities may be accomplished by formal agreements or by letters of intent between the institutions involved in the program, providing for continuity of effort in the absence of the key personnel at the Site Coordinator level, or if performance is not satisfactory.

The Network Coordinator's suggested responsibilities include: (I) overseeing network monitoring stations; (2) establishing and maintaining standardized procedures for measurement, sampling, data format, and reporting; (3) developing new monitoring stations at appropriate sites; (4) relocating monitoring stations as required; (5) providing training programs for site monitors (workshops, manuals, etc.); (6) promoting data utilization; (7) establishing and maintaining liaison with national repositories for numerical data and scientific materials; (8) establishing and maintaining liaison with other national and international monitoring and data networks; (9) conducting periodic on-site review of monitoring stations; and (10) reporting to the Chairman of the Executive Board of the

Ecological Monitoring Council.

Senior Science Policy Committee

This Committee should initially include members who have participated in the Working Group. A mechanism to ensure liaison with the Ecological Monitoring Council should be devised. The function of the Committee is to provide the Network Coordinator with the information and advice that will help him to make informed and wise management decisions in the following areas: (1) standardization of methods and techniques; (2) intercalibration requirements; (3) data management; (4) release of archival scientific materials; (5) proposal review; (6) selection of new sites; (7) relocation of monitoring stations; and (8) data acquisition.

Site Advisory Committee

This would be a self-selected group of representatives from various sites in the monitoring network. Its primary function would be to serve as a forum for discussion of site monitoring and management problems in order to assist the deliberations of the Network Coordinator and to enhance the exchange of information between the three management levels.

Site Coordinator

The success of the pilot monitoring network will depend on the conscientious performance of personnel at the site level. One individual should be charged with the responsibility for monitoring activities at each site. In some situations it may be feasible to combine this task with other site management activities if they contribute to the most effective conduct of the monitoring program.

The specific responsibilities of the Site Coordinator may vary with the monitoring site, but they should generally include the following: (1) acquisition, security, and management of numerical data, scientific materials and collections, maps, photographs, imagery, etc.; (2) adherence to standards of sampling procedures, analytical techniques, and data control (data quality and compatibility of format); and (3) reporting to the site director (e.g., laboratory or station director) on operation of the site monitoring program and projected operational budget requirements.

The Site Coordinator's duties may include: (1) maintaining software and hardware; (2) promoting the use of data; (3) counseling investigators; (4) maintaining liaison with national sites and investigators; and (5) recommending new sets of research data, observational data, instructional/teaching/class data, and historical data.

Data Bank

It is desirable that each major site should develop and maintain a computer-based interactive data bank. It is essential that a data bank be established that is reliable, carefully documented, consistent among sites and easily used. Few data banks have succeeded in meeting these criteria, but there are now some successful systems such as the Man Computer Interaction Data System developed at the University of Wisconsin.

The data bank should be structured hierarchically to provide for efficient searching of the data bank as well as for establishing different levels of access by different user groups. This file structure will allow for a variety of data sets but maintain a logically consistent and usable system. Thus, data sets could be labeled by a variety of indices to expedite search. In addition, each data set should include the name of the collector of the set, the collector's address, the method of collection and information on intercalibration with other collection methods, Inclusion of this type of identifying information will, it is hoped, encourage a generally high standard of data set quality. Policies for offline storage (disc and tape) should be established and circulated. Again, this information would be provided to the user upon command. Finally, regarding hierarchical structures, attention is directed to the EPA's structure for the designation of species.

Data handling prior to insertion into the bank should be kept to a minimum. By using standardized forms which could be displayed on an interactive computer terminal, the data could be presented as on traditional laboratory forms. A hard copy cross-check would be produced. Security for the machine's internal files and data arrays is essential and can be accomplished by standard soft-ware procedures. The system should allow data to be inserted under various protocols which would have been established by the network coordinator in consultation with the Senior Science Policy Board. Data clearance rules and procedures should be provided to each user through the query system.

Guidelines for a Data Bank

The details of the data bank depend on available funds and on the exact program as developed by the network management groups discussed in the previous section. However, for the sake of clarity, an example of a desirable data bank is given here. This illustrates the kinds of guidelines desirable; the exact details must await funding and further planning.

It is desirable that each major site will eventually acquire its own small computer, a telecommunication system, terminals and hard copy equipment, an information management system and a programmer/technician. Nearby or similar sites could share such facilities and facilities at nearby institutions could also be used.

Computer data banks must be consistent across sites to allow direct program transfer and machine-to-machine communications, Since the incompatibility of computing machinery often frustrates this communication and limits the exchange of software, it is recommended that all computer machinery be essentially the same. The system should include both disc and tape drives and support commonly used, higher level languages that would be shared among the sites, such as: FORTRAN, BASIC, APL, PASCAL, and possibly COBAL. If possible, 32-bit machines should be used.

Each site initially should consider having two WATS lines. One line would support both incoming and outgoing calls; the other line would be restricted to incoming calls only. The former would be used for voice communications as well as for interactive use of off-site data banks. The latter would support an interactive use of the data bank by a wide array of scientists. Time limits and access would be controlled by computer software. Additional telephone lines would be necessary for local and toll-paid long-distance use, Use of networks such as ARPA with high data-transmission speeds (greater than 1Z00 BAUD) should be considered; however, in advance of their use, large data sets could be taped and mailed to investigators.

With regard to terminals and hard copy equipment, it should be recognized that a preferable instrumentation arrangement would include at each site at least one line printer, a hard copy terminal, a CRT terminal, and an x-y plotter.

It is essential that the computer support a comprehensive data management system with a flexible query language. This system needs the following capabilities: (1) easy data insertion and cross-checking; (2) security and record keeping; (3) report generation with tabular displays and plots; (4) interactive browsing of the data bank; (5) statistical packages; (6) system performance and data completeness measures; and (7) text editing and manipulation.

The most desirable system would be able to produce two- and three-dimensional plots for even an inexperienced user. Histograms and other representations of data must be easily obtainable.

It is difficult to estimate the amount of programmer time that will be required; the work load may be most intense during the development of a site. In any case, the services of a permanent computer programmer, on at least a part-time basis, are essential for each site. Wherever possible, established soft-ware should be purchased. Again, consistency across sites is necessary; however, site-specific requirements will demand a certain amount of on-site development. Coordination between sites by the programmers will avoid duplication of effort.

Initial Measurement Requirements

In the process of establishing programs for monitoring long-term ecosystem changes, it is essential that a number of initial conditions be met in order to characterize the individual sites. For this purpose, various steps would be taken to provide standards of reference for the appraisal of potential changes in the ecosystems. The steps presented below were discussed in the report of the first Long-Term Ecological Measurements Conference of March 1977 and were considered essential; they include the preparation of the following items for each site: (1) map of geological features; (2) map of topographic and bathymetric features; (3) map of soils and/or sediments; (4) map of vegetation; (5) comprehensive lists of species; (6) recordings of biotic and abiotic aspects of catastrophic events; (7) aerial and ground benchmark photographs.

A map of the geological features should be made available to show major geological formations and, especially, the lithology. Lithology is emphasized because biota react more directly to the quality of rocks (e.g., limestone, sandstone, etc.) than to their age (e.g. Permian, Jurassic, etc.). If the lithology of the site is very complex, then it is necessary that the geological map be of the same scale as the vegetation map. A smaller scale is acceptable where the geology is uniform over major portions of the site.

Topographic and bathymetric maps are often available. For terrestrial studies, it is important that the topographic map be of the same scale as the vegetation map. For aquatic studies, watersheds should be delineated.

It is often customary among pedologists to present edaphic features by showing soil series as basic units. This procedure is acceptable, provided that the profile, texture, and structure of the soils are described. Other features, such as water-holding capacity, humus content, etc., may also be desirable, depending on circumstances. The scale of this soil map should be the same as that of the vegetation map. For soft aquatic sediments, organic content and particle size distribution should be mapped.

A vegetation map is a basic tool serving many ecological investigations. It is essential that current large-scale aerial photographs be available before the field work for preparing such a map is begun. Upon receiving the photographs, it is essential that ground truth be established with the greatest care. To photograph marsh and submerged macrophytes, special films that enhance underwater visibility are desirable. In order to assure a maximum efficiency in the use, interpretation, and application of the vegetation maps, it is important that the scale be large. A smaller scale may be adopted where the size of a site makes a large scale impractical. Aerial photography should make use of appropriate multispectral techniques not only to delineate the vegetation but also to measure water color, chlorophyll, and sediment load. The vegetation maps should be printed in color to assure the highest degree of legibility, usefulness, and applicability. The vegetation maps will provide a permanent record in a format highly desirable for data storage and retrieval. The maps should be accompanied by an illustrated text describing in detail the photographic and mapping techniques and the composition of the flora.

It is essential that current lists of species be prepared. These lists should be as complete as possible, and every effort should be made to provide corrections as needed. Updating these lists may be considered a part of the monitoring program. However, it should be recognized that additions may be needed as a result of omissions in the original list, since some species may have escaped the notice of the original compilers.

The characterization of a given site is incomplete if it does not describe catastrophic events of the past on the basis of effects that are still recognizable. Fires, hurricanes, blizzards, ice storms, severe gales, tornadoes, volcanic eruptions, earthquakes, floods, oil spills, red tides, and other phenomena may have effects that should be recorded. Such observations may add significantly to the characterization of an ecosystem.

It is sometimes possible to use existing features in the landscape as benchmarks. Surveying may become necessary where such features do not exist. The location and character of the benchmarks must be precisely recorded. It is important that the benchmark s be made recognizable from the air and on aerial photographs. Once the benchmarks are established, it is possible to use ground photography at any point identified by reference to benchmarks. Such photographic records are very useful in characterizing the ecosystems and may contribute significantly to future monitoring.

Aerial photography may be of several types, such as black and white, natural color, and false color-infrared. Each offers its own peculiar advantages for distinguishing the features of the landscape. Whenever feasible, it is strongly recommended that all three types be utilized. The use of other types may be desirable under special circumstances.

It is strongly recommended that an initial photographic mission be repeated twice in the course of the growing season wherever the vegetation is primarily herbaceous, as in grasslands, because the structural features of such sites can change substantially within a short period of time. This effort will permit a much more precise delineation of the individual plant communities within the herbaceous habitat.

Because long-term monitoring is the main objective of this program, it is recommended that the aerial photography be repeated periodically, such as every 10 years, to facilitate analysis of the changes that may have occurred. The frequency of photographic missions should be determined by the individual monitors.

