Long-term Ecological Research
Concept Statement and Measurement Needs

Summary of a Workshop
Institute of Ecology
Indianapolis, Indiana

June 25-27, 1979

Prepared for:

National Science Foundation
Directorate for Biological, Behavioral and Social Sciences
Division of Environmental Biology, Biological Research Resources Program

Sponsored by the

National Science Foundation
Grant DEB 7920243

Published August, 1979

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PREFACE

In March, 1977, a group of thirty researchers from university and federal laboratories met in Woods Hole, Massachusetts, to consider the need and scope of a possible program of long-term measurements in ecology. Findings presented showed a compelling case for such a program, but operational details were left to a second conference a year later. Reports from both conferences were published by the National Science Foundation.

Later responses to these two reports identified a need for additional definition and consensus on certain issues. The proposed program would have to answer significant ecological research questions if it were to be considered for support by the National Science Foundation. Thus, a third and larger meeting of researchers and observers from field biology and environmental science was convened in Indianapolis in June, 1979, by The Institute of Ecology, under a grant from NSF. The objective of this meeting was to exchange views on details of potential long-term research among a wide range of environmental biologists and federal agency personnel. The proposed program was by this time entitled Long-Term Ecological Research (LTER).

The first half of the workshop consisted of presentations on research results of previous long-term studies as a basis for a new but structured, continuing program. The results of these presentations and the discussions which followed are presented in Part I of the following report, along with results from the previous conferences. During the second half of the workshop the participants worked as "study panels" to consider measurement needs to meet the research goals defined in the plenary sessions. These results are presented in Part II of the report.

Following the workshop itself, all participants received a draft of the report for comment. As a result of their suggestions, the report was revised extensively. The results presented here, therefore, are a product of the iterative process, begun at the Woods Hole meetings, and continued through and following the meeting in Indianapolis in June.

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August, 1979

TABLE OF CONTENTS

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EXECUTIVE SUMMARY

This report summarizes a workshop held in Indianapolis, June 25-27,1979, to define research goals and measurement procedures for a program of Long-Term Ecological Research (LTER). Previous conferences had considered the need for and operation of such a program. Participants and observers at this workshop were drawn largely from university-based environmental biologists and from numerous government agencies.

A major reason for developing an LTER program is the expected usefulness of the data for a variety of research and policy problems. Potential users, in addition to academic researchers, include government and private industry personnel who must assess ecological impacts. The LTER program can play a lead role in developing standard methodology and providing baseline measurements to meet these needs.

A strong program of long-term ecological research must encompass individuals, who provide creativity, and institutions, which maintain longevity and continuity. The program must capitalize on both to develop the continuous data base needed to generate new hypotheses in the future and to formulate and test hypotheses from long-term measurements in the present. The LTER program outlined here meets these criteria through recommendations for a core research program at a network of primary sites, and an investigator-specific program, which may operate either at primary sites or at sites separate from the core network. The core research network will conduct standardized measurements to produce a continuous data base. These data could be used to answer local research questions or for broad geographical comparisons among sites.

The investigator-specific studies should be related to the core research program through the use of some common research sites and methods where appropriate, but they will focus on unique types of long-term measurements to test significant hypotheses. The strength and rationale of this part of the program will be the intellectual insight of individual

researchers. Research sites and measurement methods would be used which are not part of the standardized core data set, although they could be incorporated at some later date.

Management of a program combining these two research thrusts should be centered in a network coordination office. This office would facilitate interaction among LTER participants, define methods and documentation standards, and advance the collective pursuit of prog ram goals. The relationship between the coordination office and investigator-specific projects would concern documentation standards, continuity, and complementarity between the two types of research initiatives. Overall policy and review would be provided by an LTER Council.

Part II of this report outlines measurement needs and standardized methods for the core research program. Included are panel reports on site description as well as physical, chemical and biological measurements. The measurement plan presented does not attempt complete specification of instruments, methods and sampling procedures at this time but is a step toward a series of later reports which will give these details. The panel reports do, however, indicate a general consensus on the necessary measurements for the core research questions. Emphasis has been placed on the minimal number of variables needed for the core research. The most difficult problems of measurement should be analyzed on a continuing basis by program participants and advisors through the coordination office.

PART I: GOALS, STRUCTURE AND MANAGEMENT OF A PROGRAM IN LONG-TERM ECOLOGICAL RESEARCH

Long-Term Ecological Research: Background and Users

Two conferences since 1977 have considered the question of whether U.S. science programs have a major need for long-term ecological measurements, including baseline biological and environmental studies (NSF 1977, NSF 1978). The conferences noted that all biological systems undergo long-term changes, some of which may be cyclic, others unidirectional. Some may be due to natural climatic variation, geological events, and biological processes; others may result from subtle long-term anthropogenic influences. At present, few research strategies are available to determine which changes are cyclic and which are unidirectional or to distinguish anthropogenic changes from natural ones. These and other central ecological issues can be addressed only when long-term quantitative data are available for both theoretical and practical purposes.

Despite these needs, most research in the United States has emphasized the short-term. The few studies of long-term changes have been of exceptional value for current research (e.g., Beeton 1969, Keeling et al. 1976). Much ecological research seems to appear out of a temporal and spatial vacuum, lacking the context which can make results most meaningful for an understanding of natural resource systems. For the benefit of ecological science, and of science in general, the researchers at the previous meetings concluded that a long-term research program was urgent. This need is becoming more important now that human technology is bringing subtle, long-term pressures on many natural populations, communities, ecosystems, and on the earth's entire biogeochemistry.

A few examples of site-focused long-term ecological studies in North America are available, however. One is the measurement program of the Canadian Freshwater Institute, Winnipeg, Manitoba, and another is the Hubbard Brook Ecosystem Study in New Hampshire. After only a decade of measurements, these sites became a focus of intensive research on questions stemming from unusual findings of the long-term measurements. The Hubbard Brook work has been particularly important in developing programs on acid rain in North America (Likens and Bormann 1974). Such programs demonstrate that long-term measurements serve not only to test hypotheses, but also to generate significant new research questions.

Participants at the two previous conferences on long-term ecological measurements attempted to define the scope, substance and approaches to long-term studies. This report represents the results of a workshop convened in June, 1979, designed to define the research questions and outline the measurements needed. The report includes suggestions for establishing the initial phases of a program in long-term research on biotic populations and representative ecosystems, with the cooperation of federal agencies, private institutions and the scientific community.

