GOALS OF AND CRITERIA FOR DESIGN OF A BIOLOGICAL MONITORING SYSTEM

by

AN AD HOC STUDY GROUP

of the

ECOLOGY COMMITTEE

January 1980

SCIENCE ADVISORY BOARD

U. S. ENVIRONMENTAL PROTECTION AGENCY

Washington, D. C. 20460

EPA NOTICE

This report has been written as a part of the activities of the Ecology Committee of the Science Advisory Board, a public advisory group providing primarily extramural scientific information to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency, and hence its contents do not represent the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TASK GROUP ON DESIGN OF A BIOLOGICAL MONITORING SYSTEM

Dr. Gordon H. Orians, Chairman
Director
Institute for Environmental Studies
University of Washington
Seattle, Washington

Dr. Eileen G. Brennan
Professor
Department of Plant Pathology
Cook College
Rutgers, The State University
New Brunswick, New Jersey

Dr. John Cairns, Jr.
Distinguished Professor and Director
Center for Environmental Studies
Virginia Polytechnic Institute and
State University
Blacksburg, Virginia

Dr. Melbourne R. Carriker
Professor of Marine Studies
College of Marine Studies
University of Delaware
Lewes, Delaware

Dr. John O. Corliss
Head
Department of Zöology
University of Maryland
College Park, Maryland

Dr. Ursula M. Cowgill
Professor of Biological Sciences
and Anthropology
Department of Biological Sciences
University of Pittsburgh
Pittsburgh, Pennsylvania 15260

Dr. Shelby D. Gerking
Professor of Zoology
Department of Zoology
Arizona State University
Tempe, Arizona 85281

Dr. Bostwick H. Ketchum
Senior Scientist Emeritus
Woods Hole Oceanographic
Institution
Woods Hole, Massachusetts 02543

Dr. John J. Magnuson
Professor of Zoology
Laboratory of Limnology
University of Wisconsin
Madison, Wisconsin 53706

Dr. Ruth Patrick
Senior Curator of Limnology
Academy of Natural Sciences of
Philadelphia
Philadelphia, Pennsylvania 19103

* * *

Science Advisory Board Staff Officer

Dr. J Frances Allen
Staff Scientist-Ecologist
U. S. Environmental Protection Agency
Washington, D.C.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Recently there has been increasing interest in biological monitoring. Although sensitivity of chemical measurements has improved greatly, these measurements do not reveal or explain the effects of the measured chemicals on living organisms. The great number of contaminants being released into the environment is taxing measurement capabilities.

This report provides scientific insights into the environmental objectives to which monitoring is to contribute and suggests suitable criteria for choice of variables that are likely to be highly cost-effective for the regulatory purposes of the Environmental Protection Agency.

Biological monitoring can assist the Agency's major monitoring functions by

- providing advance signals of undesirable environmental changes;
- providing important data for determining the causal relationships between contaminants and their mixtures and the responses of living organisms;
- helping to determine whether regulations are being followed; and
- providing knowledge of the actual responses of living organisms to different levels and mixtures of contaminants in the environment.

Biological, chemical, and physical monitoring are all useful in assaying changes in the structure and function of ecological systems. Biological monitoring must be an essential component of any environmental monitoring system for the following reasons:

- Only biological monitoring can directly measure a biological effect: toxicity is a biological concept.
- Monitoring living organisms, which serve as continuous monitors of environmental conditions, can often be less expensive than attempting to maintain continuous chemical monitoring systems.

- Living organisms, which accumulate and concentrate chemicals in their tissues, can increase the sensitivity of measurements.

- Living organisms are the ideal system for determining the effects of complex mixtures of contaminants.

- Biological monitoring can be sensitive to a broad array of complex environmental disturbances.

A biological monitoring program should be broad in scope to help identify important pollutants and other stresses on ecological systems whose effects have not yet been appreciated. A biological monitoring system should also be continuous over time to help formulate a picture of the natural variability in ecosystem structures and processes.

A useful biological monitoring system will develop and change with time, yet must maintain sufficient consistency so that earlier and later data can be compared and the differences interpreted.

The findings in this report are not intended to replace anticipatory studies of ecological systems. This report concentrates upon processes that are sufficiently well known so that their usefulness as signals of events is already clear. It is urged that biological monitoring be developed, in part, at sites where long-term ecological studies are taking place. This should increase the chances of discovering unanticipated processes and consequences of significance.

This report is an attempt to select biological monitoring procedures that should be useful in the concept of rapidly changing technological and ecological events. It is hoped that the suggestions in this report will form the basis for a long-term monitoring program that will be as relevant in the future as it is now and one to which future components can be added.

GOALS OF AND CRITERIA FOR DESIGN OF A BIOLOGICAL MONITORING SYSTEM

I. INTRODUCTION

The Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) has defined monitoring as "the systematic collection for a predetermined purpose of intercomparable measurements or observations of any environmental variable or attribute." Monitoring involves measurement of (a) substances in various compartments of the environment; (b) the physical, chemical, and biological status of the various compartments or environmental media; and (c) the nature and magnitude of effects of various perturbations on physical, chemical, and biological targets in the environment.

Until recently the emphasis of environmental monitoring programs has been toward more precise measurement of specific contaminants. This has been stimulated by substantial improvements in our abilities to measure exceedingly small amounts of these substances and by the nature of existing legislation, which tends to be oriented toward specific chemicals. This very success has led to an increasing interest in biological monitoring because (a) the finer the level of chemical measurement, the less certain we become of the real environmental significance of what we are measuring, and (b) the large number of contaminants currently being released into the environment means that little can be learned about their combined effects without looking at the living organisms, including humans, whose health and welfare the regulations are really designed to protect.

The main objective of a biological monitoring program is to signal the likelihood of ecological and human health implications of introducing various quantities of materials into the environment. Ideally, it would be desirable to have some of these consequences expressed as effects on ecosystems. However, because ecosystems are highly plastic in their structures and responses, there are no simple diagnostic parameters of ecosystem disruption. The biotic components of ecosystems, however, are integrators of the interactive webs of cause and effect. Therefore living organisms can be used both as monitors of the movements, accumulations, and modifications of materials and as monitors of the biological effects of those materials. Criteria and standards for contaminating materials should be based on knowledge of their effects and why it is advisable to keep perturbations of ecological systems within certain limits. Monitoring of a physical or chemical nature can only tell us the quantities of those materials in the environment. Biological monitoring is needed to tell us what these materials are doing.

This report provides scientific insights into the environmental objectives to which monitoring is to contribute, develops suitable criteria for choice of variables to be monitored, and suggests specific variables that are likely to be highly cost effective for the regulatory purposes of the Environmental Protection Agency (EPA). These are difficult tasks because the number of species and interactions in natural and human-modified communities of living organisms is so large that only a small fraction can ever be monitored. Given the large amounts of money likely to be invested in biological monitoring programs, careful thought must be given to the design of a program prior to initiating it.

A program of biological monitoring must be accommodated within the overall framework of monitoring within the EPA. Biological monitoring can aid the four major functions of monitoring for the Agency in the following general ways:

(a) Anticipatory/Research Monitoring

Monitoring that provides advance signals of change in the environment that may be undesirable from the human point of view. Knowledge of these changes can provide guidance for research activities designed to determine more precisely the nature of these changes, their causes, and probable cumulative effects.

(b) Regulatory Development

Effective and reasonable regulations must be based upon solid knowledge of causal relationships between contaminants and their mixtures and the responses of living organisms. Monitoring provides data important or necessary for determining these relationships.

(c) Enforcement of Regulations (Including Self-Monitoring)

Monitoring is necessary to find out if regulations are actually being followed.

(d) Evaluation of Programs and Regulations

Judgments of the effectiveness of regulations must ultimately be based upon knowledge of the actual responses of living organisms to different levels and mixtures of contaminants in the environment. No amount of chemical and physical monitoring, however precise, can provide this information.

Biological, chemical, and physical monitoring are all useful as ways to assay changes in the structure and functioning of ecosystems. Biological monitoring is an essential component of any environmental monitoring system because:

(a) Only biological monitoring can directly measure a biological effect. Environmental regulations are designed to protect living organisms, not to achieve a certain level of some chemical in the environment. Toxicity is a biological concept.

(b) Living organisms serve as continuous monitors of environmental conditions and may accumulate and preserve in their tissues records of past conditions. Such a record can be obtained, in many cases, far less expensively with living organisms than by attempting to maintain a continuous chemical monitoring system.

(c) Because many living organisms accumulate and concentrate chemicals in their tissues, they can increase the sensitivity of measurements.

(d) Increasingly, environmental problems involve understanding the effects of complex mixtures of contaminants. Knowing the effects of these substances, individually or in simple mixtures, may reveal little about their effects in complex mixtures. Living organisms constitute the ideal system for determining the effects of these complex mixtures. Species differ strikingly in their responses to different contaminants; they can also modify some compounds into products that may cause unanticipated changes in ecological systems.

(e) There are many broadly based stresses on living organisms arising from complex disturbances which include not only microcontaminants, toxic substances, and nutrients, but also stream modification, dredging, filling, draining, exploitation of living resources, introductions and invasions of exotics, and changing land use such as forestry and agricultural practices. Biological monitoring, properly designed, can be sensitive to a very broad array of disturbances.

The importance of biological monitoring is strikingly illustrated by cases where environmental pollution problems were first identified by responses from living organisms. For example, plants have played an important role in the identification of air pollution problems. In the 1950's, chemical tests of polluted air in the Los Angeles Basin revealed a strong oxidizing power and large quantity of unburned hydrocarbons, but it was the nature of vegetation damage that identified the most toxic components of the complex mixture. Silvering of the undersurface of foliage of certain plants was associated with an unknown compound later identified as peroxyacetylnitrate (PAN) (Stephens et al., 1961). Similarly, stippling of the upper leaf surface of grape was associated with the occurrence of ozone. Today PAN and O_3 are considered the most important oxidants in the air. That other phytotoxic oxidants may be present in the air is suggested by specific responses of other plants (Heck, 1978).

Fluoride pollution of the atmosphere from specific point sources has sometimes been detected first by damage to vegetation. Accumulation of lead (Pb) and cadmium (Cd) in vegetation growing along our highways has provided evidence that the source of these toxic compounds is traffic-related. The detection of heavy metals, especially in food crops, has resulted in further studies with animals and humans.