Part II MONITORING SITES

This part of the report is divided into three sections, one on terrestrial, one on fresh water, and one on marine sites. A discussion of the need for monitoring of the interaction among different ecosystems is discussed in Appendix A. The participants at the meeting confronted a difficult dilemma in setting down a list of recommended sites and measurements. The exact technical details of what measurements will be made and how they will be made depend on the decisions of the groups discussed under the management plan above. Here, a list of very general guidelines would provide little real assistance. Therefore it was decided that a comparatively detailed list of measurements would be included in this report to serve as an example to the reader. However, it must be clear that these lists are meant for guidance and would be altered depending on the availability of funds and decisions of the management groups.

It should also be recognized that sites might be divided into major and minor ones; the major ones having the facilities suggested here and the minor ones serving as satellite sites, visited from the major ones on a regular basis.

Terrestrial Section

Habitat/Site Selection

Criteria

An integrated network of terrestrial ecosystem sites should encompass the full range of climate conditions, soil types, and biological communities found in such systems. For the purpose of a pilot monitoring project, it was deemed appropriate to limit choices to those areas relatively undisturbed by human influence. Eventually, the network should be expanded to document ecosystems undergoing modifications by man.

To insure the most comprehensive network, it was considered desirable to spread the selected sites through the greatest variety of ecosystems. For purposes of selection. ecosystems were typed on the basis of vegetation and environmental features of forest range habitats. Useful in this regard was a map developed by the Forest Service entitled Forest-Range Environmental Study (FRES), from A.W. Kuchler's 1964 Potential Natural Vegetation map. This map condensed 106 Kuchler types into 34 representative ecosystems. Sites considered for selection included the U.S. Biosphere Reserves (Franklin 1977), the sites in the proposed Experimental Ecological Reserves Network (TIE 1977), and other sites suggested at the Conference on Long-Term Ecological Measurements. Generally, the suggested pilot monitoring network includes at least one site in each of the Second Order Ecoregions developed by Bailey (1975).

Suggested Sites

The 14 sites recommended for pilot monitoring are listed in table 1. Each is large, well-protected, and representative of a specific habitat type. Each has a documented research history. A more comprehensive description of these sites is presented in Appendix B.

Measurement

Sampling Strategy

At the beginning of a monitoring program, each site may be limited to a single sampling station. Eventually, however, it would be advisable to establish multiple stations within each site. Otherwise, generalizations made on the basis of observed data may not be fully representative of the inherent variability of the ecosystem's characteristics, nor be statistically valid.

The following standard of replication is recommended. Within a given site, the vegetation/soil/slope/altitudinal variable which most closely represents the vegetation type of interest should be identified. Within the spatial range of this variable, at least five sampling stations should be selected. Subsequent adjustments in the number of stations would depend on the degree of variation encountered during initial sampling.

TABLE 1. Suggested Terrestrial sites for the pilot monitoring network.

Vegetation Types	Second-Order Ecoregions	Sites
Tundra	Tundra	Naval Arctic Research Laboratory
Boreal Forest	Subarctic	Mt. McKinley National Park
Pacific Northwest Forest	Maritime	H.J. Andrews Experimental Forest
Californian Forest	Mediterranean	San Joaquin

		Experimental Forest
Northern Desert	Desert	Arid Lands Ecology Reserve
Southern Desert	Desert	Big Bend National Park
Rocky Mountain Forest	Steppe	Rocky Mountain National Park or Fraser Experimental Forest
Shortgrass Prairie	Steppe	Central Plains Experimental Range
Tallgrass Prairie	Prairie	Konza Prairie or Wichita Wildlife Refuge
Northeastern Forest	Warm Continental	Hubbard Brook Experimental Forest or Harvard Forest
Central Forest	Hot Continental	Oak Ridge National Environmental Park, Coweeta Hydrologic Laboratory, or Great Smoky National Park
Southeastern Forest	Subtropical	Savannah River National Environmental Research Park
Tropical Forest	Rain Forest	La Selva Field Station
Tropical Savannah	Savannah	Everglades National Park

Recommended Measurements

Desirable physical, chemical, and biological measurements are described in the following outline. The ranking of these and their priority for implementation must be determined by the Management Groups outlined in the previous section on a Network Management Plan.

Physical:

1. Shortwave insolation, unless done very carefully and hence at considerable expense, would be better obtained by using the nearest U.S. Weather Service Station. In regard to temperature, for many sites and purposes, daily maximum and minimum are adequate; similarly for dew point. Wind speed would be unnecessary for many sites such as dense forests. However, where funds are available and the sites and goals require more detailed measures, the following procedures would provide a useful standardization: Dual sets of meteorological sensors could be established near each station for continuous measurement of short wave insolation ($W\ m^{-2}$), air temperature (degrees C), precipitation (cm), wind speed ($m\ s^{-1}$), and dew point (degrees C). These measurements should be recorded on devices such as independent tape cassette recorders which can be monitored for accuracy. The records should be processed, and all data should be averaged or integrated hourly. Means, ranges, or integrated values should also be calculated for diurnal and nocturnal periods. Data format and tapes must be compatible among sites.

2. The water content of soil ($cm^3\ H_2O\ cm^{-3}$ soil) should be monitored at two or more stations and at two depths in the rooting zone, by neutron probes where possible. Measurements should be made biweekly from at least five access tubes per station. If soils are frozen, under snow, saturated, or drained completely, the sampling periodicity may be extended until conditions change.

3. Both inorganic and organic erosion ($cm^3 m^{-2}$) should be measured by two or more stations following major events, or at least annually. Sediment basins, pins, photo points, and labelled litter and soil particles are possible means of estimating erosion. Where sediment is collected in a basin, a subsample of both organic and inorganic material should be air-dried and stored.

4. For those sites where snow is important, snow depth (cm) and moisture equivalence (cm) should be measured by two or more stations at reasonable

intervals; for intensive snow sites at least monthly. Dates when the ground is free of snow should be noted.

Chemical:

Chemical analyses provide a record of changes in material deposition, uptake by the vegetation, return through litter fall, and losses from below the rooting zone. Subsamples should be stored for possible future needs; e.g., analyses for heavy metals, organic chemicals, etc.

At the least. wet and dry atmospheric deposition should be collected at weekly or bi-weekly intervals, and the samples analyzed for major chemical elements required for, or likely to impinge heavily on, living organisms. Also, a certain portion of the samples from both wet and dry fall containers should be stored for future analysis. An example of an explicit, detailed, sampling program is the following, which would provide useful information where considerable detail is required:

1. Atmospheric deposition, both wet and dry fall should be collected at all stations by use of a sampler similar to that described by Volchok and Graveson 1975. This sampler, which consists of a 13-liter polyethelene container for both wet fall and dry fall collection, should be placed a minimum of two meters above the ground. The preferable measurement procedure is as follows: The wet fall container should be sampled weekly, and the dry fall container, bi-weekly. The wet sample will be analyzed for pH, Ca++, Mg++, Na+, K+, SO4, PO42, Cl-, NH4+, and NO3-. At periodic intervals, a 125 ml archive sample should be frozen and stored in a central repository. The dry fall sample bucket will be rinsed with distilled water to remove all solid material. The solution will be filtered and analyzed for the same constituents as the wet fall sample. The filter paper, including a sample of unused filter paper, will be stored and shipped periodically to the central repository. Both buckets will be acid washed before returning to the sampler.

2. Soil samples should be collected in cores from at least two stations. These should be quarterly or more frequently, but no more frequently than weekly. Analyses of nutrient content (Ca, Mg, K, Na, SO4, PO4, N, C) would be performed on samples from major horizons in the rooting zone. Some undisturbed cores should be dried and stored in a central repository. Exchangeable cations, cation exchange capacity, and bulk density should also be measured.

3. Suction lysimeters should be placed below the rooting zone in at least two stations for sampling soil solution chemistry. Measurements should be made at the time when concentrations are maximum and minimum. Subsamples should be frozen and stored in a central repository.

Biological--Vegetation:

1. Leaf area, which indicates both ecosystem condition and biomass, should be measured at every station in each site. In each vegetation stratum, leaf area should be measured annually or more often (if dictated by phenology). Where growing season and phenology overlap, one measurement during peak leaf growth or at end of growing season is adequate. Where species composition includes both cool- and warm-season species, the sampling schedule should accommodate both types. Leaf area in the tree canopy should be appraised with leaf screens or traps. Leaf area on shrubs may be measured with leaf traps, ocular methods, or dimensional analysis. For herbaceous understory, leaf area may be estimated by ocular or mechanical means. The number of samples collected at each station must be adequate to represent the site. For each stratum: specific leaf area (g cm-2) should be determined for weight-to-area conversions.

2. Tree diameter measurements should be made to help estimate biomass production rate. At the five stations on each site, initial measures should include species location, and metric diameter at breast height

(DBH) of every tree, and diameter at ground level of shrubs. Then, at 5-year intervals, the DBH of a subsample of these trees, plus a sample of new trees, should be measured at a time of high soil moisture (to minimize drought-induced bole shrinkage).

3. At all stations in each site, an annual record of tree falls should be maintained. Tree falls aid in both estimation of life history characteristics of individual species and detecting changes in community composition.

4. Vegetation maps of each of the five stations should be constructed initially and at 5-year intervals thereafter. In each intervening year, a sample of the vegetation should be mapped. Perennial plants greater than 1.35 m tall should be tagged, and heights of major strata should be measured directly or estimated through surveying techniques.

5. Five photographic points should be established at each station for annual photographs of the ground cover and tree canopy. In sites with appropriate vegetation, photographs should be made twice a year.

6. Litter fall should be collected biweekly from five or more traps at each station. Collections should be separated into photosynthetic organs, twigs, and grass. Material should be air-dried and weighed, and a subsample should be placed in the central repository. Litter measurements help to estimate production and may be useful for subsequent research concerning changes in biotic or chemical composition.

7. At each station, a small number, on the order of six plant species, should be selected for phenological study. Specific phenological observations will vary with vegetation or composition, but the following are considered minimal: time of vegetative growth initiation; time of bud break; flowering time; and time of leaf fall or senescence. Chosen species should be native to the site and characterized by distinct, conspicuous phenological stages. Where possible, pairs of species should be selected that flower at widely separated times and preferably in different seasons. Where appropriate, one member of each pair should be deciduous.

Biological--Animals:

1. Rodent populations could be monitored as an aid to understanding the interplay of physical and environmental variables and key trophic interactions. At each station, live traps or similar devices should be designed to yield an estimate of the mean for dominant or crucial species within a defined statistical limit. For example, for some sites, the following would be a reasonable scheme: At each station, a fixed line of 40 live traps should be deployed over a 5-day period four times a year. Routine measures should include species, sex, and metric size of all trapped specimens.

2. At a location near but not adjacent to each station, a few adult male specimens of the most abundant rodent should be live-trapped twice a year, frozen, and stored in the central repository. Biochemical and morphological changes noted in rodent tissues will help us to understand population dynamics and reflect vegetation quality.

3. Large herbivorous mammals should be counted annually by aerial photograph and other techniques appropriate to the site. The information thus provided will help us to understand the nature of an important faunal/floral relationship.