A significant part of the justification for an LTER program rests with the variety of ways in which the data can be used. The spectrum of possible users runs from state and federal resource management and regulatory agencies through the academic research community to private industry. in addition to primary scientific use by one or more researchers, other specific uses include policy analysis, decision-making on policy options, environmental assessment, resource management studies, and instruction. For example, state and federal agencies involved in resource management can use data on "normal" ecosystem functioning as a standard against which to compare their resource use practices.

Federal agencies such as the EPA, BLM, DOE and the Corps of Engineers use environmental data obtained from their own programs; however, these agencies use independent data to appraise the adequacy of environmental impact statements and projections of the effects of their policy decisions. The new regulations of the Council on Environmental Quality (CEQ) take effect in August 1979. All federal agencies are required now to conduct more systematic and meaningful environmental analyses, estimating over broad spans of time and space the environmental consequences associated with the activities each agency performs. Since there is no broadly accepted methodology to do this, the LTER program could provide a lead role in developing standard methodology as well as baseline measurements for future comparative studies.

Industry also requires ecological data in evaluating the effects of their activities on biotic systems function. State and federal governments, as well as the public, require that they provide a broader perspective on the influence of construction and operation of major industrial facilities on biological systems in the region-terrestrial as well as aquatic. A part of these user needs could be satisfied by general ecological data coming from various components of an LTER program. Probably the most important contribution, however, is the general advance expected in scientific understanding of natural as opposed to anthropogenic variations induced in species, populations, and ecosystems, and their result is important to virtually everyone associated with biological resources.

Scope and Types of LTER

Initiatives

Both individual scientists and groups representing institutions may wish to carry out long-term studies on problems central to the advancement of ecological understanding. The need for precise measurements and well-documented records over a long period of time favors the longevity that goes with institutions, while the motivation to seek insights demands the involvement of individuals. Any program of long-term research, therefore, must involve both individual and institutional participation in some collaborative manner.

The need for cooperation is evident in the scientific goals of long-term research. On one hand, some ecological observations must be obtained to generate hypotheses, an inductive approach. On the other hand, hypotheses already exist which require long-term experimental tests. This deductive approach provides depth and generality to the scientific results and emerging theory. The inductive approach is enhanced by standardized measurements; the deductive approach can be more individualistic. To meet the goals of both good observations and advances in ecological theory, the scope of the LTER program should include a wide variety of projects. Some may focus on comparisons over time at a single research site, while others may contribute to broad geographical (longitudinal) comparisons over time at many sites. The two classes of research discussed here encompass this diversity.

1. Core Research Questions

Initially, at least, only a modest number of research questions can be asked in a uniform and coordinated fashion at a majority of participating sites. The following are five areas of core research suggested for a majority of the sites, whether they are focused on terrestrial or aquatic systems.

(i) Dynamic patterns and control of primary production, over time, and in relation to natural and induced stresses or disturbances.

Evidence presented by several researchers indicates that several key measurements of the producer system (e.g., standing crop, photosynthetic surface area, water use, and others) provide a basis for inter-correlation with physical and climatological measurements at the site. These measures seem to have great potential for estimating derived parameters at the site or for longitudinal cross-sections of continental resource systems.

(ii) Dynamics of selected populations of seed plants, saprophytic organisms, invertebrates, fish, birds and mammals in relation to time as well as natural and induced stresses or disturbances.

The causes of population fluctuations, or sustained population declines, are among the most elusive of biological problems. Although observations cannot be maintained on even a majority of the species at LTER sites, certain indicator populations can be identified that have "equivalent" species at other sites. Records of the population variations in such species in a network context will permit testing and development of hypotheses central to the question of maintaining biotic diversity.

(iii) Patterns and control of organic accumulation (biomass) in surface layers and substrate (or sediment) in relation to time or natural and Induced stresses or disturbances.

Remineralization or accumulation of carbon and associated nutrients often is a dominant aspect of ecological regulation. While many of the important questions in this area require experimental manipulation, certain measurements of the annual organic additions and long-term accumulations are essential to designing and interpreting the experimental work.

(iv) Patterns of inorganic contributions (atmospheric or hydrologic) and movement through soils, groundwater, streams and lakes in relation to time and natural or induced stresses or disturbances.

Current research has shown unusual variations and trends in inorganic contributions to ecosystems from the atmosphere. These inputs reach aquatic systems, in part, through surface and subsurface hydrologic flows, which in turn vary in relation to precipitation inputs. Long-term measurement of the most prominent constituents of this geochemical system will provide benchmark measurements for comparative as well as manipulative research.

(v) Patterns and frequency of apparent site interventions (disturbances) over space and time (drought, fire, windthrow, insects or other perturbations) that may be a product of, or induce, long-term trends.

Virtually all of the potential LTER study systems (land and water) will include unusual but probably natural local disturbances, e.g., floods, fire, insect attack, etc. Study of the response of the system to these interventions is an essential part of the LTER program. Thus, a class of research to be pursued relates to the pattern and frequency of interventions (some may be very infrequent), and the status of the population recovery (which, in forest succession, may be very long).

2. Investigator-Specific, Long-Term Research Questions

In contrast to the core research questions listed above, requiring comparable data collection procedures over a variety of sites, there is another class of research which requires long-term measurement but does not necessarily require system-wide institutional treatment. These projects can take advantage of special site characteristics or the special expertise at a site or institution, and provide opportunities to work on problems which require unique measurements. Proposals for this type of research may originate with individuals or groups of researchers who may or may not be directly involved with the "network" of major research sites. In addition, investigator-specific research (for example, on populations of particular interest) need not be confined to a single location but may involve a number of sites within a study region.

Two general types of investigator-specific long-term ecological research can be expected: unique (i.e., non-standardized methodology) but site-focused long-term studies, and multi-site studies focusing in novel ways on individual components of ecological systems. While some of these studies may be related to the core research program, they will tend to be more individual and more exploratory than is possible in a standardized measurement or network approach. Projects of this type which prove to be of significance nationally could become incorporated into the core research program at some future date. In addition, some investigator-specific projects may need data from a moderate number of locations within certain regions of the country. For example, the several scales of spatial heterogeneity needed for population regulation and speciation processes is now widely recognized. By adding a long-term dimension to such investigations, insights can be expected that are not easily obtained in other ways.