The existence of a daily pulse of water with high concentrations of heavy metals in the Sacramento River below Keswick Dam was first detected by high mortality rates of salmon. The sources of the metals were abandoned mines, but analysis of surface waters of the water column in the reservoir of the Keswick Dam had failed to reveal the presence of heavy metals. However, diatoms placed in the river below the dam plasmolyzed at about 5:00 p.m., and water sampling at that time revealed the presence of heavy metals. Subsequently, it was established that the pulse of metals in the water was caused by the opening of the Shasta Dam gates at noon for production of peaking power. Four hours later these waters reached Keswick Dam, causing turbulence to agitate the bottom sediments containing the metals. These sediments then passed through the gates of Kewsick Dam, and the colloids were sorbed onto diatoms and the gills of fish. The continuous and easy monitoring provided by the diatoms enabled rapid pinpointing of the precise time of day when heavy metals were present in the water column.

Animals have also been useful in identifying environmental problems ever since coal miners carried canaries into the mines as quick indicators of carbon monoxide concentrations. Some geochemical prospecting is being done in Finland (Boyle and Garrett, 1970) by utilizing trained dogs to

locate mineral deposits by detecting sulfur dioxide that emanates from oxidizing sulfide minerals. Canadian companies are currently financing a project to investigate a broader use of canines for geochemical prospecting. Termites are being used as assistants in geochemical prospecting in deserts of South Africa because they may burrow as deep as 160 meters to find water and carry earth particles from those depths to their earthen homes near the surface.

Despite these important contributions, the potential for biological monitoring has just been touched.

Focus of This Report

The orientation of this report is toward the four major roles of monitoring in EPA (page 4). We show when biological monitoring can provide data more difficult to obtain by physico-chemical methods, and when biological monitoring can be more cost-effective. We recognize the importance of quality control, data storage and retrieval, and methods of analysis of samples, but we do not provide specific suggestions on those topics. We also recognize the potential value of remote sensing systems for detecting changes in communities of plants and animals but this technology lies outside the scope of this report. We also exclude monitoring of groundwater, because physical and chemical methods are superior to biological ones for that important component of the environment. We also dwell only briefly on the important topic of biological monitoring in the open ocean because responsibility for that activity lies primarily with other agencies. Our attention is directed toward the overall goals of a biological monitoring system, criteria for selection of species, their attributes and biological processes to be measured, criteria for site selection, and interpretation of results.

The recommendations contained in this report are not intended to replace anticipatory studies of ecological systems to reveal underlying processes whose importance for the activities of the EPA are not now evident. Instead we concentrate upon processes that are sufficiently well known that their usefulness as signals of events are already clear, and we urge that biological monitoring be developed, in part, at sites where long-term ecological studies are taking place because this should increase the chances of discovering unanticipated processes and consequences of importance.

II. PRINCIPLES OF BIOLOGICAL MONITORING

A. SOME BASIC CHARACTERISTICS OF ORGANISMS AND THEIR ENVIRONMENTS OF IMPORTANCE FOR MONITORING

Only a small fraction of the millions of living species can be monitored: those few should be selected to be representative of broad categories of organisms whose responses are expected to be similar to those of the test species. The basic characteristics that should guide the selection process include the following:

Trophic Level. A monitoring program should include organisms at all trophic levels because species in each group may be exposed to different human-caused stresses and different concentrations and forms of contaminants because materials are modified by other organisms and because pollutants are concentrated and accumulated in the tissues of organisms at each trophic level. Thus, a monitoring program should include both the effects of stressors on the environment and the effect of the "environment" on stressors. The kinetics of biotransformation influence residence times of materials and are, therefore, important for the selection of test methods.

Structural Complexity. Living organisms range from relatively simple unicellular species to large and complex multicellular forms. Associated with these levels of tissue and organ complexity are striking differences in metabolic rates, ability to assume resting stages, longevity, patterns of biotransformation of ingested materials, bioaccumulation capabilities, mobility, and diet. Therefore, monitoring should include organisms covering a broad range of structural complexity.

Life History Characteristics. All organisms grow, reproduce, and die, but they differ widely in the ways in which these activities respond to environmental stress, as follows:

(a) Longevity: Short-lived organisms respond quickly to rapid environmental changes, long-lived ones integrate stresses over several years or decades.

(b) Growth: Species with high metabolic rates and, hence, rapid growth are often more sensitive to contaminants than are species with lower metabolic rates. Rapid growth rates are often characteristic of species adapted for rapid colonization of disturbed sites.

(c) Reproduction: Species allocate different proportions of their energy budgets to reproduction. The rate and success of reproduction are often the most sensitive responses of a species to perturbations. Therefore, monitoring reproductive rates is often a good way to detect biologically important perturbations.

(d) Defense: In addition to seeking food, living organisms devote some of their resources to avoiding being eaten. Some species have physical and chemical defense mechanisms while others do not. This may have important consequences for their responses to perturbations.

(e) Mobility: Some organisms are sessile, while others move easily, thereby escaping areas with high concentrations of contaminants. At the same time, by their movements they may transport contaminants to new areas.

B. THE COMPONENTS OF A BIOLOGICAL MONITORING SYSTEM

Biological changes can provide the first signals that something needs to be examined more closely and can indicate where attention needs to be directed. Because these signals must be detected over a background of natural variation, a monitoring program must be broad in scope and continuous in time. Continuous data over long time periods provide a picture of the natural background of variability in ecosystem structures and processes, causes of which are still largely poorly understood, without which the nature of human-induced changes cannot be estimated. A broad approach is also important because many important pollutants and other stresses on ecological systems have not yet been identified and many new ones are certain to be created. Any monitoring system geared to known pollutants will quickly become outdated. Moreover, breadth of the program is important if the biological impacts of complex mixtures of pollutants are to be demonstrated.

A useful biological monitoring system must develop and change with time, but it must also maintain enough consistency so that earlier and later data can be compared and the differences interpreted. Methods must also be consistent geographically to permit meaningful comparisons of results among different regions of the country. Because of the many differences among ecological systems and species, few species are widely enough distributed to occur in all, or even most, areas where monitoring is needed. However, there may be groups

of species, usually closely related to one another, that are similar in their responses to perturbations that can serve as relatively uniform monitors. Thus, by careful selection of species and processes to monitor, differences caused by changes in associated species can be distinguished from differences caused by variable environments and, hence, the conditions to which the species are exposed.

We have attempted to select biomonitoring procedures that should be relatively insensitive to rapidly changing technical and ecological events. Hopefully, our suggestions will form the basis for a long-term monitoring program which will be as relevant in the future as it is now and which will remain a part of the basic program to which future components can be added.

Important aspects of biological monitoring are measurements of species richness and the rates of important ecosystem processes. Much can be learned about an ecological system from an enumeration of species present and estimates of their relative abundances. Shifts in basic metabolic process, such as the increase in respiration rates due to increased bacterial use of organic nutrients, as measured by the biological oxygen demand (BOD) of a system and the resulting reduction of dissolved oxygen (DO), may also provide important clues about ecosystem processes. The concentration, distribution, and rates of recycling essential plant nutrients, such as available nitrogen, phosphorus, and silicate, can give clues about the enrichment or impoverishment of an ecological system. The concentration of critical compounds can indicate important ecosystem processes. For example, chlorophyll and phaeophytin are indices of photosynthetic potential of an ecosystem, and measurements of ATP or RNA are indices of its total biomass and heterotrophic capacity. In terrestial systems, where measurements of useful rates are much more difficult to obtain than in aquatic, for the present at least, a monitoring system should focus on responses of particular species rather than on system level processes.

Biological monitoring can be easily coordinated with a program of chemical monitoring, and the biological data can greatly enhance our ability to interpret the causes and significance of observed changes in chemical parameters. For example, a progressive increase in standing crops of certain kinds of organisms can presage eutrophication of the ecosystem; nutrient measurements may identify potential causes.

Knowledge of the species or species groups in the community is needed for interpreting measures of structure and processes in communities of organisms. Caution is necessary when interpreting measurements of species richness or ecosystem processes. While such measurements can give quantitative assessments of rates, these measurements may not reflect

important changes in the quality of the populations involved. For example, high rate of primary production can be due to unpalatable species as well as to those that are valuable as food for herbivores. Many blue-greens and some small green algae are not ingested or digested by herbivores and may accumulate to nuisance levels in ecosystems.

C. IMPORTANT CRITERIA FOR SELECTION OF SITES FOR BIOLOGICAL MONITORING

Sites for anticipatory monitoring should be established with a view to their long-term utility because the value of monitoring data increases with the length of time over which they are available. Also, as pointed out previously, the value of biological monitoring data is increased by the availability of prior and concurrent physical and chemical monitoring from the same sites. The following criteria are important for selecting anticipatory monitoring sites:

(a) Sites should represent the major terrestrial, freshwater and marine ecosystems in the United States.

(b) Sites should include natural ecosystems and those that have been perturbed by human activity.

(c) Site-specific programs should utilize available regional pools of trained scientists and laboratories.

(d) Sites with previously gathered data on physical, chemical, and biological processes are preferable to those without such data.

Monitoring to determine the efficacy of regulatory standards and to detect potential violations of those standards must be carried out at sites close to specific polluting facilities and in areas where concentrations of one or more pollutants are known to be close to the limits established by regulation. Wherever possible such monitoring should be preceded by a process of hazard evaluation that estimates the risks to an ecological system. This process requires evidence about (1) toxicity -- the inherent property of the chemical that will produce harmful effects to an organism (or community) after exposure of a particular duration at a specific concentration (the same strategy may be used for other stressors such as suspended solids or heat); and (2) environmental concentration --those actual or predicted

concentrations resulting from all point and nonpoint sources as modified by the biological, chemical, and physical processes acting on the chemical or its byproducts in the environment (Cairns, 1978). This is the predictive control in Figure 1 from Herricks and Cairns, 1979. A more detailed description of the hazard evaluation process may be found in Cairns et al. (1978). Protocols for this purpose are in Cairns and Dickson (1978).

If this process is carried out, the biological monitoring can serve to verify the predictions, leading to broader understanding of underlying processes. It also provides an error control if either the predictions (i.e., hazard evaluation) were inaccurate or the recommended concentrations were exceeded. Systems useful for evaluating the effectiveness of regulations are of two types: (1) early warning systems, which expose organisms before the material enters the ecosystem (van der Schalie et al., 1979) and (2) receiving system monitors that determine biological response after the material had entered the aquatic or terrestrial ecosystem (Patrick and Strawbridge, 1963). Various techniques for both purposes in use in a number of industrial countries are described in Cairns et al. (1977). A summary of the literature on early warning systems may be found in Cairns and van der Schalie (in press).