4. Predators should be counted by methods appropriate to site and species. including monitoring scent stations and searching for scats. Predators may be important regulators of herbivore abundance and composition. Moreover, they are particularly sensitive to pollutants that accumulate in tissues.

5. Passerines, which play a key trophic role in ecosystems, should be counted twice a year For this purpose, a standard transect at each station can be monitored by the singing male technique and appropriate,

supplementary methods.

6. Picids, corvids, columbids, and other small non-passerines should be counted annually at each station by methods appropriate to site and species, including monitoring at selected habitats.

7. Raptors should also be counted annually at each station by methods appropriate to site and species. Like other predators, raptors concentrate pollutants; moreover, many are endangered. Archiving of some samples of raptors would also be useful.

8. Insects on vegetation should be sampled by DeVac biweekly over a standard transect at each station. Samples should be preserved in isopropyl alcohol and stored in the central repository. Such insects are major determinants of vegetation composition and biomass, and they also integrate the effects of meteorological variables.

9. Flying insects, which are important for similar reasons, should be collected biweekly from one malaise trap and one blacklight trap at each station. Samples should be preserved in isopropyl alcohol and stored, unsorted, in the central repository.

10. One sample of litter arthropods should be processed monthly at each station through a light-operated Berlese funnel. Collections should be preserved in isopropyl alcohol and stored unsorted in the central repository.

FRESHWATER SECTION

Habitat/Site Selection

Criteria

Aquatic habitats may be classified under three general headings-streams, lakes, and wetlands. Appendix C includes a number of tables and figures describing these systems. The criteria used by the Ad Hoc committee to select a representative sample of habitats for ecological study are outlined below.

Streams. In the process of selecting stream sites for long-term monitoring, priority was given to locations where active programs exist. At each of the several major site candidates considered, (See Appendix C, table C-1) there is a data base of at least 3-5 years and the potential for future data collection appears high. As would be expected, these sites do not cover the complete range of vegetational zones and stream sizes in the United States. For unrepresented areas, another series of sites was identified--locations where laboratory facilities and ecological personnel exist on or near the stream system, but where few if any stream data are being collected (See Appendix C, table C-2). It is presumed that a series of minimal measurements could be made at such sites if funds were available.

Most large streams (greater than order 6) have been dramatically affected by human disturbance (e.g., impoundment and inputs from point and non-point sources). Because of their lesser variability, greater predictability, and higher long-term stability, only relatively undisturbed sites have been listed. Any program of long-term ecological data monitoring initiated on such sites could be interfaced with ongoing programs on larger, more disturbed rivers. The past, present, and predicted future disturbance of a site is, in most cases, a function of the type of controls exercised by public or private agencies.

Lakes. Within each of the major lake regions in the United States (See Appendix C, table C-3), there is a diversity of water bodies with differences in stratification pattern, chemical composition, productivity. and other variables. Ideally, a spectrum of lakes representative of each region should be monitored, because their patterns of response and the mechanisms causing these responses would be expected to differ. Therefore, priority was given to sites from which monitoring of a variety of lakes could be carried out.

The suitability of a site for long-term monitoring by terrestrial, stream, or wetland groups was also considered important. Recent studies have shown the importance of land-water and lake-stream interactions in affecting fresh water. It has also been shown that the paleoecological record in lake sediments can provide vital information about the terrestrial watershed.

The interaction of a lake or stream and its watershed can be evaluated most readily, accurately, and inexpensively where hydrological budgets for watersheds can be simply measured. In general, watersheds that do not have complicated ground water regimes would be most suitable. Research has shown that it is necessary to know water flow-through and chemical mass-balances to interpret much of the variability that occurs in freshwater lakes. The availability of data on meteorology and precipitation chemistry were also considered to be of great importance in selecting sites.

Further consideration was given to the suitability of lakes for the detection of currently recognized long-term problems. For example, the effects of acid precipitation can be seen most easily in lakes of low buffering capacity. The effects of nutrient addition are easiest to detect in oligotrophic waters where primary producers are limited by nutrients rather than light. Lakes with varved sediments are considered particularly valuable because of the accuracy with which historical records can be dated. Meromictic lakes can be very useful because low temperatures and anoxic conditions in deep waters provide excellent preservation for biological materials.

Other criteria provided even further bias. In some cases, a long history of limnological work in an area gave a site an extraordinary data base. An example is the Trout Lake Station in Wisconsin, where a number of sensitive chemical and biological parameters were studied by Birge and Juday as many as 50 years ago. Such a data base would facilitate interpretation of long-term data much sooner than at sites with no historical record. Areas where there were long histories of terrestrial, stream, or wetland work were given still higher priority.

Established monitoring groups also exist at a number of locations outside the United States: for example, the Canada Center for Inland Waters, Burlington, Ontario; the Experimental Lakes Area near Kenora, Ontario; and the acid precipitation and eutrophication monitoring groups in Norway and Sweden. Because many potential long-term ecological problems are international or even global in scope (e.g., pollution by acid precipitation or nuclear fallout), an attempt should be made to establish communication and standardization with such groups. In many cases, such international databanks would assist in interpretation of patterns observed at U.S. sites.

There are several large and/or unique aquatic resources in the United States that are of considerable economic and ecological value, even though they are outside or unrepresentative of major lake regions. Examples include the Great Lakes, Crater Lake, Great Salt Lake, and Lake Tahoe. These resources are of sufficient value to warrant monitoring programs in their own right. In general, their size and diversity call for a considerable commitment of resources to carry out even a minimum monitoring program.

In many cases, monitoring programs already under way could be coordinated with this network; but consideration should be given to applications for unique sites where no such programs exist. A modest program for the Laurentian Great Lakes is suggested as an example.

Wetlands. A selection of wetland sites for long-term monitoring can be based on vegetation and habitat categories, together with geographic considerations. Within or near a given site there should be wetlands of a broad range of salinity and of vegetation type. The range of sites should be geographically comprehensive, including all the major wetland regions of the United States, and perhaps a few other sites selected for their special or unique characteristics.

Most wetlands are receptors of stream flow or, in the case of salt marshes, are influenced by tidal flushing. Hence, it is important to integrate wetland studies with stream studies or with marine studies. Many other wetlands occupy lake margins, and integration with lake studies is important in these situations. Adjacent uplands, which provide input via stream flow. should be considered in any program of wetland monitoring.

Suggested Sites

Streams. The three best examples of sites with terrestrial-stream watershed studies under way are Hubbard Brook (New Hampshire), Andrews Experimental Forest (Oregon), and Coweeta (North Carolina). Each has a multidisciplinary program. At Hubbard Brook, data on many factors have been collected for nearly 15 years. At the Andrews site, considerable emphasis has been placed on the ecology of the stream systems themselves.

The River Continuum Group integrated network of study sites is an example of project with a database varying from 3 to 10 years. Included in the cooperative network, along with the Andrews Experimental Forest project, are the Salmon River (Idaho), a portion of the Kalamazoo River Basin (Michigan), and part of the Brandywine Basin (Pennsylvania). Recently, a watershed in the tallgrass prairie (Kansas) was proposed as an addition.

Both of the above-mentioned groups of sites deserve consideration for a pilot program of long-term monitoring. Three other sites, with ongoing programs smaller in scope and with interrupted periods of data collection, are Oak Ridge (Tennessee), Savannah River (South Carolina), and the Pymatuning Laboratory (Pennsylvania). A list of other possible sites for pilot monitoring is presented in Appendix C, table C-2.

Representative Lakes. None of the sites suggested here met all of the selection criteria, and it is acknowledged that better multipurpose locations may exist among sites not chosen or even among sites totally overlooked by this conference. A complete list of sites considered for inclusion appears in Table C-3.

Table C-3. In the following review of suggested sites, both advantages and disadvantages of these areas for pilot monitoring are discussed.

HUBBARD BROOK, NEW HAMPSHIRE--This site met more criteria than any other. It is representative of large areas of northern New England. Active terrestrial and aquatic programs have been underway since 1963, producing more than 250 publications. Hydrology, meteorology, and precipitation chemistry are well known. While there is no wetland area and only one freshwater lake at the site, there is a variety of stream habitats. Senior investigators from several institutions have ongoing work at the site, ensuring long-term stability and continuity. Personnel are well-equipped for most of the proposed monitoring. The site has good long-term protection and a history of associated experimental work.

ITASCA STATE PARK, MINNESOTA--This site has lakes of a variety of edaphic and morphometric types representative of calcareous regions of the Lake States, including varved, meromictic, mesotrophic, eutrophic, and dystrophic lakes. A considerable body of terrestrial and paleoecological data on the area has been collected, although contemporary limnological data are scattered. Though in a transition zone, it is one of several alternative sites selected for terrestrial monitoring. There is a variety of wetland and stream ecosystems, with some ecological background. An NSF-sponsored year-round laboratory exists at the site, run by the University of Minnesota. The site is well protected. On the negative side, most of the lakes at this site have considerable inputs or outputs from ground water, so that hydrological budgets may be difficult to obtain. Moreover, none of the lakes in the area represents the extreme softwater, oligotrophic end of the spectrum for glaciated regions.

TROUT LAKE AREA, WISCONSIN--Limnological data on a number of important variables were collected as many as 50 years ago by Birge and Juday. There are nearly 200 publications characterizing the area, and original data are well-categorized. Softwater lakes representative of glaciated areas are present in a variety of morphometric and edaphic types, and they are reasonably unaffected by acid precipitation. Oligotrophic, mesotrophic, dystrophic, and meromictic lakes are represented, as are various streams and wetlands. Some watersheds are protected; a few others are available for manipulation. The site is in a relatively unaffected softwater area ideal for studying effects of acid precipitation. A permanent NSF-sponsored laboratory is present. One drawback to the area as a monitoring site is that it has the same groundwater problems as Itasca. In addition, on many of the watersheds the forests have been logged.

KELLOGG BIOLOGICAL STATION, MICHIGAN--A well-established laboratory has studied lakes and streams of this area for a long period. Most of the required information indicated as required in this report is currently collected. Nearly 400 ecological publications are available, spanning a period of over 40 years. However, the lakes, at this site, with one exception, are calcareous and mesotrophic to eutrophic, with large seepage inputs. Various streams and some wetlands are present. While some watersheds are protected, they are in a transition zone and not considered to be representative of major terrestrial types. All are all second-growth.

Great Lakes. The following Great Lake stations are also suggested as possible sites for pilot monitoring:

LAKE SUPERIOR--One open-water station in western Lake Superior located in reasonably deep water (more than 200 meters) would be acceptable. The station might be serviced from the Bayfield region by the U.S. Fish and Wildlife Service Laboratory, which operates a research vessel out of Bayfield. Laboratory facilities exist at that laboratory and at the University of Wisconsin at Superior, the University of Minnesota at Duluth, and the EPA Water Quality Laboratory at Duluth. The Apostle Island National Lake Shore under the U.S. Park Service provides long-term protection for the islands and adjacent waters of the region.