3. Summary of LTER Program Scope

The suggestions for program scope outlined above lead to the concept of long-term ecological research as a program with two related thrusts: (i) a series of core research questions that should be examined with standardized measurement procedures at a modest number of primary sites throughout the country; and (ii) an aggregate of local studies and sites for investigator-specific research, which could take place at the primary sites or at other locations. The goal of both approaches is to provide an extended observation period for research on particular populations, communities or ecosystems, within the context of geographical representation throughout the U.S. and the capabilities of individual investigators or institutions.

Inter-agency Considerations

The LTER program envisioned here will require the participation or cooperation of numerous federal agencies which may sponsor research, function as land-holders, or use the results. The LTER program should supply a sound data base to answer fundamental ecological questions facing these agencies and aid in natural resource management decisions. Data from other federal research programs can augment the LTER program and increase its usefulness. The kind of cooperative research illustrated by the relationship between the academic community and the Forest Service at the Andrews Forest, Oregon, and Hubbard Brook, New Hampshire (Likens et al. 1977) should be promoted elsewhere and serve as an example to prospective participants in LTER studies.

In particular, the land managing agencies of the federal government have substantial holdings of natural landscapes which can be utilized for the LTER program. Some of these sites already have been committed to research programs through their designation as Experimental Ecological Reserves. These and other federal lands are valuable in that:

a) they are managed within specific mandates (preservation, multiple use, habitat preservation, ecological research, etc.);

b) ecological information dating back many decades is often available and consistent management methods can be anticipated over time; and

c) federal lands are currently used in diverse ways which complement and can contribute to long-term ecological research programs, making maximum use of limited resources.

Existing cooperative arrangements among federal agencies should be utilized to the fullest extent possible. For example, the Federal Committee on Ecological Reserves and the Man and the Biosphere (MAB) program already are operating and will aid the LTER program in numerous practical ways. These inter-agency and government-university arrangements will provide important communication links and possible sites for the LTER program.

Coordination and Management

Most of the workshop participants had read the suggestions for program development, coordination and management as presented in the second Woods Hole conference report (NSF 1978). Time did not permit a systematic re-examination of those proposals, but comments during the conference indicated general approval of the concept outlined previously. The focus of coordination and management should be on the long-term ecological research as a program, including both core research and investigator-specific studies to broaden and balance the program.

1. Definition of Coordination Needs

Suggested responsibilities of the coordination office ranged from providing leadership in synthesis of presently existing long-term data, to operating workshops on measurement methods, to conducting periodic "audits" of laboratory and data reduction procedures at study sites. In most of these suggestions, the intent appeared to be one of enhancing interaction and promoting consensus among operational LTER project personnel, program advisors, and coordination office staff to achieve the goals desired. The coordination and management activity also will be subject to "site review" by LTER personnel and outside reviewers.

Management of the program will consider activities at four levels:

a) Central policy and overview (through a policy board or council);

b) Network coordination (for primary core research sites);

c) Site coordination (through local LTER project site staff); and

d) Documentation and report coordination among investigator-specific LTER projects.

Operationally, LTER program management also will involve committees to advise on many aspects of program initiatives, standards of data reduction, new standard measurements, and aspects of site management related to long-term ecological research goals. The proposed management structure should be designed to facilitate expansion of the pilot network by the inclusion of additional sites or initiatives by other federal agencies.

The earlier workshops suggested that an LTER Council provide oversight to program operation. The Council should include representatives of organizations with land ownership/management functions; including the Bureau of Land Management, National Park Service, U.S. Department of Agriculture (Forest Service and Agricultural Research Service), Department of Energy; universities; foundations; and other agencies with research interests; such as the National Science Foundation, Council on Environmental Quality, National Oceanic and Atmospheric Administration, and the Environmental Protection Agency. The suggested responsibilities of the Council include:

a) Establishing general policy regarding LTER and its long-term goals;

b) Securing continuing financial support;

c) Assisting system development (e.g., site acquisition, security, etc.);

d) Establishing committees or advisory groups as may be needed for the effective conduct and management of the system; and

e) Providing guidance to the coordination office.

2. Operating Procedures of the Coordination/Management Offlce

All participants in the LTER program will have responsibility for the quality of the program and its operation as a program, but the contractor for coordination and management will have especially large responsibilities. The 1978 Conference Report (NSF 1978) suggested management of the program should be the responsibility of the coordination office, assisted by the Council, site advisors, and individual participants, with review by the funding agency. The Coordinator should provide for the efficient conduct of the research and measurements program at all locations with specific regard to quality control, security, and longevity of the data record. The specific responsibilities of the coordinator's office will differ somewhat between core research projects and investigator-specific research, but the concern with quality, documentation and longevity will be similar.

Management of the core research program will require emphasis on standardization of measurements at a network of primary sites. Specific responsibilities here, in conjunction with site project staff, will include:

a) Overseeing network measurement sites;

b) Establishing and maintaining standardized procedures for measurement, sampling, data format, and reporting;

c) Facilitating the development of new core research sites (in conjunction with granting agencies);

d) Advising on the relocation of monitoring stations as required;

e) Providing training programs and seminars for site or other agency personnel (workshops, manuals, etc.);

f) Promoting utilization of data and results;

g) Establishing and maintaining liaison with national repositories for numerical data and scientific materials;

h) Establishing and maintaining liaison with other national and international monitoring and data networks;

i) Conducting periodic on-site reviews of measurement activities;

j) Reporting to the LTER Council and the supporting agencies on the network as a whole.

Management of investigator-specific research projects will be largely the responsibility of the individual investigator. The role of the Coordinator, however, will depend to some extent on the location of the research (i.e., whether at primary or investigator-specific sites). In addition to the quality and continuity provisions cited above, specific responsibilities of the coordinator's office will include: a) Review to assure mapping of research sites and other measures to avoid disruption of the continuity of the records; b) Assuring that any "standard" measurements being done are consistent with primary network procedures; c) Maintaining documentation standards, monitoring the periodic summaries of data, and assuring flow toward a "public record"; and d) Recommending adoption of certain research procedures from investigator-specific studies for the core research program.