Network monitoring involves periodic collection of information at a large number of sites that are not specifically identified by an existing problem. Selection of these sites depends upon both the importance of gathering information from a variety of different environments and the availability of volunteers available to cooperate with the program. In each case, the specific questions to be answered or patterns to be detected must be articulated before the monitoring needs appropriate to those issues can be established. A substantial amount of network monitoring is already being carried out, and any new system should make full use of such activities, among which are the integrated Mussel Watch program of EPA and the monitoring of the Delaware River and its estuary.

D. THE UTILITY OF BIOLOGICAL MONITORING FOR EPA'S GOALS

As indicated previously, monitoring serves four major roles for the Environmental Protection Agency. They are (1) Anticipatory or Research Monitoring, (2) Monitoring for Regulatory Development, (3) Monitoring for Enforcement of Regulations, and (4) Monitoring for Evaluation of Programs and Regulations. We now consider how these roles can be furthered by biological monitoring activities.

1. Monitoring for Anticipatory and Research Needs

An important goal of any regulatory agency is to anticipate problems so that corrective action can be taken in time to avert or at least diminish their impact. Because our knowledge of the biological effects of chemicals is so meager and because we are annually developing so many new chemicals about which nothing is known, it is clear that the EPA needs to take advantage of all useful sources of advanced warning information. Living organisms are especially suited for this purpose because they are inevitably exposed to all environmental contaminants whether or not we know about them or have decided to measure them. Therefore, living organisms are the best possible signals of environmental events that need timely investigation. For example, if a certain plant species begins to exhibit a new type of injury symptom of unknown cause, some new air pollutant may be involved. The nature of the injury may also suggest the probable type of contaminant.

Living organisms can also be useful in the reverse manner. For example, if a new pollutant is identified, EPA may wish to search for a plant species that exhibits unusual sensitivity toward that contaminant to provide a conspicuous environmental "marker."

For living organisms to be useful, however, it is not sufficient to collect and store specimens and data. All materials need to be analyzed promptly and the results disseminated to researchers and regulators so that there can be quick, appropriate responses to the information. Unanalyzed specimens and samples may be of retrospective use, but they can contribute little to our ability to anticipate problems, initiate suitable research, and develop appropriate regulations.

2. Monitoring for Regulatory Development

The heart of development of regulations is the preparation of criteria documents. Adequate criteria require knowledge not only of effects close to the source of the contaminants but also of the patterns of their movements, the sites of their accumulation (if any), and their modes of breakdown.

The amount of accumulation varies with the species, the chemical, exposure time, and age of organisms. For each program those organisms should be used that are known to have rapid and high accumulation rates. Ratios between amount accumulated, rate of water flow, and time of exposure for each site are highly useful and should be developed as quickly as possible.

3. Monitoring for Enforcement of Regulations

Promulgation of regulations does not guarantee that they will be observed. In fact, the level of violations can be expected to be inversely correlated with the intensity of monitoring activities capable of detecting such violations. This type of monitoring will generally be source specific, and the systems designed to measure directly the output of particular point sources. Even here, living organisms have important advantages because they preserve in their tissues records of past pollution events. Therefore, collection of tissues and their analysis on only an intermittent basis can provide a continuous record of past episodes and, hence, violations of regulations.

Biological monitoring can also involve people living near point sources of pollution. For example, small gardens in which an array of plants with different sensitivities to air pollutants are planted can provide opportunities for citizens living near major point sources of pollution to both monitor progress made in cleaning up the air and to detect sudden changes. People are generally more interested in and more impressed by actually observing spots developing on the leaves of familiar plants than they are in hearing figures about the number of parts per million of some pollutant in the atmosphere.

4. Monitoring for Determining the Effectiveness of Regulations

The purpose of regulations is not to achieve some level of an environmental contaminant for its own sake but to protect the health and welfare of living organisms, including humans. Therefore, the ultimate test of the efficacy of a regulatory program is its effects on living organisms. The decision concerning what level of protection we desire and are willing to pay for is a political one. However, the evaluation of whether we have, in fact, achieved a politically-determined desirable objective is a technical problem to which biological monitoring can and should make a key contribution. Substantial progress has been made in the design of biological monitoring systems for point source pollution. The general monitoring of changes in species abundances and distributions, growth rates, and fecundity reveal a great deal about how well living organisms are doing. Therefore, most of the monitoring programs we will suggest should contribute to the ongoing process of evaluating the progress toward the attainment of desired standards of environmental quality.

III. RANK ORDERING OF PRIORITIES

An ideal biological monitoring system would require commitment of resources beyond those likely to be available in this country on a sustained basis. Therefore, though we regard all aspects of the monitoring program suggested in Appendix A as being important, we feel compelled to offer some suggestions for the type of program that might best be implemented under different levels of funding. To make this more explicit, we imagine a monitoring program with low, medium, and high levels of funding and indicate those components that we feel should be carried out at each of these three levels. Our decisions are not made simply on the basis of the importance of certain kinds of information. We also give heavy weight to the utility of information that can be gained with little effort. Some of our suggestions, though vital to a good biological monitoring scheme, require considerable investment of funds if they are to be attempted at all. Our suggestions are summarized in Table 1, and the arguments for them are contained in the Appendices.

The use of air pollution gardens, honeybees, fur and skins of mammals, feathers and eggs of birds for terrestrial environments and diatoms as measures of aquatic productivity are excellent for a low level funding program. The advantage of utilizing these indicators is that they may make use of amateurs and existing personnel in different governmental agencies and offices, are simple to coordinate, and provide quick indications of important environmental quality problems.

The use of lichens and other plants as detectors of heavy metals, insects at ultraviolet lights, molluscs, fishes, and retrospective monitoring of sediment cores require more funds if they are to be effective. The historical record in sediment cores is being effectively stored in natural systems at no cost, and its treasures can be tapped during periods of good resource availability. There is no need for such a program to be continuous other than the value of sustained funding of laboratories to maintain a pool of qualified scientists to carry out the work.

Monitoring of outbreaks of defoliating insects and analysis of sediments in lakes are judged to be less cost-effective than our other suggestions and are most suitable for a monitoring program with a high level of funding.

We emphasize that these are tentative judgments based on our current assessment of the needs of the EPA and the extent to which different biological monitoring methods have been developed. Changes in regulatory needs and new advances in monitoring techniques and interpretations will, of course, alter these judgments.

The entries in Table 1 should not be taken to mean that any one of the components at level one should be fully developed before any of the components at level two are initiated. Rather, those aspects of the program suggested for implementation at low funding levels can and should be increased at moderate funding levels at the same time that additional components of the program are activated. We have not attempted to provide details as to how much of each general type of activity should be carried out at each of the vaguely defined funding levels. Questions of specifics of design must be addressed when actual resources are known and the extent of cooperation with other governmental agencies has been determined. The advice of biologists should be sought again at that critical time.

TABLE 1

Activities best suited for an anticipatory biological monitoring program at different levels of funding. Judgments are based on current status of ecological knowledge.

	ACTIVITY	UTILITY	LOW LEVEL OF FUNDING	MEDIUM LEVEL OF FUNDING	HIGH LEVEL OF FUNDING	APPENDIX A (pages)
TERRESTRIAL	Higher plants as air pollution detectors	Pollution effects	X	X	X	21
	Lichens	Pollution effects		X	X	22
	Heavy metals monitoring with plants	Pollution effects		X	X	24
	Insects at ultraviolet lights	Pollution effects		X	X	27
	Outbreak of defoliating insects	Accumulation of toxicants			X	26
	Honeybees	Accumulation of toxicants	X	X	X	26
	Fur, feathers, and eggs	Accumulation of toxicants	X	X	X	29, 30

TABLE 1 (Continued)

	ACTIVITY	UTILITY	LOW LEVEL OF FUNDING	MEDIUM LEVEL OF FUNDING	HIGH LEVEL OF FUNDING	APPENDIX A (pages)
AQUATIC	Diatoms	Pollution effects	X	X	X	32
	Bivalue molluscs	Accumulation of toxicants		X	X	33
	Fishes	Pollution effects		X	X	34
	Aquatic productivity	Pollution effects	X	X	X	35
	Species richness in aquatic environments	Pollution effects	X	X	X	35
	Sediment analysis	Accumulation of toxicants	X	X	X	41
	Retrospective analysis of cores	Accumulation of toxicants		X	X	42

IV. IMPLEMENTATION OF A BIOLOGICAL MONITORING SYSTEM

The details of implementing a program of biological monitoring are outside the scope of this report. Nonetheless, it is appropriate to include a few remarks of a technical nature that are particularly important if a biomonitoring program is to be genuinely useful.

Quality Control. A monitoring system can be no better than, though it can be worse than, the quality of the measurements it gathers. Therefore, it is necessary to use high quality instruments and to institute a regular program of calibration of all instruments used. There needs to be an adequate training program for all technicians using that equipment and close supervision by project leaders. Careful thought should be given to standardization of techniques prior to initiation of the program and rigid adherence to those techniques unless a system-wide decision is made to initiate some change.

The value of stored specimens and samples also depends upon the adequacy and uniformity of storage conditions. Storage is too costly in human resources and money to be done poorly. Many existing collections are of limited use for retrospective analysis because of improper conditions of storage.

Data Retrieval. Monitoring programs generate enormous quantities of data, which are likely to be useless unless stored in a readily retrievable form. Even more important, however, is that there needs to be a clear idea why the data and materials are being gathered. If a real need for the data is felt by the persons gathering the information and by those involved in its storage and maintenance, then the information is likely to be examined and interpreted. If this need is not perceived, the data are likely to be neglected. Therefore, it is important that persons involved in all aspects of the monitoring program be thoroughly informed of the goals and objectives of the program and that they receive regular updates on progress, interesting results and actions taken because of the monitoring program.

Interpretation. Masses of data do not automatically tell interesting stories. Data become valuable when analyzed by qualified persons who understand the patterns that exist, are alert to different types of changes and what they may signify, and who know what should be done in the event that certain anomalies appear. Great volumes of computer printouts may be impressive, but their utility is directly proportional to the qualifications of the persons examining them and the time and resources that are allocated to their interpretation on a regular ongoing basis. There is little value in starting a monitoring program without a serious commitment to the analysis and interpretation of the data.