LAKE MICHIGAN--Two open-water stations, one in the somewhat impacted southern basin and one in the more oligotrophic northern basin, would be advisable. These stations could be serviced from the University of Wisconsin Great Lakes Research Facility at Milwaukee. Vessels operated by the University of Wisconsin, the University of Michigan, and EPA are based at, or operate from, this facility. Both basins are accessible by these vessels. The University of- Wisconsin Research Facility is installed permanently at a year-round ice free port with adequate docks, laboratories, scientific staff, and excellent communication and transportation access.

LAKE ERIE--Monitoring might be carried out by two open-water stations, one in the shallow eutrophic western basin and one in the deeper eastern basin. These stations could be serviced from the Ohio State University laboratory at Put-in-Bay near Sandusky.

Vessels may be available from EPA and the NOAA Great Lakes Environmental Research Laboratory. Laboratory facilities and scientific staff might be obtained from Ohio State University, the EPA Grosse Isle Laboratory, and the NOAA Great Lakes Environmental Research Laboratory.

Wetlands. Wetland studies in the United States have focused chiefly on the salt marshes of the East Coast. Among freshwater wetlands, those of Minnesota have received a good deal of attention. The vegetation, hydrology, and water chemistry of prairie wetlands in Iowa and the Dakotas have been examined in some detail recently. The Everglades region has been the subject of many investigations, and other southeastern wetlands have also been studied. However, wetland ecology generally has been much less studied than terrestrial, freshwater, and marine ecology. On the basis of studies conducted thus far, it is difficult to choose one group of sites over another for inclusion in a monitoring network. It is anticipated that site selections will be based on the merits of proposals to conduct specific studies.

MEASUREMENT

Criteria

In general, the studies recommended here are aimed at measures that define conditions in successive years, so that changes over time can be followed on an annual basis over decades. However, it is readily apparent that sampling intervals must be determined by the parameters to be measured--in some cases, by turnover times of abiotic parameters; in others, by the sizes and life spans of organisms. The employment of sediment markers (such as radio-carbon, plutonium, the rise in Ambrosio pollen, or additions of relatively inert materials such as brick dust) can serve to calibrate the time-series implicit in the sedimentary record. In this connection, it will be necessary to pay attention to bioturbation and differential sorting of sediments. Cores already measured for some factors also need to be stored; in the future, other parameters may become important and require close correlation with the earlier measurements.

The need for standardization of measurement techniques is paramount. Historical records are much more useful when the data sets are homogeneous in terms of technique. Moreover, analysis of time series by sophisticated mathematical techniques is possible only if the data are standardized and of equal quality. In particular, the usefulness and adaptability of data for rigorous time-series analysis increases with the length of the series. Therefore, the concept of building a time series of data should be viewed as an investment in knowledge that grows much like a monetary investment whose value increases by compound interest.

Recommended Monitoring

Measurements will be needed to characterize climate and weather; watershed; hydrology; physical and chemical characteristics of water; biota; and historical records. These measurement needs are outlined below for watersheds with aquatic habitats, lakes, streams, and wetlands. Needs are further classified in terms of physical, chemical and biological measurements. It is recommended that a handbook of appropriate techniques used by the investigators in the network be compiled. The techniques should be approved and intercalibrated before adoption, and the handbook should be updated regularly.

TABLE 2--FRESH WATER MONITORING

I. Base Data
   A. Watershed
      1. Location-latitude, longitude. and altitude; political boundaries and jurisdiction.
      2. Degree of protection; e.g., wilderness area, national park, status of mineral rights, etc.
      3. Size (area).
      4. Contour map to show relief and watershed boundaries.

5. Soil parent materials--type, extent, and depth.
6. Underlying soil types--extent, development of humus layers, profile development.
7. Watershed cover--vegetation; fire history, pollution, and other disturbances. Documentation required through aerial photos, ground truth maps, documentary sources, and personal inquiry.
8. Historic and prehistoric records--documents, maps, photographs, tree rings, fire scars, personal inquiry, etc.

B. Streams

1. Stream order.
2. Relation to topography, soil parent material, soil type, vegetative cover, land use, human impact.
3. Relation to ongoing terrestrial, lake, and wetland studies.
4. Channel gradient and major channel woody debris. Once baseline is established, remapping at least after major flood years. A 100 to 1000 meter reach preferable.
5. Sediments--general mapping of distributions (point bars, etc.) at least every 2 to 3 years. Characterization of sediment composition and water color.
6. Riparian vegetation survey at least every 2 to 3 years.

C. Lakes

1. Bathymetric maps.
2. Shore and bottom types--physical features and littoral vegetation.
3. Inlets, outlets, and groundwater sources.
4. General Limnological Description:
   a. Thermal--temperature, mixis
   b. Trophic-water color, Secchi disk, chlorophyll concentration
   c. Chemical--classification on the basis of ionic composition and salinity.
5. Relation to topography, soil parent material, soil type, vegetation cover, land use, human impact.

D. Wetlands

1. Aerial photos--black and white, color, infrared.
2. Topographic map.
3. Topographic survey of mineral soil surface and peat surface, and of spring (high) and late summer (low) water table.
4. Vegetation survey.
5. Long soil and peat cores within major vegetation zones.

II. Monitoring Data

A. Physical	Streams	Lakes	Wetlands	Sampling Plan
1. Temperature				
a. Air	x	x	x	National Weather Service-- nearest station.
b. Water		x	x	Streams: weekly maximum and minimum. Lakes: profiles every 2 weeks in ice-free period and once in Feb. for several representative lakes. Lake center and deepest point, 1 meter intervals, 0.1 degree C accuracy.
c. Sediment	x	x	x	Soil surface; wetlands: profile in deepest peats twice a year.

d. Icecover x x x Date 90% covered, date
90% open; Lakes: thickness
in 5 places,
monthly, in several lakes.

e. Snow depth x x Lakes: 10 places at
random; monthly,
on several lakes; same
date as ice
measurements.
Wetlands: site-specific.

2. Precipitation x x x On site. by weight; daily
or weekly.

3. Humidity, wind, x x x National Weather
Service--nearest
weather data station; daily.

4. Hydrology
a. Water level x x Four a year,
including maximum and
minimum.
b. Discharge inlets x x x Continuous (possibly
daily) at
and outlets all streams and lakes,
if possible.

5. Solar radiation x x x U.S. Weather Service--nearest
station.
Streams: integrated
ozalid papers at
stream surface.

6. Water transparency x x x Secchi disk and
absorbance at
320-350 nm (on
filtered samples);
every two weeks.

7. Morphology x x x Streams: full channel
cross sections at
bench marked locations
once a year at
base flow.
Wetlands: high and low water
annually.
Lakes: aerial
photography-ca. every 5
years.

B. Chemical (Standards in E.L.A. Manual)

1. Specific conductance x x x Streams: site-specific
Lakes: profile every
3 years, late
summer.
Wetlands: site-specific.

2. Major ions (Ca, Mg, x x x Streams: base flow and
high stage of
Cl, Si, S04, Al, Fe, hydrograph.
Mn) Lakes: every 3 years,
fall overturn.
Wetlands: every 3 years.

3. Total P, total acid by x x x Streams: 2
gran titration, Lakes: spring and
fall overturn and alkalinity,

dissolved inorganic summer and
winter stratification.
carbon, pH Wetlands: site specific.

4. DOC, POC, NO3, K x x x Streams: 2
Lakes: site-specific.
Wetlands: site-specific.

5. Sedimentation x x x Streams: once a year
in settling

basins.
Lakes: site-specific.
Wetlands: site specific.

6. Water sample x x x Use 0.45 um filter
and freeze both

water and filter.
Streams: base level and

high-stage.

Lakes: spring and

fall overturn.

7. Precipitation x x x See terrestrial.

C. Biological

1. Phytoplankton and x x x Streams: (large rivers
only) site
chlorophyll a, specific.
numerical density Lakes:
Integrating epilimnion tube;
and species sample spring
composition and fall overturn;
summer and winter

stratification, preserve

in Lugol and

formaldehyde. Samples should
represent

replicated composites of the

open lake. Store samples.

2. Zooplankton, x x x Streams: (large rivers
only) site-
numerical density specific.
and species Lakes:
Integrating epilimnion tube
composition sampler using a 70 um
mesh; spring

and fall overturn,

summer and winter

stratification. Kill and

fix in buffered

3% formaldehyde. Store active
portion in alcohol

and glycerol.

Create a

composited, replicated

sample.

3. Benthos, numerical x x x Streams: fall-winter
and spring-
density and species summer.
composition Lakes: February
profundal, multiple

cores or grabs,

composited replicate

samples. Littoral

zone: intensive

survey every 5 years,
site-specific.
Preserve in formaldehyde
and store in
alcohol.
Wetland: site-specific.

4. Periphyton species, x x x Streams: scrapings or
tiles or slides,
composition, winter-spring and
summer-fall;
chlorophyll a site-specific.
Lakes and Wetlands:
site-specific.
Preserve as
for phytoplankton.

5. Macrophytes, species x x x Streams: every 3 years,
late summer
composition, cover, harvest; mapping,
site-specific.
biomass Lakes and Wetlands: every
3 years,
photomapping and
harvest; biomass
estimates, site-
specific. Store dry
herbarium specimens.

6. Fish, species x x x Streams: annual sampling by
composition, electrofishing,
site-specific.
size frequency x x Lakes: annual sampling
mid-summer
using a variety of gear-
site-specific;
e.g., fyke net,
boom shocker, vertical
gill net, minnow
traps, seining,
diving survey.
Preserve subsamples in
5% formal-
dehyde with borax;
freeze small
subsample of
predators' muscle and
liver with gall
bladder intact.

7. Birds, mammals, x x x Streams, Lakes
amphibians, species Wetlands. site-
specific studies.
and numbers

8. Genetic structure x x x Encourage
population genetics studies
of aquatic organisms
(site-specific).

9. Paleoecology x Encourage
population genetics studies
of aquatic organisms
(site-specific).
Encourage
paleolimnology study at
site. Best storage is in
the lake bottom
or peat until needed.

10. Wetland biota x See following description.

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1. The x's indicate where measurements are recommended.

2. Characterizing the chemistry of streamwater may present a unique sampling problem. The chemical concentration of an element may or may not be influenced by streamflow. If there is a direct relationship between streamflow and chemical concentration, samples must be taken as streamflow changes. An alternative is to use a proportional sampler, which must be used in conjunction with some sort of gauging mechanism. If chemical concentration is not strongly affected by streamflow, it is acceptable to sample on a routine basis; the frequency would be a function of the variation in the concentration. At a minimum, samples should be taken once each month.