Criteria for Grant Determination and Funding Period

Discussion of procedures for grant determination and funding periods for an LTER program was limited during the workshop, but conference participants agreed that the primary criterion for LTER proposal review should be evidence of the research capabilities of the lead individuals or institutions involved. The usual criteria for likelihood of successful research (e.g., problem statement, knowledge of the field and publication record) would be used to indicate individual research capability. An "institution" may have to meet these criteria as well, in that people may leave, and in long-term research the institution may be expected to maintain an "equivalent" individual in the program.

Secondary criteria for the review of core research site proposals should include site characteristics or site distribution within the "network" concept. Specifically, the suggestion was made that if researcher and institutional capabilities in competing proposals were equivalent, overall proposal ratings and grant decisions should be based on characteristics of the site or the requirements of geographic/ ecosystem type dispersion. For investigator-specific research projects, secondary criteria might include geographic dispersion, critical process-related information, the nature of the assurance of continuity for the research, and the relationship to the core research program.

The question of length of grant period in relation to program planning and appropriate review/termination procedures was discussed briefly. The conference participants agreed that a 5-year planning horizon with 3-year grant instruments, renewable upon review, would be acceptable. The renewal proposal should not be a completely new competition in the usual sense. If review of a primary site program were to indicate an "unacceptable performance," a warning and a period for recovery should be permitted before the site is terminated. The prospect of termination must exist for any site, regardless of prior record, but if the core research sites function as the system is conceived of here, no part of it should fall behind a consensus standard of excellence. Similar principles seem applicable to investigator-specific research.

PART II: MEASUREMENTS REQUIRED FOR CORE RESEARCH AT LTER SITES

Each participant in the workshop took part in one of four panel studies of standard measurements needed for a program of long-term ecological research; the following sections present results from the first phase of work by these panels. Proceeding from topics identified in the previous conference reports (NSF 1977, NSF 1978), each group was asked to specify data needed to answer the core research questions. The panel reports in their present form, however, leave many questions to be resolved as the LTER program takes shape.

Several problems confronted the measurement panels in trying to specify data to be collected in the "network" site studies. It seems impossible to know precisely which data will be most valuable for future research. Collecting all possible information about a site will increase the valuable data obtained, but will greatly increase the amount of low value data and cost. The panel reports generally attempt to recommend the minimum measurement program likely to produce the most valuable data. In some cases site-specific measurements are suggested.

Once the numerical data have been obtained, they must be documented and summarized in order to have the lasting value expected of them. Details of how this should be done and how the costs will be divided are among the questions still under consideration. These issues probably will need continuing attention as the program develops.

Further study will be undertaken over the next few months to improve the definition of measurement methods. Where agreement on instruments or measurement procedures is reached quickly, a summary will be made available to NSF and the ecological research community. Some questions may prove too difficult to answer in a short time and will be left for consideration by participants and advisors to the LTER program during its early development, probably through the office of the program coordinator. Thus, the reports presented now must be read as a step toward a shifting goal, following a process that is now well-defined but whose products will emerge gradually in the months ahead.

PANEL I: SITE DESCRIPTION AND BASELINE MEASUREMENTS

Long-term ecological research will have a more complete background and may be more readily interpreted where the physical, chemical and biological characteristics of the study site are well known and fully documented. The following documentation procedures should be implemented fully at the primary research sites comprising the proposed network for an LTER core research program; less complete documentation may be appropriate for the sites used in investigator-specific long-term research.

Site description should be a synthesis of background knowledge as well as information being collected at an LTER site. The site description process should begin with an inventory of existing data, although the inventory may have to be revised at a later date to fill the needs of new aspects of the long-term research. The initial grant to a site should include funds to assist a complete collation of information and to fill gaps in existing data so as to achieve a final fully-documented site description. Such a synthesis should be updated regularly and made available to all site users as a separate report.

Site description data should be presented so as to be of maximum usefulness to site management and local as well as remote researchers. The following desiderata are not intended to represent an exhaustive site description but rather a reasonable set of descriptors to be made readily available at LTER sites. Baseline description will include the initial inventory plus sufficient follow-up measurement to document seasonal and annual variance.

1. Macroclimatic data: Each site should be described in terms of general and regional macroclimate. These macroclimatic measurements should encompass annual and monthly means and extremes plus year-to-year variance. The following should be included:

(i) air temperature - standard weather bureau records with total radiation, precipitation, dew point, wind velocity and direction if available in the area.

(ii) edaphic - soil temperature and soil moisture (at USDA standard depths if available).

(iii) hydrology - depth to water table and/or describe subsurface flow.

(iv) water characterization - water temperature, salinity, pH, turbidity, dissolved oxygen, transparency, tidal measurements (and hydro-period for wetlands).All of these variables will continue to be measured as part of the standard physical and chemical measurements programs (see later reports).

2. Geological mapping: Geological descriptions should include topography from USGS quadrangle maps and surficial geological maps. Other geological features of interest may be provided by air photos. Tectonic and mass movement features should be identified if present. Topographic maps should be at least 1:20,000.

For freshwater and estuarine sites, a combination of marine and land navigation or geodetic and tidal benchmarks should serve as the geologic map base. Information should be provided on faulting, fractionation and substrate texture.

3. Soils and sediments mapping: Soils should be mapped on the basis of soil series and/or functional groups. If there are existing soil series maps, these should be validated by new surveys to confirm their accuracy. Soil units should be named using standard nomenclature; for example, that of the USDA Soil Conservation Service (7th approximation, Handbook 436). Marine and other aquatic sites should maintain up-to-date sediment maps, including organics, at convenient scales, and artificial markers or landmarks.

4. Vegetation inventory: Vegetation studies should provide an historical baseline through an appropriate vegetation mapping. The mapping should complement the development of species lists and voucher collections. It also should utilize an appropriate regional classification wherever one is available. All units should be physiognomically and/or functionally delineated. Appropriate quantitative methods must be used to characterize the type and aid in determining boundaries. In most vegetation types, an importance value (two or three of % cover, % frequency, % density) would be appropriate. Site-specific variation will have to be considered in determining the size of minimum mapping units.

Permanent plots should be established and photographed where appropriate, and vegetation on these plots carefully mapped. For forested areas this may include permanent hectare plots divided into 1/16 ha sub-plots where all trees greater than 5 cm, including snags, are mapped and permanently marked.