Updating the System. As mentioned previously, there is considerable value in uniformity of measurement techniques and consistency of types of measurements in space and time. Therefore, we have attempted to suggest programs which are likely to be useful for long time periods. For this reason specimen and sample banks are likely to be very useful because those materials are available for analysis in the future for new pollutants and by new techniques. Therefore, they are likely to be valuable for new problems and analytical methods not anticipated when the system was initiated.

Coordinating a Biological Monitoring Program with Existing Activities. There is substantial biological monitoring activity already underway in the United States. For economy of human and financial resources, it is important to integrate EPA's monitoring program with those of other agencies. Also, the value of biological monitoring data will be enhanced if specimens are gathered in areas where there is also extensive physical and chemical monitoring. This will enable the relationships between the results of biological monitoring and physico-chemical events to be better understood. As a consequence, the predictive power of biological monitoring will be increased. Personnel of other Federal and state agencies can also be employed in a nationwide monitoring program. Other ways in which interagency cooperation could be developed that would enhance the capabilities of all the units involved should be vigorously explored.

Amateurs can be usefully employed in a nationwide monitoring system. This not only provides a substantial increment to the human resources available, but it also involves citizens in efforts to improve their environments. If people feel that they are a part of efforts to enhance the quality of life, they will be more supportive of such efforts and better informed about the prospects and problems associated with them. For many years, the National Audubon Society has utilized large numbers of amateur ornithologists in an annual breeding bird census of many habitats in the United States. Some of these records provide the longest continuous censuses of bird populations anywhere in North America. Many interesting trends in species abundances and distributions have been revealed by these censuses. Similar projects involving persons interested in other taxonomic groups, such as butterflies and flowering plants, could be very productive.

Appendix A

PROCESSES AND TAXA FOR BIOLOGICAL MONITORING SYSTEMS

To supplement our suggested goals of a biological monitoring program and the criteria by which sites, taxa, and processes can be selected, we offer here specific suggestions for events to monitor in terrestrial and aquatic environments. The selection is not intended to be comprehensive but rather indicative of processes that are currently adequately understood so that the Task Group could judge their practicality and the circumstances under which they would be useful. As ecological knowledge and insights increase, additional processes and taxa will emerge as suitable for inclusion in an evolving biological monitoring program, and the same or similar criteria can be employed in their selection.

BIOLOGICAL MONITORING IN TERRESTRIAL ECOSYSTEMS

The efforts of hundreds of ecologists throughout the world involved with the International Biological Program (IBP) have clearly demonstrated the great time and effort required to obtain even rough estimates of rates of basic terrestrial ecosystem processes. Moreover, because terrestrial productivity is highly sensitive to normal variations in temperature and precipitation, changes due to human-induced stresses are difficult to detect over the high levels of background "noise." For these reasons productivity measurements, although ultimately of great importance, are not currently well suited to an extensive biological monitoring program where cost-effectiveness is of prime consideration. However, sites where productivity is being measured may be excellent ones for incorporation into a monitoring network because those measurements will enhance the value of the monitoring data.

Our suggestions center around the use of selected groups of terrestrial organisms having one or more properties of special utility for anticipatory and regulatory monitoring. Because of their size, complexity, and dominance in terrestrial systems, we begin with vascular plants, then consider simpler plants and, finally, animals.

1. Higher Plants as Air Pollution Detectors

Higher plants can function as a very effective air pollution detection system because of the sensitivity of certain species to particular pollutants and because characteristic symptoms are exhibited following acute exposures to different gases.

In the 1950s, smog was a familiar phenomenon in California, but the toxic components of photochemical oxidants were unknown until they were revealed by plant assays. Lesions on bean, spinach, and grape leaves indicated the presence of ozone (Middleton, 1956) and on annual bluegrass indicated the presence of peroxyacetylnitrate (Bobrov, 1955). Should another toxicant be released into the environment some other plant species might be affected by it before the atmospheric chemist recognizes it.

In the last 25 years, detailed descriptions have been published of species that are sensitive to the major pollutants and of symptoms that are readily recognizable. An array of colored prints has been indexed in <u>Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas</u> (Weinstein and McCune, 1970). These so-called indicator plants are extremely useful in delineating air pollution episodes. Bel W3 tobacco has been used extensively in the United States and Europe as an indicator of ozone contamination. Heck and his associates (1969; 1970) developed the technique. In a recent publication on photochemical oxidants by the National Academy of Sciences (1977), Heck concluded that the response of Bel W3 tobacco can provide estimates of the frequency of occurrence of phytotoxic concentrations of oxidants, the relative severity of each episode, and the regional distribution of oxidant pollutants.

Thus, there is considerable return for little money. Although tobacco is a good indicator of oxidant phytotoxicity, it is not a good indicator of oxidant concentrations in the ambient air. (Heck, 1977). Tobacco injury does not correlate well with oxidant concentrations on a weekly basis, probably because other environmental factors influence plant response. This is a significant shortcoming, but chemical and meteorological data alone do not give a clear picture of the biotoxicity of air pollution episodes either.

Weinstein and McCune (1970) have advocated the use of plants as indicators of HF pollution. To ensure success, they have urged that the planted plots under observation meet the criteria of uniformity in general background and cultural maintenance, sufficient abundance, sufficient sites in the area to account for pollutant dispersion, a species composition that will develop specific symptoms, and sufficient variety of plants to represent a range of susceptibility.

2. Simpler Plants as Air Pollution Indicators

Simpler terrestrial plants such as lichens and mosses have no vascular tissues; rather, they absorb water and nutrients directly from rainwater and air. They also absorb pollutant particles from airborne or substrate-borne water solutions. Short-term sensitivity of lichens to toxins is no greater than that of vascular plants, but, because lichens absorb and concentrate pollutants much faster than vascular plants, toxic effects appear sooner.

Because SO_2 absorbed into tissues converts chlorophyll to phaeophytin, which is nonphotosynthetic, exposure to SO_2 reduces photosynthetic capacity. Presumably it is the accumulation of toxins from prolonged exposure that retards or halts vegetative growth and reduces or prevents reproduction. The effect is faster and/or more pronounced on lichens with a more luxuriant growth form, that is, with a greater surface-to-volume ratio. Also, the effect of toxins is greater if humidity is high, perhaps because high humidity allows absorption to proceed faster.

A useful index for detecting the effects of air pollution on lichens is Lichen Species Diversity, a measure combining both the number of species present and their relative abundances. Abundance is conveniently measured in terms of extent of coverage of substrate area, but growth form and degree of luxuriance can also be entered into the index.

Lichen species diversity declines with increasing levels of SO_2 pollution in the air and declines with increasing levels of other toxins, such as heavy metals, on substrates. Its decrease is caused by reduction in the number of species and in the abundance (areal coverage) of each species, particularly because abundant species usually decline in abundance more than others. In general, fructicose lichens become proportionately more rare in number of species and in real coverage per species than foliose lichens, and foliose become more rare than crustose.

To diagnose pollution, one must compare lichen species diversities on affected and unaffected areas with the same sampling method on comparable sites. Important site conditions include:

(a) Substrate. Boles of living, vertical, unshaded trees are best because they are exposed to wind; their poor buffer capacity does not mask SO_2 levels (high pH weakens SO_2 effect), and they have high lichen species diversity in unpolluted areas. Where trees are absent, acid stonework, the top foot of free-standing sandstone walls, granite tombstones, old asbestos roofs, or calcareous stonework can be used instead.

(b) Shelter. Pollutants which get trapped in thermal inversions, such as SO_2, have less effect in sheltered valleys and narrow ravines than on exposed ridges.

The accuracy of lichen species diversity is high if a scale which measures the abundance of a large number of species on uniform substrate, shelter, and humidity is used. Experiments show that SO_2 and at least some heavy metals (zinc and

cadmium) are toxic and strongly reduce the photosynthetic capacity of lichens after short-term exposure. Also, the negative correlation of lichen species diversity with distance from pollution source is close and corresponds to levels of mean ambient SO_2 concentration measured electronically.

3. Plants as Monitors of Levels of Heavy Metals

About 45 years ago Goldschmidt (1937) and Vernadsky (1934) showed that some elements were accumulated by humus and vegetation. As a result of their discoveries, the use of biological methods in search for deposits of important minerals began to be developed. The basic underlying assumption is that a given element in the substrate, bedrock, or soil will be accumulated in a repeatable manner by a specific plant, and that a high quantity in the plant will indicate a high quantity in the substrate. The studies of Cannon and her co-workers, (1960; 1964), carried out on the Colorado Plateau on the distribution of uranium in plants, facilitated the discovery of several uranium ore bodies. This approach to the discovery of the presence of elements could also be employed by EPA. Furthermore, because contamination of the environment by toxic amounts of elements will be indicated by the presence or absence of certain plants, this observation could be used as a monitoring device.

In certain portions of Utah where the apiary industry suffered from an abnormal loss of bees, it was discovered that the death of bees was caused by selenium toxicity from their pollinating of seleniferous plants. Seleniferous plants were spreading into that region in large enough numbers to account for the observed bee mortality. An enhanced distribution of seleniferous plants has also been observed elsewhere on the western slope of the Rockies.

In a study concerning the distribution of lead in plants growing near Canadian highways, Warren and Delavault (1960; 1967) showed that gasoline exhaust from cars and trucks is distributed in and on vegetation growing near highways and that plants in such an environment could accumulate as much as 1,000 ppm of lead in their ash despite the fact that they grew far from any area known for lead mineralization.

Not all plants react in the same fashion to the anomalous quantities of an element or an assemblage of elements in the bedrock. Certain species of plants, such as <u>Astragalus bisculcatus</u>, will grow only where there is a specific element or assemblage of elements present, in this case selenium. The selenium accumulators of the genus <u>Astragalus</u> are universal indicators; if they are present there is at least 2 ppm of selenium in the soils. They will not grow in the absence of selenium, although their accumulating ability may vary from season to season as well as from one growth state to the subsequent one (Cowgill, 1979).

Some plant species will grow in an environment and accumulate one or more elements if present, but if these elements are absent the plants grow perfectly well. A typical example of such an accumulator plant is hickory (Carya spp.) which grows quite well in the absence of rare earths, but which accumulates them in high quantity when present, suffers no ill effects, and even manages to deter insect predators from its leaves (Robinson, Whetstone, and Scribner, 1938; Robinson, Bastron, and Murata, 1958).

Plants known to accumulate specific elements are listed in Appendix B.