Wetland Biota--Measurement Needs:

Floristic composition, to be studied seasonally in fixed plots, including tree mapping and diameter and height measurements.

Vegetation composition in fixed plots.

a. Biomass harvest above and below ground at peak standing crop.
b. Leaf area of major tree species, once or more a year.
c. Counts and sizes of major species through the growing season.

Phenology of common species.

a. Dates of bud-break.
b. Dates of vegetative shoot emergence.
c. Dates of flowering (choose species flowering at all possible seasons).
d. Cessation of growth (where possible).
e. Leaf senescence (color change) and fall.

Animal population censuses (for resident species and perhaps for migrants also).

a. Aquatic invertebrates (including those in water and in soils and peats)
b. Insects--sitting--flying
c. Amphibians
d. Small mammals
e. Large mammals
f. Birds

Soils and peats--short (20 cm) cores for chemical analysis (organic, carbonate, and clastic fractions; cation exchange capacity; exchangeable cations; total N; total P) at intervals of a few years.

N.B.: Samples of selected plants, animals, and soils or peats should be stored for future analytic needs.

MARINE SECTION

Habitat Selection

Criteria

All the habitats and sites discussed herein are coastal. They encompass such overlapping categories as salt marshes, estuaries, intertidal and subtidal rocky and soft substrata, and coral reefs. Because of the limited time available to prepare this report, continental shelf and open ocean sites have not been included, but this is not to imply that they are less important than other marine habitats for ecological study.

Priority was given to areas involving several habitat types whenever possible, not only because adjacent systems can be monitored from one station, but also because it is important to study the close relationships that exist among neighboring areas in coastal waters.

It was felt that areas with very high variability should be avoided, because there is little hope of unraveling the causal relations involved. Moreover, the limited resources available for monitoring argue for. selection of areas where major short-term fluctuations are expected to be minimal. Although some disturbed areas are mentioned, the focus is on areas where the long-term prospects for serious man-induced alterations appear low. Sandy beaches were excluded because of their inherent instability; highly polluted estuaries, because of man-induced instability.

The choices of habitats and specific sites reflect the biases of the conference participants and should be considered merely as examples of areas where the potential for contributions to ecological theory seems maximal. It is expected that the final selections of both habitats and sites will be based on consideration of proposals to conduct specific monitoring projects.

Choice of Habitats

Coral Reefs

Coral reefs are large, nonequilibrium, biogenic land forms. They contribute to geophysical and geochemical processes on a global scale. Biologically, they are centers of high productivity and constitute a diverse and ecologically complex species assemblage. Coral reefs have historically concerned ecologists especially in connection with problems of growth, productivity, and community structure, but little is known about long-term fluctuations and trends in these areas, or about the eventual effects of specific interactions that have been observed in them.

An understanding of sequential changes occurring in coral reefs may be obtained through a two-pronged approach involving long-term observations and retrospective measurements of individual coral growth rates and reef history (available from data on cores). Such an approach would help to establish contrasts regionally and between Caribbean and Indo-Pacific faunas.

Hard Rock Coastal Areas. North American rocky intertidal areas have been shown to be particularly useful for long-term studies to answer fundamental biological questions. Thus, preservation of such areas is important not only for aesthetic and conservation reasons, but for basic scientific research as well.

Long-term study of the structure of the intertidal community in terms of the distribution. abundance, size, and diversity of its organisms may help us to understand the organizing forces present. Experimental tests of hypotheses based on short-term observations have yielded valuable information about general ecological processes and principles. However, short-term studies reveal little about long-term stability properties of the system, either with regard to the persistence of populations at a given location over time or the response of the system to perturbations. A number of ecological and evolutionary questions concerning populations, communities, and ecosystems cannot be answered without such information.

Rocky subtidal areas are also ecologically important but are more difficult to study. Important interactions occur between rocky shores and adjacent soft sediment areas, and these interactions should be addressed in the proposed research.

Soft Bottom Coastal Areas. The shallow subtidal marine soft bottom adjacent to the shore is important in its own right as a zone of relative physical and biological stability. The spatial and temporal homogeneity of many undisturbed shallow-water benthic sites make them excellent candidates for long-term monitoring. Studies of benthic habitats can provide data to test hypotheses regarding shifts in community structure in other environments. Species composition and abundance in soft sediment areas provide clues about the cumulative effect of environmental influences. These areas are often contaminated by chemical waste, and they can thus serve as sensitive indicators of anthropogenically caused changes in marine systems. At a number of locations on both the east and west coasts, this type of habitat has been the subject of past study, including several long-term investigations. An area representative of this habitat type should, therefore, be included in the pilot program.

Salt Marshes/Estuaries. Salt marsh/estuarine ecosystems are important sites of coastal productivity and nutrient cycling, and they serve as nursery habitats for marine coastal fishes. They are relatively simple systems, especially in their intertidal areas, and are readily accessible (from the air and from the surface). Over the last 20 years, the interactions of flora, fauna. chemical, and physical environmental factors in salt marshes/estuaries have been studied extensively at a few sites on U.S. coasts.

Site Selection

Criteria

The ideal monitoring site would have a long history of research, and data would be available on the target habitats as well as adjacent ones. The presence of a scientific institution with an active, ongoing research program in ecology would be highly desirable. The area should be assured of long-term protection to the greatest degree possible, i.e., be publicly or privately owned and dedicated to conservation and research. Since the pilot program will include only a limited number of sites, those areas with more than one type of environment are the most desirable, but they should not be so variable as to obscure causal relations. For similar reasons, areas with major short-term fluctuations should be avoided.

Suggested Sites

From a list of several dozen site candidates (See Appendix E), three sites were chosen: the coral reef at Palau; the rocky intertidal, rocky and soft-bottom subtidal areas at Monterey Bay; and the salt marshes and estuaries at Sapelo Island.

Coral Reef--Palau. A primary site, ideal for faunal contrasts, should be located in the midst of the Indo-Pacific faunal distribution and should be relatively free from major cyclonic activity. Human disturbances should be minimal, if possible, yet the area should be readily accessible. No single site appears to meet all the optimal criteria. However, Palau was selected because of its central location in the Indo-Pacific, the early research done there, the fact that it is under U.S. jurisdiction and served by an airline, and its reputation as an undisturbed area.

Rocky Intertidal, Rocky and Soft-bottom Subtidal--Monterey Bay. Monterey Bay has, within a limited geographic area, several well-developed, representative habitats worthy of intensive long-term study: rocky intertidal habitats, rocky subtidal habitats, kelp beds, and soft-bottom benthic habitats. These habitats have been the subject of studies carried out, at least intermittently, for several decades. Several institutions in the immediate area, with ongoing research programs, either are now conducting or could easily undertake long-term ecological measurements in these habitats and in the adjacent Elkhorn Slough. These institutions are the University of California at Santa Cruz, the Moss Landing Marine Laboratories (a laboratory operated by a consortium of California State Universities), and Stanford University's Hopkins Marine Station. Several State and Federal agencies are similarly concerned with fisheries and marine mammals in these habitats.

Among the investigations now underway are: long-term studies of water chemistry and circulation in Monterey Bay and vicinity; studies of population dynamics of rocky intertidal and subtidal invertebrates, particularly sea-urchins and abalone, which are important both in the structuring of rocky substratum communities as browsers and as the subject of commercial exploitation; a study of benthic (soft bottom) animal life histories, especially for the development of methods specifically for use in detecting man's influence on this habitat. Obviously, understanding biological processes in each of these habitats is important.

Salt Marshes and Estuaries--Sapelo Island. Sapelo Island seems ideal in many ways. The marshes surrounding the tidal Duplin River and the islands bordering them are permanently protected by State ownership and designated as an estuarine sanctuary of wildlife and research areas. Studies of the salt marshes and associated estuaries there have been underway since the early 1950's. There have been several studies of marsh primary productivity, including one which calibrated aerial photography for use in measuring production and vascular plant distribution. There have also been numerous descriptive and experimental studies of marsh and estuarine system structure and function during this period. Research has been done on near-by environments (beaches, the near shore benthic system), which would provide background data for study of exchanges.

The University of Georgia maintains a laboratory on the island with an active research program closely associated with the staff of the main campus at Athens.

Measurement

Long-term monitoring in the marine environment requires that specific measurement techniques be applied to particular habitats. It should be emphasized, however, that even simple techniques if systematically applied over a sustained period will yield valuable data. Such techniques presuppose definitive, repeatable observations at plots and locations specifically marked for positive long-term identification. For example, hard substrates, (coral reefs or rocky habitats) should be identified with site markers and documented by aerial photography.

In view of the limited resources and scale of the pilot project, minimal sampling in the selected habitats is suggested. Some important measurements, such as periodic inventory of all benthic and planktonic species, have been omitted because of the difficulty of obtaining accurate identifications and because of the limited availability of qualified taxonomic specialists. Suggested measurements of each of the three selected habitats are outlined below.

Coral Reefs

Desirable physical data would include standard meteorological information and local tide recording, complemented by continuous monitoring of temperature, salinity, light penetration, suspended matter, etc. Other data needs would depend on local features and cannot be prescribed in great detail here. Sampling is required for such contrasting areas as windward and leeward sides of the reef, reef crest and slope, reef flat, lagoon, etc. In accessible reef areas, sampling should be done at intervals of 5 meters to a depth of at least 20 meters. Observations on sedimentation and erosion are needed annually and after storm events.

Ideally, stereo photographs of surface areas of 1 square meter should be repeated each year, with approximately four replicate plots in each area to be sampled. This approach facilitates estimates of recruitment, growth, and mortality. All sessile organisms should be identified and matched with voucher specimens. Line transects of 30 meter length at 5-meter depth intervals should be recorded once a year. Some attention could be given to measurements and observations on individual large coral heads. Destructive sampling must be avoided in such plots.

Initially, and at 10-year intervals thereafter, more comprehensive surveys of major groups of organisms should be conducted. The primary criterion for inclusion of a group is the potential for adequate and consistent treatment. Part of such a survey might include attaching 50 x 50 centimeter opaque artificial surfaces to the reef for measurements of recruitment and density estimates of cryptozoic organisms. The survey may require a whole year to describe seasonal changes. Density estimates, obtained with documented techniques, are very valuable, even when they seem accompanied by large sampling errors. In some cases, nearest-neighbor distances may provide the simplest means to estimate density (groups to be included, for example: macroalgae, echinodermata, mollusca, coelenterata, sponges, fishes, macrocrustacea).

Aerial photography for the region as a whole can provide general information on gross topography, algal and coral cover, etc. This type of aerial survey should be conducted at 10-year intervals, if possible.