For aquatic sites, emergent vegetation and submerged macrophytes should be mapped. For some marine macrophyte communities, vertical transects may be needed.

5. Faunal inventory: Each site should develop a comprehensive list of fauna with an indication of relative abundance at the time of the initial survey. For vertebrates these lists should be developed to the species level. For invertebrates, each taxon should be listed at the lowest readily identifiable unit; e.g., genus or family. A reference collection of all forms should be established at the site. These collections and taxa lists can be improved as specialists become available to work on these groups. It is recommended that site-specific keys be developed for both flora and fauna, if not already available.

6. Effects of disturbances: Documentation should be provided on patterns and frequencies of apparent interventions over space and time (e.g., drought, fire, wind, insects, and other perturbations) that may be a cause of, or result from, long-term trends. The nature of past disturbances (frequency, magnitudes, duration) should be identified initially and indicated on site maps. Further characterization of disturbances known initially should involve, for example, determination of whether they are single or episodic events, or whether they are of local or regional occurrence. Appropriate comparisons of disturbed and undisturbed components of the system could be conducted as part of the research program via comparisons over space or time. Core data also should be taken in such a way that possible relationships between ecological and environmental variables can be explored by long-term time series analyses. Where possible, comparable data should be taken at more than one location at a site to permit independent analyses of trends.

The system of core measurements also should include sufficient analysis to identify potential disturbances (where possible) and initial changes taking place in biological components at the sites. The appropriate study of the patterns of disturbances and responses to disturbances should be inherent in the baseline measurements. (Study of mechanisms involved may be the subject of intensive study alone or more sites.)

Two additional elements should be incorporated into site description data in order to facilitate the identification of disturbances: 1) the series of photo stations described above showing possible changes in the vicinity of instrument locations; and 2) a diary describing the occurrence, extent and duration of short-lived events, both physical and biological ecological. These materials are to be a part of the permanent site record.

7. Site management: For any long-term ecological research program, certain management procedures are necessary to assure maintenance of baseline information and instruments:

(i) There should be an explicit arrangement described guaranteeing the security of management on the site and specifying responsibilities for making changes when needed.

(ii) There should be continuous updating of maps indicating the locations of various research projects to avoid catastrophic disruption of LTER studies. Each component proposal should indicate the number of manipulated and undisturbed control sites required, in addition to preferred areas where research will take place. The site manager will be responsible for deciding the allocation of areas to experimental treatments if such are required. In some cases manipulations could be carried out off-site and compared to baseline conditions on the site.

(iii) Each site should maintain a bibliography of past and present published research from the site and, as far as is possible, a separate collection of site publications and internal reports to serve as a resource Iibrary for researchers at the site.

(iv) A reference collection of Landsat images should be collected and kept on file for the site if at all possible. These should include major phases in the yearly phenology of the area.

Site description and baseline measurements are the best defined of all proposed LTER measurements at this time. Additional details can be resolved as needed by program participants and advisors through the office of the network coordinator. In a sense, many of the measurements being considered by other panels can be thought of as baseline measurements, since they represent system structure, function and response over time. Thus, in time, the measurement standards of the physical, chemical and biological components should become the standards for baseline summarization.

PANEL II: PHYSICAL MEASUREMENTS

The physical measurements component of a long-term ecological research program must serve several purposes:

(i) provide a long-term record of the physical environment in support of the core research program;

(ii) provide a basis for correlative analysis between physical (environmental) measurements and biological phenomena;

(iii) characterize infrequent and extreme changes in the physical environment; and

(iv) provide baseline measurements for geographical comparisons among the major sites.

The results of these measurements should provide estimates of central tendency, short-term variability and extreme conditions. Thus, the core measurement program should consist of a single central station, supplemented by others as needed. Where a site contains sharp topographical, altitudinal or other gradients, additional stations will be required.

Table 1 summarizes the physical measurements suggested for terrestrial sites, and Table 2 outlines needs for aquatic sites. Details of the specific equipment needs for standardization of these measurements are being considered by the panel and will be announced in later reports. Procedures that are the same as or equivalent to standard weather bureau or other national monitoring programs will be used. Specific comments on certain measurement areas follow.

Table 1. Terrestrial site physical parameters.

Variable	Frequency	Instrumentation & Location
1. Short-wave Insolation	Continuous	Standard clearing
2. Air Temperature	Continuous, max/min, heat	Thermocouple, standard clearing sums (daily integral on 0•° C and 5•°C basis)
3. Dewpoint	Continuous	
4. Windspeed	Continuous	Sensitive anemometer, standard clearing
5. Wind Direction	Continuous	Recording direction indicator, standard clearing
6. Soil Water Content	Biweekly, multiple locations	Neutron Probe under representative getation

		cover (site-specific consideration heat and water content profiles through litter)
7. Groundwater Level*	Weekly	Cased well
8. Precipitation	Continuous event	Recording rain gauge; time, duration, intensity
9. Runoff/Erosion*	Event	(Site specific)

10. Sensible, long-wave or total radiation should be recorded (e.g., Phranograph) to indicate sensible heat load.

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*Optional as determined by site considerations wherever possible, provided these are not conflicting.

1. Climate: Meteorological measurements should be obtained at the central station (except as noted in the Tables), and recorded on automatic data logging equipment to facilitate transfer to computer data files. However, chart recording or other mechanical recording of measurements on the same or additional instruments also should be used, both as a back-up and in order to perform routine checks of instrument performance and eliminate data gaps from instrument failure and power interruptions. A logbook of periodic (at least weekly) quality assurance procedures, calibrations, changes of instrumentation and other "change of station" events should be maintained as part of the permanent site record.

Table 2. Aquatic site physical parameters.

Variable	Sampling Plan
1. Temperature	
a. Air	Same as terrestrial.
b. Water	Streams: daily 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	At surface; Wetlands: profile in deepest peats twice a year.
d. Ice cover	Date 90% open; Lakes: thickness in 5 places, monthly in several lakes.
e. Snow depth	Lakes: 10 places at random; monthly on several lakes; same date as ice measurements. Wetlands: site-specific.
2. Precipitation	On site, by weight; daily or weekly; same as terrestrial.
3. Dewpoint, wind, other weather data	Same as terrestrial.
4. Hydrology	
a. Water level	Four a year, including maximum and minimum.
b. Discharge inlets and outlets	Continuous (possible daily) at all streams and lakes, if possible.
5. Solar radiation	Same as terrestrial. Streams: integrated ozalid papers at stream surface or canopy closure estimates.
6. Water transparency	Secchi disk and adsorbance at 320-350 nm (on filtered samples), every two weeks.
7. Morphology	Streams: full channel cross sections at benchmarked locations once a year at base flow. Wetlands: high and low water annually. Lakes: aerial photo-graphy, at least every 5 years.
8. Tidal Fluctuation	Tidal max/min; time and height.
9. Salinity	Daily max/min and time, at same location as tidal fluctuation.