The use of indicator accumulator plants and physiological and morphological changes in plants, brought about by excess quantities of elements, have both advantages and disadvantages as a system in biological monitoring. The advantages are:

- Plant roots extend into areas that are not immediately obvious to the observer and hence may provide information more easily and more quickly than soil and rock sampling would readily provide. Trees, for example, may have an extensive root system which might provide information on the amounts of chemicals in the groundwater 40 m below. Furthermore, plants with extensive root systems, such as Astragalus, sample a much greater area and volume of soil than one would normally obtain in a soil survey.

- Plant samples are easier to collect, are lighter than soil, and are easily identifiable by a botanist.

- Interference problems in chemical analysis are minimal in plant material as compared to soils, rocks, and lake and river bottom muds.

The disadvantages are:

- Trained botanists are needed to correctly identify the plants, and trained field workers are required for the sampling.

- Other factors, mostly physical, such as drainage, slope, soil type, age differences, available moisture, and pH can have an effect on the chemical composition of a plant.

- A statistically adequate number of individuals of a given species must be available in the sampling region.

- Plant samples are far more susceptible to contamination than soils, rocks, and muds. Greater care is required in their collection, handling, storage and maintenance.
- Background levels of elements of interest in natural vegetation in uncontaminated regions must be determined. This requires collection of much basic chemical information not currently available.

4. Honeybees as a Monitoring System

Bees and the materials they carry back to their hives are already being used to determine the distribution and abundance of a variety of pollutants including more than 40 elements, among which are copper, zinc, phosphorus, cadmium, lead, arsenic, fluoride, and sulfur. Bees also accumulate radioactive substances leaking from waste disposal areas or power plants. Radioactive fallout materials from such natural sources as the radionuclide beryllium formed in the stratosphere and from the Chinese atmospheric weapons tests have been detected in the bodies of bees. The materials available for analysis are pollen, honey, water, and the bees themselves. Chemical analyses of pollen are well suited for the detection of particles that settle out of the air.

An important advantage of using bees as monitors is that there already exists an elaborate network of commercial beehives covering most of the United States. It is a simple matter to collect bees at the entrances to their hives with a vacuum apparatus and freeze them immediately on dry ice. Beehive operators could readily become directly involved in routine collection of bees and in preserving small amounts of honey at the time of annual collection.

5. Monitoring of Outbreaks of Defoliating Insects

Outbreaks of defoliating insects are an important environmental problem throughout the world. They cause severe economic losses, and attempts to control them may involve use of dangerous or controversial pesticides. Physical and chemical stresses on plants, both natural and human-induced, may reduce their abilities to defend themselves against insects (White, 1974; Rhoades, 1979). There is evidence that insect outbreaks are more likely to occur downwind from large factories and power plants then elsewhere in the same general region. If these activities increase the frequency and severity of such outbreaks, serious regulatory problems may arise.

The U. S. Forest Service has a program for monitoring outbreaks of a few forest pest species, but insufficient attention is being paid to subeconomic level infestations and their dynamics. An integrated monitoring system of potentially outbreaking insects and, in particular, relating such a system to patterns of pollution-caused stresses on forest trees would be a valuable source of information. The personnel needed to carry out these surveys are already employed by the United States Government, but their collective activities do not constitute a useful monitoring system.

6. Monitoring of Insects at Ultraviolet Lights

Entomologists have long collected insects at night by the use of ultraviolet lamps (black lights). Such lights are general attractors of insects, and little can be learned about exactly where the insects came from and what they were doing. In addition, the numbers and kinds of insects arriving at UV lights are highly dependent upon immediate weather conditions. This makes it difficult to detect overall trends in insect populations. Nonetheless, entomologists have observed, for example, that many large moths no longer come to black lights in the northeastern states; other losses of species groups might be noted if there were more careful monitoring of arrivals at black lights.

A potentially useful way of accomplishing such a program would be to utilize personnel manning the large number of U.S. Forest Service lookout stations throughout the United States. These persons should have ample time to collect insects at black lights on a limited number of nights during the summer; however, such a program should not be initiated unless a system of regional storage and identification centers, such as the proposed system of regional taxonomic service centers which has been vigorously proposed by the Entomological Society of America and by the Assembly of Life Sciences of the National Research Council, has been established. Otherwise the result is likely to be vast but uninterpretable collections of insects.

7. Monitoring of Terrestrial Vertebrates

Terrestrial vertebrates are generally large and conspicuous and attract a great deal of attention. Moreover, they are physiologically more similar to humans than other organisms and can be expected to respond similarly to a variety of environmental contaminants. Birds and mammals are the most promising of terrestrial vertebrates for these purposes. Birds can, for example, absorb some toxicants through their feet, and roosts have been treated with fenthion and endrin to control birds. Fowle (1972) demonstrated that birds that perch on phosphamidon-treated twigs can be killed. Takemoto et al. (1974) reported that pigeons living in highly industrialized areas of Japan developed lung pathologies when aerial pollution

levels were only one-tenth the value of those that produce analogous pathologies in human lungs. Available information suggests that birds may be good monitors of both gaseous and particulate pollution (Lewis et al., 1978; Takemoto et al., 1974; Tashiro et al., 1974; Takemoto, 1972; Neal and Olstrum, 1971).

Birds exhibit many characteristics that make them potentially good pollution monitors. They are conspicuous, generally day-active, typically live above ground, and fly at levels where gaseous and other respirable pollutant levels may be highest. The lungs and respiratory tract are particularly valuable for monitoring air pollution. In contrast, ingested pollutants probably selectively affect the liver and the kidney. Small birds, especially when in flight, have very high metabolic rates, and the external respiratory system probably acts very much like a high volume sampler. Birds are relatively long-lived, and life histories of most are well known. Of considerable importance, also, is the fact that birds are well known and readily identifiable. There is more information on the population biology and behavior of birds generally than for any other class of animals, and there is an excellent fund of knowledge on the physiology of birds.

Birds typically deposit large fat stores in winter or prior to migration. Thus, they are especially good accumulators of lipophilic pollutants and are often subject to delayed mortality, since the residue may be sequestered in the fat bodies until they are mobilized during molt, migration, or incubation.

Mammals vary greatly in behavioral and ecological characteristics, showing the greatest extremes in size, metabolic rate, and life span among terrestrial animals. Small mammals, especially the more abundant rodents, can be collected easily, although populations may fluctuate widely from year to year. Many species in mid and high latitudes hibernate and are only seasonally available. Burrowing species may have limited exposure to many pollutants.

As pointed out by Lewis and Lewis (1978),there is considerable species variation among small mammals in susceptibility to pollutants. However, adults of the small rodent species that are most amenable to study (e.g., Peromyscus, Microtus, Rattus) appear to be highly resistant to direct acute and sub-acute exposures to most of the more common pollutants. The abundant and widely distributed deer mouse, Peromyscus, appears to be practically unaffected by normal or even heavy applications of various pesticides (Robel et al., 1972). This species can tolerate ten times as much dietary DDT as can the laboratory mouse (Cordes, 1971).

The potential use of small mammals as air pollution monitors has been given very little attention. Elevated body concentrations of lead have been demonstrated in small mammals along major highways. Yamaoka et al. (1973) reported a number of increases in organ weights (e.g., lungs, kidneys, adrenal glands, and spleen) of experimental rats after 30 to 100 days of exposure to urban air (relative to controls).

8. Systematics Collections

Museum and herbarium collections have been frequently employed for retrospective analysis. For example, laboratories assessing transport and effects of pesticides began using museum materials collected before the 1930s as "blanks" for purposes of chemical comparison. Vertebrate materials assayed in the past have included bone, soft tissues, hair, skin, feathers, or nails. Products such as eggs have also been assayed. A number of special types of museum collections such as comparative serological collections, alcohol preserved tissues, and freeze-dried specimens are also of potential importance. (Lewis and Lewis, 1978).

> "Sampling strategies and methods of preservation and storage of general and research collections are not generally satisfactory for chemical analyses of pollutants that are widely distributed in nature. Nevertheless, used with care, museum collections may prove very valuable. Such collections are often more amenable to biological monitoring and therefore, play a supportive role in relation to specimen banks designed for retrospective chemical analyses." (Lewis and Lewis, 1978)

Also, according to Lewis and Lewis (1978), hair and feathers are a major excretory route for some chemicals such as methyl mercury, heavy metals and radionuclides. The treatments and preservatives employed for most museum skins to prevent infestations by pests are an important source of contamination, but integumental structures are stable under normal museum management. Appropriately cleaned, they can provide valuable information on the extent of historical pollution by trace contaminants such as lead, arsenic, cadmium and mercury (Dorn et al., 1974; Gordus et al., 1973).

However, there is considerable doubt as to the usefulness of using most soft-bodied museum specimens for determining past levels of metals in the environment. Collection techniques, large and sometimes unknown variations in preservatives, and lack of knowledge of the handling of specimens subsequent to collection usually prevent confident utilization of museum specimens for this purpose (Nat. Mus. Nat. Hist., 1976).

Several programs to use and expand taxonomic collections for monitoring purposes are already in existence. They include the National Pesticide Monitoring Program and the National Environmental Specimen Banking System. The latter system is intended to provide monitoring data for an environmental early warning system and well preserved and documented environmental samples for future retrospective analysis. Its stated objectives are to (1) conduct a survey and evaluation of existing specimen collections in the United States, (2) organize a planning committee to evaluate the feasibility of such a banking system, (3) develop a five-year plan for carrying out the work, and (4) develop a program to establish criteria for sample collection, preparation, storage, and analysis (Rood and Goldstein, 1977).

Road kills, though they represent non-random samples of hard-to-collect mammals, may be a valuable source of information on population densities, reproductive rates, and accumulation of toxicants. Hunters' bags have already proven useful in wildlife management surveys including pesticide monitoring. Wings of mallards, black ducks, and mourning doves have been monitored nationwide for pesticide residues. Duck wings that were collected during the 1965 and 1966 hunting seasons were assayed for organochlorine pesticides (Heath, 1969), and the process was repeated during 1969-70 (Heath and Hill, 1974). Residues of DDE, DDT, dieldrin, and PCBs in these species have declined in certain flyways since 1969 (White and Heath, 1976).