The systematics of most of the organisms to be monitored are subject to change, and it is imperative that specimens be submitted to experts in each taxonomic group. Small collections of all species observed locally should be carefully curated. At 6-month intervals, three single specimens of Tridocna or of other filter-feeding molluscs (100-500 grams of soft tissue) should be collected, frozen, and maintained at less than -20~ C. Hard parts should also be stored. This inventory will permit retrospective estimates of many chemical contaminants.

Rocky Intertidal and Subtidal Areas

Physical information required for long-term studies in rocky habitats is principally meteorological: wind speed, wind direction, air temperature, water temperature. number of hours of sunshine, precipitation, and wave stress. But this information is valuable only when taken in conjunction with two general types of biological information:

(1) A photographic record of selected areas. This record, based on annual surveys, should include high-resolution, color-reversal infrared photographs taken from the air, as well as ground photographs. The recorded data will provide an estimate of coverage and patch sizes of various algal genera and other space holders.

(2) Annual quantification of patterns of space occupation, abundance, and size of spatial dominants, as well as selected information on predators and herbivores. Studies addressing the intensity and timing of recruitment could be based, in many instances, on photographic censuses of 1 square meter plots. General information on recruitment rates of the major space holders, such as barnacles, mussels, and dominant algae, can be obtained via panels and denuded areas.

In rocky subtidal areas, photographs should be made monthly of quadruplicate plots measuring 1/10 meter square at 5-meter depth intervals. Species should be identified and recorded at the time the photographs are taken.

Soft Bottom Habitats

Long-term monitoring of soft bottom habitats requires seasonal sampling. At least three replicate samples measuring 1/25 meter square should be taken at each site. The sites should be representative of relatively homogeneous areas so that variability among replicates is small, limited to variability within the assemblage. The organisms must be collected on a screen mesh small enough to retain all the individuals of the major taxa, such as polychaetes, molluscs, crustaceans, etc.

Biological measurement data should include the composition. abundance, and population size and structure of the dominant species. In addition. estimates should be made of fecundity and recruitment, either through larval sampling, studies of gonad development (histological examination; egg, sperm, or brood counts). or studies of defaunated and/or caged sediments. It is suggested that these measurements be made twice a year at 5-year intervals.

Patterns in recruitment may reflect patterns in water chemistry and fertility. Therefore. it is important to measure temperature, salinity, oxygen concentration, suspended particle concentration, and fluorescence (if possible) both at the sampling location and at stations along the axis of major current movement in the area. These measures should be made at various depths to within 1 meter of the bottom in order to map the variables in both vertical and horizontal dimensions.

Because benthic organisms are sensitive to the texture (particle size) of bottom sediments, patterns in shifts of sediment texture (cycles or trends) must be detected and described. Sediment cores should be collected annually, or more often if seasonal patterns in deposition are pronounced, from locations where the sediment surface appears least disturbed. Particle size distributions should be determined from sediments at the top of the core sample, in the zone of bioturbation, and perhaps from subsurface seasonal or annual layers or varves (if they exist). Additional core samples should be frozen and stored for later analysis of trace contaminants.

The influence of predation by larger, less common animals should also be examined. These species might include large invertebrates such as starfish not collected in the above-mentioned sampling, as well as sharks, rays, etc. Determining important changes in predation may help to explain possible shifts in benthic community structure not associated with the physical environment. Such an examination may be possible only if fishery-related studies are being conducted simultaneously in the same vicinity.

Salt Marshes and Estuaries

Aerial photographic surveys should be made annually with infrared color reversal film to determine the distribution of dominant marsh plants, principally the grasses. and to estimate their productivity. A scale in the range of 1/5,000 to 1/10,000 seems most appropriate. The photographs should be calibrated on the basis of ground measurements of biomass made at 2-week intervals during the 6 weeks of maximum standing crop. For maximum information content, the serial photographic record would be made on a calm, clear day at low tide.

These pictures would also provide data on the positions and sizes of large aggregations of sessile animals, such as oysters and mussels, and on changes in marsh size and topography. If possible, another series of photographs should be taken earlier in the year, after winter snow and ice have gone but before grass growth has hidden the ground. This series would provide clues as to how sand deposition, ice rafting, and other such factors contribute to the changes in topography and productivity that appear on the summer series.

The study should include aerial surveys of the other intensively studied marshes along the coast. Ongoing studies at other marshes would provide the necessary ground truth and associated data.

Every 5 years a detailed survey of fauna should be made to see how changes in plant cover and production have affected the higher trophic levels in the marsh. These surveys extend down into the intertidal flats and estuarine bottom, and they should include sand flats, mud flats, creek banks, streamside marshes, and low and high marshes. Plots measuring 3 x 3 meters should be set out in triplicate within each habitat in fairly uniform areas. Within each plot, two or three samples measuring 1/10 meter square would be used to collect data on large macrofauna such as fiddler crabs, mussels, and large burrowing polychaetes. The actual distribution and number of plots and samples would be determined by survey and should encompass the natural and spatial variations of the environment. Faunal counts and weights would be determined, along with measurements of particle size and water content of the sediment.

Samples should be stored for future reference and study of pollutants-hydrocarbons, heavy metals, etc. Core samples must be large enough so as not to be affected by the coring device itself. They should be handled carefully to prevent contamination, frozen quickly, and thawed only when ready for analysis.

A periodic sampling of fishes is highly desirable and might be accomplished easily by netting a creek at high tide and collecting the individuals caught during the ebb. A 1l4-inch mesh would be suitable. The data set should include at least a list of the species and some indication of their relative abundance.

One process measurement is recommended--a survey of nitrogen fixation. Every 5 years, cores 15 centimeters in diameter and 10 centimeters deep should be collected and analyzed by acetylene reduction measured at 2-centimeter intervals. Ten replicates from all regularly flooded marsh types are suggested. Since fixation of surface algae and bacteria associated with the rhizosphere of the grasses is sensitive to the availability of fixed nitrogen, the survey should provide an integrated measure of the presence of this limiting nutrient in estuarine areas, as well as a measure of nutrient input from pollution sources.

Surveys in the estuarine part of the system should include standard physical and chemical measures of temperature, salinity, turbidity, light penetration, plant nutrients, and chlorophyll. These measurements should be made over several tidal cycles once each season to provide an estimate of the variation in conditions over short time intervals.

APPENDIX A

Notes Regarding the Need for Integrated Long-Term Monitoring of Interactions Among Ecosystems

Overview

In recent years, there has been an increase of interest in the linkages among ecosystems, particularly in the interactions between terrestrial and aquatic systems (Likens and Bormann 1974, Hasler 1975). Such linkages are most readily apparent in organisms, especially insects and amphibians, that spend different parts of their life cycles on land and in the water. Energy transfers may be of even greater importance, as in streams whose primary energy stems from terrestrial leaf detritus and whose ecosystem metabolism is essentially heterotrophic (Hynes 1975). Chemical budgets are also greatly influenced by ecosystem interactions in some areas, for example where the weathering of upland soils provides the major nutrient input to oligotrophic wetlands, streams, and lakes (Schindler et al. 1976), or where sea spray adds salts to terrestrial and wetland ecosystems (Gorham 1958, 1961). Also important is the transport of toxic substances (e.g., acids, heavy metals, biocides) from upland to wetland and aquatic ecosystems via runoff and ground-water flow; some of these substances may be transferred back again to the uplands, as in the global distillation of mercury and DDT from aquatic habitats to the land via the atmosphere (Wood 1974, Goldberg 1975).

All of the above-mentioned ecosystem interactions should be monitored. It is apparent that primary succession in natural ecosystems will inevitably be greatly affected by interactions with other ecosystems. Moreover, in ecosystems altered by man, secondary succession will be similarly influenced. Only long-term monitoring can reveal important interactions among ecosystems and their response to natural changes in the environment or to stress induced by man's activities. Such monitoring of ecosystem interactions can best be accomplished by integrated studies of watersheds containing a diversity of terrestrial communities, streams, wetlands, lakes, and (in some situations) coastal estuarine and inshore marine communities. At the same time, proper attention must be given to atmospheric interactions with watersheds. In some situations it will be important to choose sites in transition zones, such as between forest and prairie, or between areas strongly influenced by regional atmospheric pollution (e.g., acid rain or heavy-metal fallout) and those only slightly affected by it.

To highlight the need for integrated monitoring of terrestrial, wetland, and aquatic communities, a sample of specific questions is presented below.

1. Do climatic fluctuations affect terrestrial, wetland, and aquatic ecosystems in different ways and/or at different rates; and how do such ecosystems interact in response? How is microclimatology affected in the different ecosystems? How is the hydrologic budget affected?

2. How does terrestrial succession (for example, in recently deglaciated or burned sites) influence hydrologic and chemical budgets, as well as biotic succession, in associated wetlands, streams, and lakes?

3. What is the role of upland inputs. via rivers and streams, in the development and functioning of estuarine ecosystems? What is the role of tidal flushing from the open sea?

4. What is the significance of dustfall from cultivated lands, especially prairies, as a nutrient source for adjacent terrestrial, wetland, and aquatic ecosystems, particularly those that are extremely oligotrophic (such as Sphagnum bogs)?

5. How important are the associated wetland and aquatic ecosystems for upland animals, particularly those that move freely from one system to another (e.g., moose, birds)? How does succession alter the utilization of such habitats by animals and influence their population dynamics?

6. Do acid rain and its associated toxins (heavy metals and aromatic hydrocarbons) and nutrients (nitrogen, phosphorus) affect terrestrial, wetland, and aquatic ecosystems in different ways and/or at different rates? How do these systems interact in their response to such stresses?

7. Do the patterns and rates of accumulation of toxins (radioactive fallout, biocides, heavy metals) differ in terrestrial, wetland, and aquatic habitats? If so, how do such differences affect ecosystem structure, function, development, and interaction?

Criteria for Site Selection

In the process of selecting sites where integrated monitoring of interacting ecosystems can be most rewarding, several rather diverse criteria must be applied. The following characteristics are regarded as highly desirable:

1. The presence of a broad range of interacting terrestrial, wetland, and aquatic ecosystems, with a lake (or the ocean) as the terminal receptor.

2. A substantial record of past study and research in the area.

3. Good facilities in close proximity to the site, together with an active program of study and research by qualified scientists.

Secondary criteria may be both numerous and diverse, depending on the questions to be addressed. A few examples will illustrate this point:

1. A site should lie in a transition zone for the major variable under investigation. so that changes will be readily and rapidly apparent.

2. Sites should include relatively natural (baseline) ecosystems, as well as those impacted by man.

3. The area should be such that it is possible to construct an adequate hydrological budget, which is prerequisite to constructing accurate chemical budgets of nutrients or toxins. This objective can best be

attained in rock basins, although some drift basins can be budgeted less accurately (and at much greater expense).

4. Lakes serving as terminal receptors should have anoxic bottom waters in summer and winter, or (best of all) be meromictic, thus favoring preservation of a fossil record in the profundal sediments. Varved sediments are of particular value because they can be dated accurately.