10. Dissolved oxygen Daily max/min, at same locations as other sample sites.

For certain measurements, it may be most appropriate to utilize a sampling system on an event-related basis (e.g., "rainfall") rather than on the usual continuous basis (which is costly in terms of both data storage and reduction). Such an approach involves recording only the time at which a parameter has changed by a predetermined amount and requires minor adaptation of existing hardware and software. This design will reduce the total amount of information collected, yet allows the acquisition of the pertinent data.

For several physical measurements, such as air, water and soil temperatures, wind speed, short- and long-wave radiation, and others, cumulative totals are needed. They should be collected in addition to, not in place of, periodic measurements. Potentials for accommodating this measurement approach should be outlined; the choice of measurements taken on a cumulative basis may be site-specific, although a standard approach is encouraged.

2. Dab reduction: For data processing, the "continuous" (through-the-day) records should be processed and stored as single number-per-day estimates as well as the original "continuous" record. Examples are max/min and the average daily temperature, the daily heat sum on a 0 degree C and 5 degree C basis, the cumulative daily short-wave and sensible radiation, average daily wind speed and direction, total daily precipitation and average and max/min daily dewpoint.

It should be emphasized that the limited physical measurements program being outlined at this time is not intended nor designed as a full characterization of a site but is simply a minimal, standard, long-term record of certain aspects of the physical environment. Other measurements will be necessary on a site-specific basis and for testing specific hypotheses. The measurements listed in Tables 1 and 2 eventually will be cast in terms of instrument specifications in order to achieve the expected standardization among sites. These specifications are expected to be complete and available as supplemental reports (for most items) by the time decisions must be made on initiating research at proposed sites.

PANEL III: CHEMICAL MEASUREMENTS

In considering which basic chemical measurements should be included in a program of long-term ecological research, the panel took note of the usual temptation to include too many parameters, thereby making the program unworkable. For each measurement proposed for a primary site, essential need for the core research questions was considered. If a particular measurement was regarded as peripheral to those questions, the panel decided to postpone a recommendation or have it included in investigator-specific research (at least for the time being), rather than in the core of data to be taken at every site.

The list of possible measurements discussed by the panel was based on those presented in the report of the second Woods Hole conference (NSF 1978). Some measurements were added to the list, others deleted and most modified in some way, based first on the above criterion. Other criteria entered into the decision as well, including issues such as agreed on methods of measurement and data handling so that results would be useful.

The possibility of using a mass balance approach in chemical studies was also discussed. This would be desirable, particularly at sites consisting of complete watersheds, and the measurements listed below are designed to achieve this calculation.

In many cases the exact procedure for taking a sample, or the specific method for making a measurement, has not been included in this report. The panel had to leave these items for later consideration, but expects to be able to provide additional specifics in the months ahead. There are several reasons for this:

(i) For some measurements, different procedures are possible depending on a variety of site-specific variables which currently cannot be assessed. In these cases it should be the responsibility of program participants and advisors, in conjunction with the network coordinator's office, to make a determination of the appropriate procedure.

(ii) Another reason for lack of exact procedures is uncertainty at this time about the relationship between chemical and other measurements to be taken and archived as a part of a primary site study. The availability of samples taken for other purposes might justify making certain chemical measurements (e.g., chemical measurements on biotic sampIes). For the present, this seems to be a question best left to the participants as the program becomes better defined. With time, for example, the network coordinator's office may find a particular measurement is being made as a part of investigator-specific research at many of the sites; the program as a whole might wish then to recommend that the measurements be standardized and added at all other sites.

The sections below were written by individual members of the panel and reflect the discussion of the entire panel. Each section represents a type of measurement to be made (or at least considered), and for which standard procedures will be recommended. The section on the general problem of archiving samples seems especially important in light of the limited number of measurements to be made initially. In reviewing these proposed measurements the reader should keep the following questions in mind:

* Is a mass balance necessary and can it be obtained?

* How many sampling stations should there be for each LTER site?

* What should be the frequency of sampling?

* What is the best equipment to use for each measurement?

* What specific methods should be used for each parameter? What standard methods manuals are available?

* Should pollutant parameters, e.g. Pb and Hg, be measured?

* Wetlands and marine systems are not considered.

* How should they be treated?

These questions and others will be considered further by the panel as it tries to reach final recommendations. All of the proposed measurements are summarized in Table 3.

Table 3. Summary of Chemical Measurements Considered tor Primary LTER Sites

Measurement	Sampling	Parameters
ATMOSPHERIC		
Wet Fall	Volchok sampler, weekly samples	Total and free acidity, pH alkalinity, conductivity, S04, P04, N03, NH4, Cl, K, Na, Ca, Mg, total carbon, total phos-phorous, total nitrogen
Dry Fall	Volchok sampler, weekly samples	Consistent with NADP network (see text)
Particulates	Vacuum pump	
Gases	Continuous	C02, S02, N0x, 03
TERRESTRIAL		
Soil	Annual composite samples from per-manent plot (see text)	Organic matter, pH, total carbon, cation exchange capacity, exchangeable cations, total phosphorous, ortho-phosphate, distilled water extractable phosphorus, total nitrogen, N03, NH4, S04
Lysimeters	(see text)	
AQUATIC		
Streams	Weekly volume--integrated composite	S04, P04, N03, NH4, Cl, K, Na, Ca, Mg, total phosphorous,

	samples	total carbon, total solids
	Weekly grab samples	Conductivity, temperature, pH, D0, alkalinity
Lakes	Vertical profile just after spring turnover and just before fall turnover	Temperature, pH, dissolved oxygen, conductivity
	Surface and bottom composite water samples at above times	S04, P04, N03, NH4, Cl, K, Na, Ca, Mg, total phosphorous, total carbon, alkalinity, Mn, total and dissolved Fe
Sediments	(see text)	

ARCHIVED SAMPLES

Samples of all of the above, except gases, should be preserved in appropriate archiving media. (see text)

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1. Atmospheric Chemical Measurements

(i) Wet Fall - Each site should expect to join the National Atmospheric Deposition Program (NADP), which is developing standardized procedures for a national network of wet and dry fall collection and chemical measurement (J. Gibson, personal communication). The Volchok sampler, for example, is used at each site, and precipitation is analyzed for a variety of standard parameters by a central laboratory, the Illinois State Water Survey. Quality control is monitored by the USGS in cooperation with EPA and DOE. In addition to standard Atmospheric Deposition network parameters, total carbon, nitrogen and phosphorus should be measured. Measurements for trace elements, pesticides and other compounds may be done as required.