Relationships between disease, including carcinomas, pollutant burdens, other effects, and air pollution have been observed in zoo animals (Lombard and Witte, 1959; Snyder and Ratsliff, 1969; Bazell, 1971; Tashiro et al., 1974). Because most zoos are in urban or suburban environments, and the animals may be attended by full or part-time veterinary staffs, tissues can easily be taken from healthy, ill, moribund, or recently dead animals. Clincial records, vital statistics and extensive life history information would be available on many of these animals. The value of zoos is enhanced by their global distribution which offers the possibility of worldwide monitoring of vertebrate animals.

9. Eggs of Birds

Bird eggs are readily gathered and stored, and large collections covering more than a century of activities already exist in the museums of the world. Such collections were not initially intended for monitoring environmental changes, but, with the discovery that DDT accumulation causes eggshell thinning in many birds, interest in bird eggs as indicators of environmental pollution was stimulated. To date, bird eggs have been studied to determine their altered physical properties as a result of pesticide accumulations, but eggs may also be very useful for chemical monitoring as well.

The average avian egg shell contains 99 percent solids, of which about 2 percent are organic materials (mainly protein) and about 98 percent are inorganic materials, almost entirely crystalline calcium carbonate (calcite). The organic materials include a protein-glycosamino-glycuronoglycon, glycoprotein complex, and peptides combined with galactose, mannose, fructose, and hexosamine. Thus, there is sufficient chemical complexity in eggshells to make them potentially excellent monitors of many important environmental changes. However, the possible utility of eggs has not been adequately explored, and a research program should be initiated simultaneously with a monitoring program. There is no reason, however, to delay the establishment of a systematic collection of birds' eggs, because the areas from which eggs should be taken and the kinds of species which should be represented can be established on general ecological considerations.

Extensive geographical representation is important because of differences in basic energetic and nutrient cycling processes in different types of ecosystems and because pollution loads vary geographically. A variety of bird species with different diets is important because species feeding low on the food chain are exposed to quite different concentrations of many pollutants in their food from species much higher on the food chain.

The bird species selected should be common in the region, and approximately ten sets of eggs from each habitat type should be collected once every five years. Sampling more often is not likely to reveal important trends not detectable by a less frequent sampling schedule.

10. Tissues and Products of Domestic Animals

It is possible to collect and bank regulated animal products such as milk and blood. The value of such a system is that it would involve sampling of human food or non-destructive sampling of animals that are of high economic importance. For example, a number of pollutants may be excreted in relatively large concentrations in milk. It was implied that lactation was the major route of excretion of dieldrin in dairy cattle that were provided with contaminated diets (Braund et al., 1968; Lewis and Lewis, 1978).

BIOLOGICAL MONITORING IN AQUATIC ECOSYSTEMS

Because similar types of lakes and streams can be found in widely separate geographical regions of the country, aquatic sites can be especially useful in comparing anthropogenic effects among regions with different histories and degrees of development and rehabilitation. The best organisms and processes to monitor differ depending upon whether the objective is anticipatory or regulatory in nature. A monitoring program

to anticipate changes caused by human activity must be based on the fact that future perturbations are largely unpredictable. Therefore, features which signal changes in the functioning of organisms and basic processes in the communities are highly appropriate for monitoring. Special attention needs to be given to species composing the various stages of energy and nutrient transfer in the ecosystem and to those that represent sinks for various chemicals. Also important are the factors that affect ecosystem stability, the diversity of habitats in the system, and factors that influence productivity as measured by biomass and effectiveness of reproduction. Discussion of established and innovative types of monitoring are presented by Bascom, 1978; McErlean, Kerby, and Swartz, 1972; Pequegnat, 1978; National Science Foundation, 1977, 1978.

An aquatic monitoring program for determining the effectiveness of and compliance with regulations needs to be tailored to measure the effect of an outfall or non-point source on a receiving body of water. From a general knowledge of the source of pollution, an estimate can be made of probable types of perturbations. Given this knowledge, those organisms that most accurately determine the presence of those pollutants can be chosen for the monitoring system. Some generally useful aquatic organisms include the following:

1. Algae

Algae are excellent organisms for measuring the effects of pollutants entering a body of water. They may be studied by examining carefully selected natural areas or by the introduction of artificial substrates, such as glass slides or styrofoam.

Algae vary in their usefulness as indicators of different types of changes. For example:

- Eutrophication -- increases in nutrients can be estimated by increase in biomass of diatoms, Spirogyra, Oedogonium, Stigeoclonium, Cladophora, and various genera of blue-green algae.

- Heavy metals and radioactivity -- Diatoms and some other algae are known to be able to concentrate heavy metals and radioactive materials many thousand times, thus making them extremely effective collectors of those materials.

- Organic compounds -- These are accumulated by those species that store fats and oils, but more research is needed to establish the concentration factors.

2. Higher plants

Floating and rooted plants also increase in biomass with increases in nutrients. Aerial photography is an efficient way to estimate yearly changes in the extent of beds of these plants, though more detailed mapping may also be needed. The tips of Elodea leaves accumulate heavy metals and can be used to monitor the entrance of these substances into a body of water, but as yet the exact correlation between the amount that is concentrated and ambient input is not known.

3. Molluscs

Both fresh and salt water species of bivalve molluscs have been used for monitoring. The most useful species are well known biologically; are sedentary and relatively long-lived; bioaccumulate heavy metals, transuranic elements, petroleum hydrocarbons, and halogenated hydrocarbons (Goldberg et al., 1978); and preserve a record of some of these chemicals in their valves.

Species which can be employed as sentinel organisms include: Mytilus, Crassostrea, and Ostrea sp. in outer estuaries and coastal waters; Geukensia sp. and other marsh genera in tidal marshes; and Anodonta sp. and related genera in fresh water lakes, rivers, and streams (Goldberg et al., 1978; Patrick and Kiry, 1976). Bivalves can be examined in natural beds or placed in introduced substrates, either suspended from wharves or piers, or anchored to the bottom.

A few critical stations should be established along the three coasts of the United States and at the mouths of major lakes and rivers for monitoring once a year in mid-fall. By this time bivalves have completed their reproductive cycle and are "fattening" for the winter, much of the warm-season shell has been added, and if the population is growing, young of the year will have settled among the adults. Quality of the soft tissues of adults can be determined by growth rate of marked individuals, condition of soft tissues (primarily glycogen), and presence or absence of pathogenic viruses, parasites (histopathological changes), and noxious chemicals.

Determinations can be made of metals, pesticides, and hydrocarbons in soft tissues, and of metals in shell (Carriker et al., in press; Goldberg et al., 1978). The shell laid down during the previous year must be separated from the rest of the shell to provide estimates of heavy metals and radioactive nuclides for that year. Shell growth is periodic, and degree of concentration of elements varies in different layers with environmental conditions (Carriker et al., in press; Nat. Mus. Nat. Hist., 1976). Whereas chemicals incorporated in the shell remain there with some permanence, different chemicals vary in

the rate of flushing from, or accumulation in, soft parts. Additional studies are needed to determine the rate of retention and concentration of these chemicals in soft tissues, as well as the effect on their uptake of salinity, dissolved organic matter, non-filterable particles, and yearly sexual cycles. It will also be necessary to determine whether a composite sample of 25 individuals is adequate for satisfactory reduction of the sampling variance in soft tissues (Goldberg et al., 1978).

4. Insects

Insects are known to be useful as indicators of eutrophication or acidification (blackfly and chironomid larvae), various toxicants (mayflies and stoneflies), temperature changes (stoneflies), loads of suspended solids (caddisflies), and heavy metals (caddisflies). Detailed taxonomic knowledge is important because there are striking species differences in responses. For example, some species of caddisflies thrive in the presence of concentrations of heavy metals that eliminate other species. Similarly, some species of blackflies increase with stream acidification while others decrease.

5. Fishes

Fishes are economically important in most aquatic environments, and they attract considerable public attention. In addition, because of their long generation time, fishes are informative indicators of long-term changes in physical and chemical pollutants, as measured by bioaccumulation, body growth, and community changes.

Non-biodegradable materials (pesticides, heavy metals, and radionuclides) may be concentrated as they pass through the aquatic food chain until they reach the apex consumers, the fishes. Depending upon the substances to be monitored, the liver, gall bladder, flesh, and bones should be analyzed. Growth can be measured more sensitively and accurately than other physiological parameters of fishes because the history of growth rates of a fish is preserved in the annular marks in the scales and other hard parts of the body such as otoliths. Nonetheless, the significance of changes in growth rates may be difficult to determine because growth rates of fishes are sensitive to population density, food supply, and temperature as well as to concentrations of toxicants.

Systematic surveys of fish populations will often reveal the effects of some outside influence by virtue of changes in relative abundance of species, loss of species, or the presence of new invading species. Short-term impacts may be detected by behavior. Fish may avoid areas of altered temperature or

increased concentrations of toxic materials, and a noticeable migration away from an area may suggest the presence of pollution. Acute toxic responses of fishes to toxicants include the cough response, opercular movements, and abnormal activity.

A summary of the utility of different aquatic organisms for anticipatory and regulatory monitoring purposes is provided in Table A.1. Procedures are divided into intermittent and continuous activities, but the original references must be consulted for details of the intensity of data gathering needed for different purposes and for details of actual methods.

MONITORING DIFFERENT AQUATIC ENVIRONMENTS

FRESH WATER SYSTEMS

Rivers

From a chemical standpoint, streams in the United States fall into the following types:

(a) Streams of low conductivity and productivity.

(b) Streams of low conductivity but high in humates, such as blackwater streams.

(c) Streams with low calcium-carbonate hardness (less than 50 ppm).

(d) Streams of medium hardness (50-200 ppm).

(e) Very hard streams ($>$200 ppm).

(f) Streams that are rich in alkaline metals, such as sodium and potassium, and high in carbonates of various types.

The monitoring system should include streams of all of these types at various altitudes, because high altitude streams are often exposed to more fallout. Also, streams should be measured in various major ecosystems of the country, preferably in conjunction with the terrestrial monitoring program.

Monitoring rivers for anticipatory purposes and effectiveness of regulations should include the assessment of numbers and kinds of species and productivity (reproductive success and biomass) of algae, invertebrates, fishes, and other vertebrates if they occur in sufficient numbers to be important in the functioning of the ecosystem. The most important groups of organisms are benthic and vagile species. When they occur, species that live in the land-water interface should be included.

The monitoring of rivers for regulatory development and enforcement of regulations should use those organisms which concentrate or show physiological changes that indicate the pollutant in question. Useful methods include continuous field monitoring, semicontinuous monitoring, and laboratory monitoring as set forth in Table A.1.