APPENDIX B

Terrestrial Sites

Rationale for Selection of Potential Sites

The following criteria were used to select the sites given in Tables B-1 and B-2.

The Man and the Biosphere (MAB) program is an international effort to study the relationship between man and his environment. In the United States, MAB has been divided into 14 projects, all of which may profit from long-term ecological monitoring. At present, 28 Biosphere Reserves have been established, and they represent many of the major biogeographical zones in the United States.

During the second Conference on Long Term Ecological Measurements, the Biosphere Reserves were identified as probable sites for long-term monitoring and many are suggested as initial example sites in this report (see Terrestrial Section).

At the Great Smoky Mountain National Park Biosphere Reserve, a project jointly sponsored by the National Park Service and Environmental Protection Agency, is currently underway to monitor air and water quality.

MAB planners feel that research should be funded on these Biosphere Reserves and that there should be common measurements on all the sites. Therefore, these Biosphere Reserves are prime locations for long-term ecological monitoring and for associated collaborative research.

Although the concept of a monitoring network that provides at least one site for each major vegetation type seems sound, it should not be regarded as an end point. Such a network provides the basic framework for answering long-term ecological questions on a nationwide scale, but it does not encompass all such questions of interest to biologists. The following comments are intended to establish a principle for adding to the basic network wherever possible and to suggest a rationale for such additions.

Neither transition zones nor ecotones are covered by the primary network even though they represent large land areas. These areas present interesting ecological questions in their own right. For example, a small change in environmental conditions is more likely to cause an observable change in plant and animal distribution in these than in other areas, because most of the resident species are approaching their distributional limits. Sampling in the center of a major ecosystem type finds most species well within their range (and therefore their ecological tolerance limits) and much less apt to show a response to a small environmental change. This phenomenon enhances the utility of transition zones for detecting subtle long-term ecological trends. Furthermore, transition zones often have characteristic species adapted specifically to the transitional conditions. Because of the ecological variability of these zones, such species tend to be less dependent upon community structure for protection from environmental extremes and more reliant upon their own adaptive complexes.

A number of unique sites of limited size may be worthy of inclusion in the network simply because of past research records or special biological characteristics. These may include habitats within

Experimental Ecological Reserves, National Environmental Research Parks, and other research sites receiving considerable attention from ecologists. There may also be utility in achieving correspondence between aquatic and terrestrial sites.

Other special situations can make long-term measurements particularly useful. For example, sites lying in the drift -path of pollution sources or subject to grazing or logging histories would be especially critical to understanding the impacts of man's activities. Additional monitoring sites could be established in areas currently or potentially affected by major human influence. These, in the long run, may greatly improve our ability to predict and appraise the ecological effects of man's activities.

Tables B-1 and B-2 represent two possible bases for selection of terrestrial sites. Both are based on recognized and accepted classifications, that provide a rationale for selecting representative sites across the United States.

Bailey's classification is the more generally used, but the FRES classification offers greater refinement. If only a few sites can be chosen, the Bailey classification would be appropriate; if a greater number of sites can be funded, then the FRES system would be preferable.

TABLE B-1. Potential monitoring sites for the major terrestrial ecosystems, as modified from Bailey's Second Order Ecoregions. (Bailey, 1976)

ECOSYSTEMS	SITE
Tundra	Naval Arctic Research Laboratory
	Niwot Ridge (Mountain Research Laboratory)
Boreal forest	Mt. McKinley National Park
Pacific Northwest coniferous forest	Young Bay Experimental Forest
	Coram Experimental Forest
	H.J. Andrews Experimental Forest
	Wind River Experimental Forest
	Cascade Head Experimental Forest
	Stanislaus-Tuolumne Experimental Forest
	Mt. Rainier National Park
	Olympia National Park
	Sequoia Kings Canyon National Park
	Three Sisters Wilderness
	Friday Harbor Laboratory
	Hopland Field Station
California (Mediterranean) forest	San Dimas Experimental Forest
	Hastings Reservation
	Sierra Ancha Experimental Forest
	San Joaquin Experimental Range
	Channel Islands National Monument
	Jasper Ridge Biological Reserve
Northern desert	Arid Lands Ecology Reservation
	U.S. Sheep Experiment Station
	Nevada Test Site
	Desert Experimental Range
Southern desert	Big Bend National Park
	Organ Pipe Cactus National Monument
	Desert Experimental Range
	Boyd Deep Canyon Research Station
	Boyce Thompson Southwestern Arboretum

	The Research Ranch
	Jornada Experimental Range
	Santa Rita Experimental Range
Rocky Mountain forests and range	Coram Experimental Forest
	Fraser Experimental Forest
	Manitou Experimental Forest
	Priest River Experimental Forest
	Glacier National Park
	Rocky Mountain National Park
	Onion Creek Experimental Forest
	Sierra Ancha Experimental Forest
	Los Alamos Environmental Research Park
Short grass prairie	Central Plains Experimental Range
	Theodore Roosevelt National Monument
Mid-grass prairie	Southern Plains Experimental Range
Tall grass prairie	Konza Prairie
	Wichita Wildlife Refuge
	Welder Wildlife Refuge
	Oakville Prairie
Northeastern forest	Hubbard Brook Experimental Forest
	Heart's Content Experimental Forest
	McCormick Experimental Forest
	University of Notre Dame Experimental Research Center
	Huntington Wildlife Forestry Station
	Isle Royale National Park
	Harvard Forest
	Lake Itasca Forestry and Biological Station
	University of Michigan Biological Station
	Kellogg Biological Station
	Central Forest Great Smoky Mountains National Park
	Coweeta Hydrologic Laboratory
	Oak Ridge National Environmental
Research Park	
	Cedar Creek National History Area
	Tyson Research Center/Arboretum and Nature Reserve
	Argonne Experimental Forest
	Fernow Experimental Forest
	Heart's Content Experimental Forest
Southeastern forests	Tall Timbers Research Station
	Savannah River Environmental Research Park
	Duke Forest
	Clemson Experimental Forest
	Hobcaw Barony
	Archbold Biological Station
	Gaylord Memorial Laboratory
	University of Georgia Marine Institute
Tropical Forest	Barro Colorado Island
	La Selva Field Station
	Monteverde Cloud Forest Preserve
	Luquillo Experimental Forest
	Virgin Islands National Park
Tropical Savannah	Everglades National Park
	Parque National Palo Verde

TABLE B-2. Potential sites for terrestrial monitoring, arranged according to Forest-Range Environmental Study (FRES) ecosystems (excluding Alaska and tropical sites).

ECOSYSTEMS	SITES
White-red-jack pine	Lake Itasca Forestry and Biological Station
Spruce-fir	McCormick Experimental Forest Argonne Experimental Forest Hubbard Brook Experimental Forest
Longleaf-slash pine	Everglade National Park Archbold Biological Station Tall Timbers Research Station Savannah River Environmental Research Park
Loblolly-shortleaf pine	Brookhaven National Laboratory Duke Forest Clemson Experimental Forest Savannah River Experimental Research Park
Oak-pine	Duke Forest Clemson Experimental Forest Savannah River Experimental Research Park Archbold Biological Station Tall Timbers Research Station
Oak-hickory	Cedar Creek Natural History Area Kellogg Biological Station Tallahatchie Experimental Forest Tyson Research Center/Arboretum and Nature Reserve Coweeta Hydrologic Laboratory Oak Ridge Environmental Research Park Heart's Content Experimental Forest
Oak-gum-cypress	University of Georgia Marine Institute Gaylord Memorial Laboratory
Elm-ash-cottonwood	No site yet identified
Maple-beech-birch	Coweeta Experimental Forest Great Smoky Mountain National Park Harvard Forest Isle Royale National Park Hubbard Brook Experimental Forest Lake Itasca Forestry and Biological Station Fernow Experimental Forest University of Michigan Biological Station McCormick Experimental Forest University of Notre Dame Environmental Research Center Huntington Wildlife Forestry Station
Aspen-birch	Univ. of Michigan Biological Station Hubbard Brook Experimental Forest McCormick Experimental Forest University of Notre Dame Environmental Research Center Huntington Wildlife and Forestry Station
Douglas fir	Coram Experimental Forest Yellowstone National Park H.J. Andrews Experimental Forest Friday Harbor Laboratory Hopland Field Station Mt. Rainier National Park Olympic National Park
Ponderosa pine	Onion Creek Experimental Forest Starkey Experimental Forest Pringle Falls Experimental Forest Los Alamos Environmental Research Park

	Sierra Ancha Experimental Forest Rocky Mountain National Park Glacier National Park Manitou Experimental Forest
Western white pine	Priest River Experimental Forest
Fir-spruce	Fraser Experimental Forest Glacier National Park Rocky Mountain National Park Stanislaus-Tuolumne Experimental Forest Three Sisters Wilderness Wind River Experimental Forest H.J. Andrews Experimental Forest Mt. Rainier National Park Olympic National Park Findley Lake
Hemlock-sitka spruce	Cascade Head Experimental Forest Olympic National Park
Larch	Starkey Experimental Forest
Lodgepole pine	Mountain Research Station Rocky Mountain National Park Manitou Experimental Forest
Redwood	Sequoia and Kings Canyon National Park
Western hardwoods	San Dimas Experimental Forest
Sagebrush	Desert Experimental Range Nevada Test Site Arid Land Ecology Reservation U.S. Sheep Experimental Station
Desert shrub	Big Bend National Park Organ Pipe Cactus National Monument Nevada Test Site Desert Experimental Range Boyd Deep Canyon Research Station Boyce Thompson Southwestern Arboretum The Research Ranch
Shinnery	No site yet identified
Texas Savannah	No site yet identified
Southwestern shrub-steppe	Jornada Experimental Range Santa Rita Experimental Range
Chaparral-mountain shrub	Channel Island National Monument The Research Ranch Sierra Ancha Experimental Forest San Dimas Experimental Forest Davis County Experimental Watershed Hastings Reservation
Juniper	Nevada Test Site
Mountain grasslands	Starkey Experimental Forest Fort Stanton Research Station
Mountain meadows	No site yet identified
Plains grasslands	Central Plains Experimental Range Theodore Roosevelt National Monument
Prairie	Southern Plains Experimental Range Konza Prairie

	Welder Wildlife Foundation Wichita Wildlife Refuge Oakville Prairie
Desert grasslands	No site yet identified
Wet grasslands	Hobcaw Barony
Annual grasslands	San Joaquin Experimental Range Jasper Ridge Biological Reserve
Alpine	Fraser Experimental Forest Glacier National Park
Tundra	Aleutian Island National Wildlife Range Niwot Ridge Naval Arctic Research Laboratory
Brooks Range	No site yet identified
Yukon	No site yet identified
Alaska Range	Mt. McKinley Park
Tropical	Luquillo Experimental Forest Virgin Islands National Park Barro Colorado Island Monteverde Cloud Forest Preserve La Selva Field Station

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APPENDIX C

Freshwater Habitats

Tables C-1 through C-3 supplement the discussion of aquatic sites in Part II of this report. It should also be noted that there is a variety of wetland types that might be included in a monitoring program. These include communities dominated by: reeds, cattails and bulrushes; Sedges, grasses and rushes; shrubs; trees; sphagnum moss. It would be desirable to monitor each of these in dilute, concentrated and saline waters.