(ii) Dry Fall - This is currently measured as part of the NADP network and should be monitored at LTER sites according to network standard procedures. However, current methods do not provide reliable measurements suitable for comparisons among sites. Improved technology is expected within the next year or so, and participation in the NADP network will make these new methods available to LTER sites.

(iii) Particulates - Airborne particulates can be sampled by filtering large volumes of air with vacuum pumps. This system has the advantage of detection and quantification of these materials at low concentrations. The degree of correlation with passive dry-fall collectors is unknown at this time, but vacuum collection may provide a better estimate of the content of the atmosphere.

(iv) Gases - Each site should measure C02, SO2, N0x and ozone on a continuous basis, with data stored on magnetic tape for output as desired. These measurements will be expensive but seem necessary as an indication of the types of stress to which some sites may be exposed.

2. Terrestrial Chemical Measurements

(i) Soil - A permanent sampling plot should be established in the major soil type of a site and sampled annually; more plots can be established as the site develops. Because of great soil variability, even in small plots, a number of cores should be taken at random in the plot and composite samples made. Three composite samples, each consisting of ten core segments, are suggested. The core should be segmented into the following sections: a) organic litter layer, b) mineral soil to 1 cm, and c) 10 cm sections for the remainder, except that no segment should bridge a visible boundary between soil horizons. The actual length of each segment should be recorded, as well as the thickness of each horizon. Site managers should obtain the service of experienced soil surveyors for this phase of the work. Cores should be taken to a depth of 150 cm in the first year and every ten years thereafter; cores in intervening years should be 45-60 cm deep.

A complete chemical analysis of each segment need be done only on the 150 cm cores every ten years. In the other years, only the organic layer and the top 1 cm of mineral soil need to be analyzed; the other segments should be archived. The soil measurements are seen as a detector of long-term change in the system, with the top layers being the most sensitive indicator. The lower layers will show change more slowly; archiving of the samples will allow reconstruction of the chemical history of the site in the event of contamination incidents.

(ii) Lysimeters - The measurement of water moving through the soil has obvious application to mass balance questions. However, there are important problems concerning reliability, type of ecosystem being monitored and the soils present. Lysimeters seem important in watershed studies, but are less useful in arid regions where there is little or no water moving through the soil. Some investigators doubt that Iysimeters can be operated continuously, or whether intermittent measurements are useful. Others ask whether they work equally well in all types of soil. A recommendation on this type of measurement remains open to discussion.

3. Aquatic Chemical Measurements

(i) Streams - Chemical measurements on streams should be done in coordination with hydrologic measurements. Weekly volume-integrated composite samples should be taken in the presence of a preservative. Two parallel samples probably will be necessary, each preserved in a different manner. This sampling method can be modified to take advantage of special conditions. Weekly grab samples should be taken where preservation is inappropriate.

(ii) Lakes - Sampling in lakes should be done just after spring overturn and just prior to fall overturn in order to have measurements at the beginning and end of the growing season. In other than dimictic lakes. different sampling times might be used, but samples should be taken at least twice each year. Some parameters should be measured along a depth profile, while others need to be measured in the epilimnion and hypolimnion. Each of the latter samples should be a composite from at least 3 stations within the lake.

(iii) Sediments - The chemical composition of sediments in lakes and streams probably should be determined but major questions exist concerning methodology and the meaning of results. On the one hand, many systems have bioturbation, storm mixing or poorly understood processes of movement among chemical constituents within the sediments. In other systems stable sediments exist, but questions have been raised as to sampling routinely when the information is being archived naturally by the sedimentation process.

4. Archiving

The discussion of archiving methods being presented here is intended to be general but applicable to a broad number of analyses which may be needed in the future. The suggested methods are also intended to be appropriate at investigator-specific research sites where highly sophisticated equipment may not be available. There also may be a need to preserve additional samples using preservation techniques for specific analytical needs.

(i) Precipitation - Three replicated composite precipitation samples should be placed in permanent storage at-10 degrees C for each of the four seasons of the year.

These samples should consist of approximately 125 ml (4 oz.) of precipitation and should be prepared by adding proportional amounts of each weekly precipitation sample (uncontaminated) to an accumulating seasonal sample which is kept frozen. The amount of sample to be added each week is based on the amount of precipitation for that week and the anticipated precipitation for that season. The sample collection and container system should be constructed of polyethylene. This method of sample accumulation requires that the entire sample be thawed and mixed prior to any future analyses. Use of the sample for as many purposes as possible should be encouraged if it is removed from permanent storage.

(ii) Vegetation - Plant tissue samples should be dried in moderate heat (60-70 degrees C) or by Iyophilization, then ground to pass a 0.5-mm (BS 35) mesh screen. The sample then should be thoroughly mixed, and a subsample of approximately 25 g placed in permanent storage. This storage should be a cool, dry location.

(iii) Soil - Samples of both the organic layer, if present on the surface of the soil, and the various layers of mineral soil should be dried at 40•° C prior to being placed in permanent storage. Exposure to higher temperature may reduce the value of these samples for future extraction since it may alter the exchange characteristics of clays and organic colloids. Storage should take place in a cool, dry location.

PANEL IV: BIOLOGICAL MEASUREMENTS

Determining which biological measurements should be made by standardized methods at every site in an LTER system has proven very difficult. Procedures for many types of biological measurements have not reached a consensus form. A large number of worthwhile measurements may be contemplated only in investigator-specific studies, at least for the time being.