Lakes

Lakes can be classified in a number of ways but for purposes of a regulatory agency the following characteristics are most important.

(a) Presence or absence of thermal stratification. Stratification can occur during the winter in regions where temperatures are low enough for freezing to occur and during the summer when warm layers may overlay colder, deeper water. In some lakes, however, there is sufficient mixing of water from all depths that little or no thermal stratification develops at any time of the year.

(b) Renewal rate of water. Lakes range from those in which the amount of water flowing through them is so great that the average residence time of molecules of water may be no more than a few months to a few years. In other lakes, flow through in relation to lake volume is so small that residence times of water in the lake may be decades or centuries. The responses of lakes to perturbations and restoration attempts depend, in large part, on the renewal rate of the water.

(c) Shape. Shapes of lakes determine the relative exposure of the water mass to shore conditions. Long, thin, shallow lakes are more strongly influenced by shore conditions than are circular, deeper lakes.

(d) Nutrient status. Because of differences in their drainage basins, lakes differ strikingly in their chemistry. Acid bogs low in nutrients and alkaline lakes rich in nutrients represent extremes along one chemical continuum.

Lakes differing in these characteristics respond differently to anthropogenic and natural perturbations. Therefore, a thorough monitoring scheme should include examples of lakes differing in as many of these characteristics as possible in a variety of geographical regions of the country.

The general groups of organisms and types of monitoring are the same as described for rivers. However, in lakes, plankton organisms are very important in the food web and should be monitored along with vagile and benthic species. Important processes to be monitored are reproductive success and rate of accumulation of biomass.

Table A.1. Continuous and Intermittent Aquatic Biological Monitoring judged especially useful for Anticipatory and Regulatory Purposes.

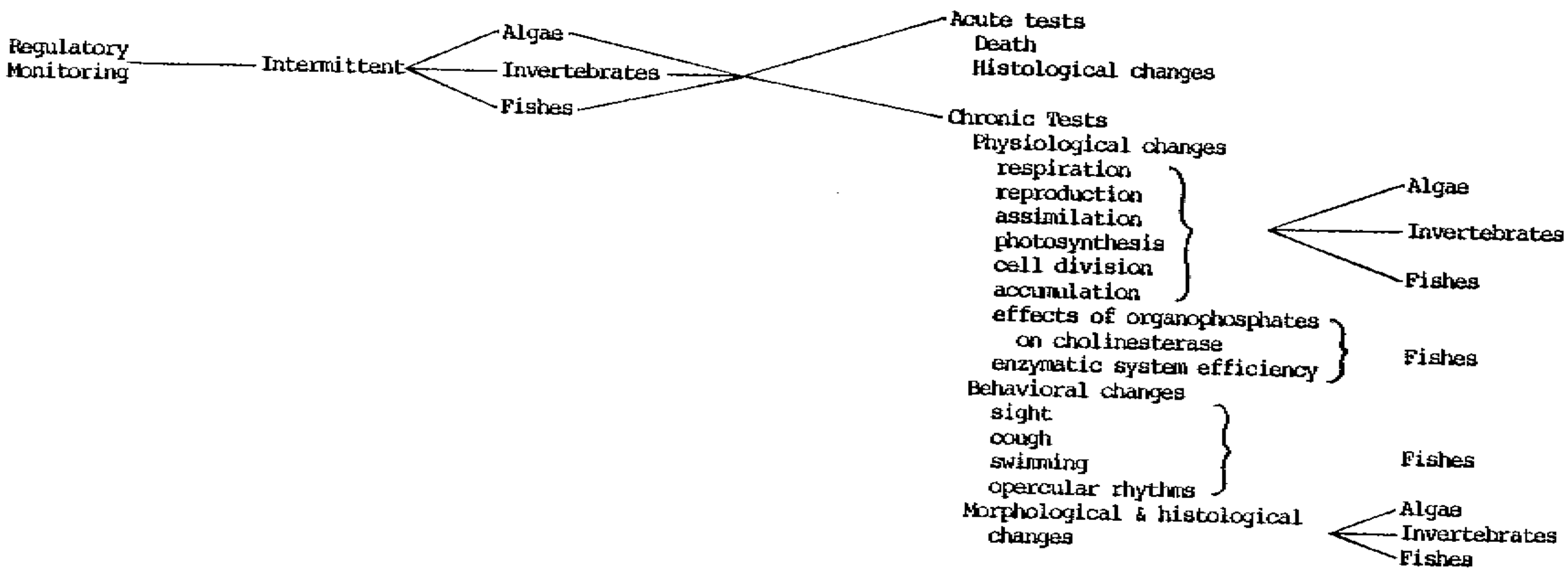
A. Anticipatory Monitoring or Program Effective Monitoring

- Intermittent
  - Biological survey -- the examination of all major groups of organisms important in nutrient transfer in the ecosystem. This is carried out by a team of trained people.
  - Suggested groups to study:
    1. Plankton species -- productivity (O_2, primary production; ^{14}C), phytoplankton, zooplankton
    2. Benthic organisms -- species, biomass, productivity; algae, protozoans, worms, molluscs, insects
    3. Aquatic macrophytes -- species, mapping size of beds, biomass
    4. Fishes -- species, relative numbers, estimate of standing crop
- Continuous
  - Algae -- artificial substrates (diatometer)
    Species, community structure, biomass, chlorophyll, ^{14}C, accumulation of insecticides and heavy metals
  - Mussels and oysters -- trays, cages, from designated beds
    Growth, condition, pests, accumulation of pesticides and metals
  - Invertebrates -- Dendy baskets
    Insects and/or Crustacea; species, numbers, biomass

Table A.1. Continued

B.	Regulatory Monitoring	Continuous	Diversion of effluent through aquaria and ponds, and mix with stream water	Algae -- on substrates Numbers and kinds of species, productivity, biomass, accumulation of heavy metals, radioactivity, pesticides and organic chemicals Fishes -- in aquaria Opercular rhythms, swimming, vision, coughing, accumulation of pesticides, heavy metals, radioactivity Mussels -- in cages Growth, feeding rates, accumulation of heavy metals, radioactivity, pesticides
			Diversion of stream or estuary water to monitor quality	Microcosms -- algae Diversity, species numbers, productivity, biomass, accumulation of heavy metals, radioactivity, and pesticides

Table A.1. Continued



MARINE SYSTEMS

Estuaries receive not only the pollutants which are added directly to the system but also those pollutants carried into the estuary by the rivers at the upper end. Conditions in the estuary reflect, therefore, all of the accumulation of pollutants from the entire drainage basin. Some of the pollutants added to the streams and rivers are, of course, sedimented or recycled before they reach the estuary; others must pass through the estuary to reach the final destination, the open sea.

Within the estuary, there is a gradual increase in salinity from the river to the offshore coastal waters. Pollutants in the estuary are gradually diluted with this increased participation of sea water in the circulation. As a result of the increased salt content and of chemical reactions with elements in sea water, some constituents are precipitated out of solution and accumulate in the sediments.

Oceanic islands, such as Hawaii, Puerto Rico, the U.S. Virgin Islands, and some coastal offshore islands, may be subjected to direct ocean dumping of pollutants that do not pass through estuaries. In such instances, biological monitoring systems would have to be implemented for purely marine communities such as coral reefs, offshore fishing banks, littoral marine communities, the marine plankton and nekton, and the marine benthos. The relevance and importance of coastal and marine communities notwithstanding, this report does not delve into communities beyond the estuary. The biological monitoring of marine ecosystems deserves additional attention by EPA.

The major regions to be monitored in marine systems are marshlands, which are the breeding and feeding ground for many invertebrates and vertebrates, and open water which is the site of plankton production, the reproductive area of fishes that spawn in the water column, and the migration paths of these organisms. The sites to be monitored should include one in the river beyond salt penetration to evaluate riverine inputs; one in mid-estuary where, under annual mean river flow, the mid-channel water column contains about equal amounts of river water and coastal water; and one at the mouth in mid-channel. Marshes adjacent to the sampling sites, if present, in each of these locations also should be monitored. In embayments, where salinity differs only slightly, or not at all, from that in outside sea water, sites should include one near the land, one in the center, and one at the mouth with companion sites on adjacent marshes if these are present.

The organisms to be monitored for anticipatory needs should represent three stages in the food web; primary producers (diatoms, blue-green algae, green algae); herbivores (oysters, mussels, crustaceans), and omnivores or carnivores

(fishes, lobsters). The specific organisms should be those most important in the food web or of commercial importance. Their growth, reproductive success, biomass, and accumulation of chemicals should be determined. Because the stage immediately following hatching is often the most sensitive, particular attention should be paid to very young animals.

For regulatory and compliance monitoring the organisms selected should be the most sensitive to a given type of pollution. For bioaccumulation of toxicants, molluscs, some attached aquatic algae, and fishes have proved most useful. For changes resulting from eutrophication, algae and attached aquatics and some types of worms are most useful.

AQUATIC SEDIMENTS

Rain and wind may bring elements such as the halogens, boron, and sulfur, and particulate matter to bodies of water far removed from their sources. Mercury (Hg) concentrations, caused by industrial activity and technological advance (Cowgill, 1975), appear in lake basins far removed from such activity. Recently, vitamin B complex has been found in rain (Parker and Wachtel, 1977), and, earlier, thiamin (Hutchinson, 1943), niacin and biotin (Hutchinson and Setlow, 1946) were noted to have a seasonal distribution in some lake waters.

Elements in water may attain concentrations that exceed the solubility product of their compounds. Minerals form *in situ*, precipitate out and slowly arrive at the mud surface. Examples include various types of calcium minerals, notably calcite, aragonite, and gypsum; iron and manganese compounds; aluminum oxides; and silicates. Aluminum and silicon minerals have been shown to be experimentally formed in water under natural conditions (Hem, Roberson, Lind, and Polzer, 1973). Presumably diatoms extracting silicon from siliceous minerals may contribute to the incidence of such compounds in the mud. Dying organisms, especially plankton, also make major contributions to elements in aquatic sediments, and their organic compounds may sorb and concentrate elements such as bromine and iodine (Mackereth, 1965, 1966; Cowgill and Hutchinson, 1966, 1970).