TABLE C-1. Major Stream Sites for Suggested Long-Term Ecological Monitoring

Sites	Cooperators	Approx. Years of Data	Protection	Stream Orders Studied	Manpower (plus cooperator)
Hubbard Brook	Cornell U./Yale U.	15	Protected (USFS)	1-3	Staff, students technicians, visiting scientists
Andrews Forest (USFS) (McKenzie R) *	Oregon State Univ.	4	Protected	1-5	Extensive interdisci-

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plinary,
students,                                                                                          technicians

Coweeta         Univ. of Georgia        4               Protected       1-
3     Staff,
Hydrologic                                              (USFS)          students,
Laboratory                                                                      technicians

Salmon River    Idaho State Univ.       3               Middle Fork     1-
8     Students,
                                                        protected               technicians
                                                        (Federal
                                                        wilderness)

Augusta         Kellogg Biological      8               Only lower      1-
3     Staff, students
Creek           Station
section                 technicians
(Kalama-
zoo R.)*

White Clay      Stroud Water            10              Some areas      1-
5     Staff, students
Creek (Buck     Research Ctr.
protected               technicians
& Doe Run)*                                             by Stroud,
                                                        some by
                                                        formal private
                                                        agreement

Konza           Kansas State U.         0               Protected       1-
5     Students
Prairie                                 (initial        KS State U)
                                        measure-
                                        ments)

Oak Ridge       Oak Ridge               5               Protected       1-
3     Staff, tech-
National
(Federal)                               nicians
Laboratory

Savanna         Savannah                0               Protected       1-
3     Staff, tech-
River           River                   (initial
(Federal)               nicians
                Laboratory              meas-
                                        urements)

Linesville                              10              Only small
3       Students
                                                        middle sec-
                                                        tion protected
                                                        (Univ. of
                                                        Pittsburgh)

-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
TABLE C-1a.  Major stream sites for long-term ecological monitoring
-------------------------------------------------------------------------------

Sites           Coupling        Data Storage    Standardization
Potential       Comments
                with other      and Retrieval   and Calibration
Manipulative    (special
                Programs        Systems         of
Methods      Research               features, etc.)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

Hubbard Brook EER (proposed) Cornell U. Extensive
Ongoing Organic and Forest Service
campus calibration nutrient budgets
and cross-
comparison
of techniques;
samples from
previous years
stored frozen

Andrews Experi- EER (funded), Oregon State U. River Contin-
Ongoing Studies on physi-
mental Forest Forest Service, campus, Stroud uum workshop
cal and biological
(McKenzie R.)* EPA, Oregon Center River on standardiz-
role of wood
Dept. Environ- Continuum
ation of debris in streams
mental Quality, Cooperative methods, EOA
and importance
USGS
standards of stream history,
organic and
nutrient budget

Coweeta EER (proposed), U. of Georgia EPA standards,
Ongoing Nutrient Hydrologic Forest campus and
comparison with budgets, detailed
Laboratory Service Oak Ridge Oak Ridge
and benthic studies
National and
Andrews concentrated
Laboratory Forest
on filler feeders

Salmon River USGS-Menlo Idaho State, River
Continu- Possible Invertebrate Univ. of
Idaho campus, Stroud umworkshops studies, salmon
Forest Service, Center River on
standardiz- populations and
Idaho Fish and Continuum-- ation
of nethods, spawning sites
Game Cooperator EPA standards

Augusta Creek EER (proposed), Kellogg Bio- River Continu-
Ongoing Invertebrate (Kalamazoo R.) Michigan State logical
Station umworkshop on studies, leaf litter
Dept. of Mini System, standardization
and processing
Natural Stroud Center of methods, EPA
Resources River Continu- standards
um Cooperator

White Clay USGC, EPA Stroud Center River Continu-
Ongoing Extensive inverte-
Creek (Buck Control proces- um workshop
on brate studies,
and Doe Run)* sor for
River standardization, terrestrial inputs,
Continuum of methods,
EPA primary
time-
share, standards production

Konza Prairie EER (proposed) Kansas State U. Proposed
River Possible
Preliminary campus,
pro- Continuum studies on

posed Stroud methods
leaf processing

Oak Ridge EER (proposed), Oak Ridge
Comparison Possible Nutrient Dept.
of Energy Laboratory with Coweeta studies
computer center

Savannah River EER (proposed, Savannah River
-- Possible Thermal effects
Dept. of Energy Laboratory
Center

Linesville Informal coup- U. of Pittsburgh
-- Possible Invertebrate
ing with River
campus (especially
Continuum
midges) and fish
Project

* Cooperation with NSF-sponsored River Continuum Project

TABLE C-2. Other possible stream sites for long-term study.

1. Colorado State University, South Platte River (J.V. Ward)
2. University Maryland, Cement Creek, Colorado (J.D. Allen)
3. University Minnesota Valley Creek and others (T.F. Waters)
4. University Waterloo, Speed River (H.B.N. Hynes)
5. University Alberta, Bigoray River (H. Clifford)
6. University Wisconsin, Lawrence Creek and others (G. Gallup)
7. University North Carolina, New Hope Creek and others (S. Riece)
8. Arizona State University, Sycamore Creek and others (S.A. Fisher)
9. Weyerhauser Co. Experimental (semi-natural), Kalama Springs Streams (J.R. Sedell)
10. University Colorado, Alpine Station (W. Lewis)
11. Michigan State University Jordan, Ausable, Red Cedar (N.R. Kevem); Augusta Creek (R. Merritt)
12. OTS, Costa Rica, La Selva Field Station
13. Battelle Northwest Laboratory, Rattlesnake Springs (C.E. Cushing)
14. Idaho State University (Desert Biome), Deep Creek (G.W. Minshall)
15. University of Washington Cedar River (R. Wissmar, J. Malick)
16. Utah State University, Blacksmith Fork (W. Helm)
17. Colorado Fish and Game, Cache la Poudre (D.G. Klein)
18. Brigham Young University, Sundance Creek (J.R. Bames)

TABLE C-3. Major Lake Regions and Representative Nearby Research Institutions.

Regions	Representative Lakes	Active Institutions
1. Tundra lakes and ponds Arctic North Slope	Imikpuk Toolik	NARL WHOI
2. Boreal forest lakes in AK	Smith, Harding, Illiamna	Univ Alaska Univ Washington

3. Lakes from Cascades west in	Washington Fern, Findly	
Univ Washington		
WA and OR	Crater Lake	
4. Lakes from Sierras west	Castle Clear Tahoe	
Univ California		
in CA		
5. Desert lakes east of	Hot Soap Moses	
Univ Washington		
Cascades and Sierras	Montezuma Well	Univ Arizona
	Pyramid Lake, NV	
6. Northern Rockies	Flathead Lake	Univ Montana
	(Biological Station)	
	Yellowstone Lake	
	Canyon Ferry Reservoir	
Montana State Univ		
7. Alpine and subalpine lakes	Alpine and Subalpine	Univ Colorado
in CO	Rocky Mountain	
	Biological Station	
8. Prairie lakes and potholes in		
eastern Dakotas		
9. Nebraska sandhill lakes		
10. Glacial lakes of northern	Cedar Bog Lake, Itasca	
Midwest	Lakes	
Univ Minnesota		
	Trout Lake	
Univ Wisconsin		
	Madison lakes	
Univ Wisconsin		
	Douglas Lake	Univ Michigan
	Gull Lake/Laurence Lake	
Michigan State Univ		
	Crooked Lake	Indiana Univ
	Okoboji Lake	Univ Iowa
11. Laurentian Great Lakes	Lakes Superior Michigan	
Univ Wisconsin, Univ		
	and	
Erie	Michigan, Univ Min-	
		nesota,
Ohio State		
		Univ
12. Finger Lakes region and	Lake Cayuga	Cornell Univ
west in New York	Green Oneida	Syracuse Univ
and Pennsyvania	Pymatuning Biological	
Univ Pittsburgh		
	Lab	
13. Adirondacks and east	Lake George	Cornell Univ
		Rensselaer
		Polytechnic Institute
		and
SUNY-Albany		
14. Maine-New Hampshire	Mirror Lake	
Dartmouth-Cornell-	Several lakes Univ	
Maine (Orono) Yale		
15. Connecticut-Massachusetts-	Linsley Pond	Yale Univ
Vermont	Dunham Pond	U Connecticut
16. North Carolina millponds	Various ponds and lakes	

North Carolina State
bay lakes Univ

17. Abandoned rice ponds in
South Carolina

18. Florida Lake Annie
Univ
Florida
(Gainesville;
Archbold
Biological Station

19. Oxbows and bayous in
Mississippi delta

20. Reservoirs in Texas,
Oklahoma, Kansas
Nebraska, and Missouri

21. Reservoirs in Southwest

22. Reservoirs in Tennessee
Valley System

APPENDIX D

Coastal Marine Habitats and Sites

The following inshore habitat types were considered by the Ad Hoc Committee to have obvious potential value for long-term study. The specific sites listed under each type of environment are intended as examples, not as an exclusive set.

Coral Reefs: Indo-Pacific: Palau; Eniwetok Atoll; Hawaii; Lizard Island and Heron Island (Australia).

Caribbean: Barbados; Belize, Jamaica; La Paquera, Puerto Rico; Panama; St. Croix, Virgin Islands National Park.

Rocky Shores: Monterey Bay, California; Puget Sound-Olympic Peninsula, Friday Harbor, Tatoosh Island, Washington; Northern New England Coast; Channel Island, California; Southeastern and Gulf subtidal reefs.

Subtidal Soft Bottom: Monterey Bay, California; Buzzards Bay, Massachusetts; Puget Sound, Washington; Long Island Sound, New York; Chesapeake Bay, Virginia; Cook Inlet, Arkansas.

Salt Marshes and Estuaries: Sapelo Island, Georgia; North Inlet Estuary, South Carolina; Mississippi Delta; Newport River Estuary, North Carolina; Buzzards Bay, Barnstable Marsh, Massachusetts; South Slough of Coos Bay, Oregon; Elkhorn Slough, California.

Mangroves: Sanibel Island National Wildlife Refuge, Everglades National Park; Great White Heron National Wildlife Refuge, Florida; La Paguera, Puerto Rico; Palau.

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