Thus, the panel has recommended fewer standardized biological measurements than were suggested in the first two conferences on long-term ecological measurements (NSF 1977, 1978). These conclusions have resulted from recognition of the major biological differences among potential sites and a concern that strict standardization of variables and processes to be measured would result in collection of information inappropriate to some sites. The panel was divided about the value of many of the potential long-term measurements, the desirability of standard measurements across ail sites, or even the usefulness of long-term data sets unless collected to test specific hypotheses. These concerns are allayed considerably if investigator-specific studies can be undertaken, in part, as a means of considering the appropriateness of standardizing certain types of measurements.

Despite these reservations, sufficient concern existed for the establishment of long-term ecological research at a variety of sites across the U.S. that the panel agreed to proceed, where possible, to recommend the types of data to be obtained and the techniques to be used for certain measurements at primary sites. As a general principle, the panel saw merit in the possibility of specifying a minimum level of performance for the individual measurements needed in parts of the core research program outlined in Part I. A performance requirement would obligate investigators to keep a retrievable record of the sampling design and frequency, to adopt statistically acceptable sample designs, and to follow methods which have been described in the scientific literature and found to be valid.

Some of the essential information on biological components at core research sites falls in the category of initial site characterization (species lists, reference collections, vegetation mapping, etc.) and has been summarized in the Panel I Report. The other biological measurements to be standardized across sites include:

(i) Primary production - Carbon uptake by plants is one of the fundamental variables being recognized as a part of the core research at primary sites. Methods for measuring and evaluating primary production will vary somewhat from arid regions (with long dormancy periods) to humid or tundra regions, and should be chosen as appropriate for each ecosystem type. The methods should be reviewed for compatibility across sites as the long-term measurement program develops and the sites are chosen. Related measurements include the phenology of dominant plant species, leaf area in each vegetation stratum, tree measurements to aid in estimates of biomass production rate, and amounts of litterfall and accumulated dead material.

(ii) Population estimates - Changes in the abundance of certain populations representing different trophic levels should be monitored. These include small mammals, large herbivorous mammals, predatory animals, certain bird species (especially those controlling insect and small mammal populations) and insects (flying forms and those present on vegetation). The techniques will necessarily be site- and taxon-specific, but they must provide population estimates (density or biomass) as appropriate. The rationale for selection of a particular species for long-term censusing should be provided by the developer of each proposal.

It is expected that permanent sampling plots or grids will be used as a reference system for reproducing sampling points. In addition to providing abundance or density estimates for various taxa at each site, certain species should be chosen for detailed population analysis. Data to be obtained include statistical, interpretable information on abundance/age-class distribution, fecundity and mortality schedules, and genetic information utilizing gross phenotypic characteristics and/or protein electromorphs. The methodology for obtaining this information will necessarily vary with the species involved. Species chosen for these studies should include keystone species (if they can be identified in the particular ecosystem), regulator or other influential species, dominant species, and rare or endangered species.

Table 4. Biological measurements at aquatic sites

Biological Variables	Sampling Plan
Phytoplankton, Chlorophyll a, and Zooplankton 1, 2, 3	Streams: (large rivers only) site-specific. Lakes, coastal marine: planktonic primary production and organisms should be sampled at such frequency as to include periods of maximum production and be associated with major events such as upwelling, water column turnover or stagnation. Kill and fix specimens in buffered 3% formaldehyde. Freshwater wetlands, tidal marshes: investigator-specific studies.
Periphyton species composition, chlorophyll a Macrophytes species composition, cover, biomass1	Streams: scrapings or tiles or slides, winter-spring and summerfall; site-specific. Lakes, coastal marine, and wetlands: site-specific. Preserve as for phytoplankton.
Macrophytes species composition, cover, biomass1	Streams: every 2 years, late summer harvest; mapping. site-specific. Lakes, coastal marine and wetlands: every 2 years photomapping and harvest; biomass estimates - investigator-specific. Include camera point for rocky intertidal zone.
Fish species composition, size frequency	Streams: annual sampling by electro-fishing--investigator-specific. Lakes and coastal marine: annual sampling mid-summer using a variety of gear or individual modifications as required to sample migratory forms--investigator-specific: e.g., fyke net, boom shocker, vertical gill net, minnow traps, seining, diving survey. Preserve subsamples in 5% formaldehyde with borax; freeze small subsample of predators' muscle and liver with gall-bladder intact.
Benthos, numerical density and species Composition l, 2, 3	Streams: fall-winter and spring-summer. Lakes and coastal marine: February profundal, multiple cores or grabs, replicate samples. Littoral zone:

	intensive survey every 3 years, site-specific. Preserve specimens in formaldehyde and store in alcohol. Marine benthic organisms, including those from the intertidal zone should be sampled in the summer. Freshwater methods, tidal marshes: investigator-specific studies.
Birds, mammals, amphibians	Species and numbers. Streams, lakes, coastal marine, freshwater wetlands and tidal marsh: investigator-specific studies.
Genetic structure	All sites encourage population genetics studies of aquatic organisms (investigator-specific).
Paleoecology	Lakes: encourage paleolimnology study at site. Best storage is in the lake bottom or peat until needed.
Wetland and tidal marsh biota	See terrestrial section.

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1 Enumerate and archive samples.
2 Replicate samples taken quantitatively should not be mixed together.

3 Sampling frequency should follow that given in the first workshop report (NSF 1977, p. 24) unless justified otherwise.

(iii) Consumption rates (herbivory, predation, decomposition and parasitism) - Standard measurements of these carbon exchange processes should be made where feasible. Methods will also vary somewhat and should be used as appropriate for each species and ecosystem type. They should be reviewed for compatibility across sites as the program develops.

Similar procedure will apply to measurements at aquatic sites, including freshwater and marine systems, as well as wetlands. Suggested sampling procedures are given in Table 4 for selected biological variables.

The measurement procedures discussed here probably are more tentative than for any other measurement panel report at this time. This is partly due to the gradual definition of the research opportunities at the same time as the panel discussion, divisions within the scientific community about the practicality of standardizing certain types of biological measurements, and the limited time available for a consensus on procedures that can be standardized. This subject will be receiving more attention as planning for the LTER program becomes more specific. Documentation of some measurement procedures should be available in the next few months, but evaluation of others may need to continue for some time.

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