Few bodies of water have been thoroughly studied from a chemical or a biological viewpoint so it is difficult to come to any conclusion that would prove generally applicable. Examination of the chemical composition of the sediments alone, on the basis of present knowledge, will not provide conclusive evidence as to the state of health of a body of water. Nonetheless, a program of monitoring elements in sediments can provide valuable information on changes taking place in the watersheds draining into those bodies of water. A well-designed

monitoring program of bottom sediments should include a series of lakes and estuaries in different climatic zones with different depths and sizes, but closely matched for these traits while contrasting in the patterns of human impacts on their watersheds. Without this aspect of experimental design, changes caused by human activities cannot be distinguished from those caused by natural fluctuations in environmental conditions.

RETROSPECTIVE MONITORING OF SEDIMENT CORES

Paleoecology provides retrospective monitoring of aquatic and terrestrial environments. Changes in the remains of algae, pollen, and invertebrates and fishes may indicate general shifts in climatic conditions, the rise and fall of the coast line, as well as the effects of development in industry, forestry, agriculture, mining, urbanization, and other land uses. Microfossils can provide temporal records of past environments. Selection of sites in different regions of the country or near different types of developments can add a spatial dimension and specific information of past conditions.

A unique advantage of these methods is that the samples are presently well preserved in the bottoms of thousands of lakes and reservoirs scattered across the United States. The occurrence or relative abundance of pigment determinations and relative sizes of pollen grains indicate ecological changes in the water and on land and the effects of human activities. Thus, the past history of major changes in the landscape can be measured or recognized.

Appendix B

PLANTS KNOWN AS ACCUMULATORS OF CERTAIN ELEMENTS OR KNOWN INDICATORS OF MINERAL DEPOSITS

ALUMINUM

Lycopodium fabelliforme	Princess pine
Afzelia africana	
Lycopodium sp.	club moss

ARSENIC

Pseudotsuga menziesii	Douglas fir

BARIUM

Bertholletia excelsa	Brazil nut
Pseudotsuga douglasii	Douglas fir (?)

BERYLLIUM

Vicia sylvatica
Aconitum excelsum
Calamagrostis arundinacea

BORON

Eurotia ceratoides	winterfat
Limonium suffruticosum	statice

CHROMIUM

Leptospermum scoparium
Cassinia vauvilliersii

COBALT

Silene cobalticola
Crotalaria cobalticola

COPPER

Gypsophila patrini	karum
Acrocephalus robertii	
Ocimum homblei	basil
Merceya latifolia	copper moss
Viscaria alpina	German catchfly
Polycarpea spirostylis	pink
Becium homblei	mint

Acrocephalus katangaensis

Polycarpaea glabra
Eschscholtzia mexicana — California poppy
Tephrosia sp.
Astragalus declinatus — milk vetch
Cassia desolata
Ptilotus obovatus
Scaevola densevestita

HALOGENS

Dichapetalum cymosum--F
Feijoa sellowiana--I

IRON

Betula sp.
Clusia rosea
Dacrydium caledonicum
Damnara ovata
Eutessa intermedia

LEAD

Erianthus giganteus — beardgrass

LITHIUM

Acacia raddiana
Acacia ehrenbergiana
Thalictrum sp.
Lycium sp.
Solanum sp.
Datura sp.
Atropa sp.
Cirsium sp.

MANGANESE

Digitalis purpurea
Fucus vesiculolus
Trapa natans
Zostera nana

MERCURY

Arenaria setacea
Holostium umbellatum

MOLYBDENUM

Astragalus declinatus — milk vetch
Quercus wislizeni — oak
Q. douglasii — blue oak
Prosopis juliflora — mesquite

NICKEL

Alyssum bertolonii
Alyssum murale
Asplenium adulterium Asplenium
Pulsatilla patens
Hybanthus floribundus

NIOBIUM

Rubus arcticus
Vaccunium myrtillus
Chamaernerion angustifolium
Betula pubescens

PHOSPHORUS

Convolvulus althaeoides bindweed

RARE EARTHS

Carya sp. hickory
Candica albicans

RHENIUM

Atriplex confertifolia
Oenothera caespitosa

SELENIUM

Astragalus bisulcatus
A. diholcus
A. haydenianus
A. oocalyois
A. racemosus
A. osterhouti
A. albulus
A. argillosus
A. confertiflorus
A. moencoppensis
A. grayi
A. pectinatus
A. toanus
A. beathii
A. gastwoodae
A. gllisiae
A. crotalariae
A. pattersoni
A. preussi
A. racedens
A. sabulosus
A. saurinus

A. preusse and *A. pattersoni* also indicate the presence of U while some species of *Stanleya* indicate the absence of U.

Oonopsis golden weed
Aster venustus woody aster
Stanleya sp. Princeplum
Xylorhiza
Townsendia incana
Gutierrezia sarothrae
Neptunia amplexicaulis

SILVER

Eriogonum ovalifolioum Eriogonum
Pinus contorta Lodgepole pine
Populus tremuloides aspen
Pseudotsuga taxifolia Douglas fir
Juniperus communis dwarf juniper
Abies lasiocarpa Rocky Mountain fir
Equisetum horsetails
Lonicera confusa honeysuckle

STRONTIUM

Echium italicum
Alhage kirghisorum
Ampelopsis vitifolia
Glycyrrhiza glabra
All known analysis of the Gramineae have shown that Sr is present (dry weight) 26-410 ppm.

TIN

Sempervivum soboliferum
Pluchea quitoc
Calluna vulgaris
Gnaphalium sylvaticum
Silene inflata
Tanacetum vulgare
Quercus sessilis

URANIUM

Astragalus thompsonae
A. pattersoni
A. preussi

VANADIUM

Allium sp.
Astragalus bisulcatus
Astragalus preussi
Castilleja
Chrysothamnus
Amantia muscaria

YTTRIUM

Calamagrostis arundinacea
Dactylis glomerata
Some Ferns

ZINC

Viola calaminaria — zinc violet
Philadelphus lewisii — syringa orange
Ruta gaveolens
Thlaspi calaminare
Gomphrena canescens
Polycarpaea synardra var *gracilis*
Tephrosia polyzyga

ZIRCONIUM

Calamagrostis arundincea
Dactylis glomerata

REFERENCES CITED

Bascom, W. 1978. Coastal Water Research Project, annual report for the year 1978. Southern Calif. Coastal Water Project, El Segundo, Calif.

Bazell, R. J. 1971. Lead poisoning: Zoo animals may be just victims. Science 1973:130-131.

Bobrov, R. A. 1955. Use of plants as biological indicators of smog in the air of Los Angeles County. Science:510-511.

Boyle, R. W., and R. G. Garrett. 1970. Geochemical prospecting: A review of its status and future. Earth Sci. Rev. 6:71-75.

Braund, D. G., L. D. Brown, J. T. Huber, N. C. Leeling, and M. J. Zabik. 1968. Placental transfer of dieldrin in dairy heifers contaminated during three stages of gestation. J. Dairy Sci. 51:116-118.

Cairns, J., Jr., 1978. Hazard evaluation. Fisheries 3(2):2-4.

Cairns, J., Jr., and K. L. Dickson. 1978. Field and laboratory protocols for evaluating the effects of chemical substances on aquatic life. J. Test. Eval. 6(2):81-90.

Cairns, J., Jr., K. L. Dickson, and A. Maki, eds. 1978. Estimating the hazards of chemical substances to aquatic life. Am. Soc. Test. Mater. Spec. Tech. Publ. 657, Philadelphia, Pa. 278 pp.

Cairns, J., Jr., K. L. Dickson, and G. F. Westlake, eds. 1977. Biological monitoring of water and effluent quality. Am. Soc. Test. Mater. Spec. Tech. Publ. 607, Philadelphia, Pa. 242 pp.

Cairns, J., Jr., and W. H. van der Schalie. Biological monitoring Part I: Early warning systems. Water Res. In press.

Cannon, H. L. 1960. Development of botanical methods of prospecting for uranium on the Colorado Plateau. U.S. Geol. Surv. Bull. 1085-A:1-50.

Cannon, H. L. 1964. Geochemistry of rocks and related soils and vegetation in the Yellow Cat area, Grand County, Utah. U.S. Geol. Surv. Bull. 1176: 127 pp.

Carriker, M. R., R. E. Palmer, L. V. Sick, and C. C. Johnson. Interaction of mineral elements in sea water and shell of oysters (<u>Crassostrea virginica</u>) cultured in controlled and natural systems. J. Exp. Mar. Bio. Ecol. In press.

Cordes, C. L. 1971. Comparative study of the uptake, storage and loss of DDT in small mammals. Ph.D. thesis, North Carolina State University.

Cowgill, U. M. 1975. Mercury contamination in a 54 m core from Lake Huleh. Nature 256:476-478.

Cowgill, U. M. 1979. Variations in annual precipitation and selenium accumulation by milk-vetch. J. Plant Nutr. Soil Sci. 1:73-80.

Cowgill, U. M., and G. E. Hutchinson. 1966. A general account of the basin and the chemistry and mineralogy of the sediment cores. History of Laguna de Petenxil. Conn. Acad. Arts and Sci. Mem. 17:7-62.

Cowgill, U. M., and G. E. Hutchinson. 1970. Chemistry and mineralogy of the sediments and their source materials. Ianula: An account of the history and development of the Lago di Monterosi, Latium, Italy. Trans. Am. Philos. Soc. 60:37-101.

Cowgill, U. M., and G. E. Hutchinson. 1970a. Ianula: A summary of the history of Lago di Monterosi. Trans. Am. Philos. Soc. 60:163-170.

Dorn, R. C., P. F. Phillips, J. O. Pierce III, and G. R. Chase. 1974. Cadmium, copper, lead and zinc in bovine hair in the new lead belt of Missouri. Bull. Environ. Contam. Toxicol. 12:626-632.

Fowle, C. D. 1972. Effects of phosphamidon on forest birds in New Brunswick. Can. Wildl. Rep. Ser. 16:1-25.

Gerloff, G. C., D. D. Moore, and J. T. Curtis. 1964. Mineral content of native plants in Wisconsin. Wisc. Univ. Agric. Exp. Sta. Res. Rep. 14:1-26.

Goldberg, E. D. et al. 1978. The Mussel Watch. Environ. Conserv. 5(2):101-125.

Goldschmidt, U. M. 1937. The principles of distribution of chemical elements in minerals and rocks. Chem. Soc. J. 1:655-673.

Gordus, A. A., C. C. Mather III, and G. C. Bird. 1973. Human hair as an indicator of trace metal environment exposure. Pages 164-487 in Proc. 1st Ann. Nat. Sci. Found. Trace Contam. Conf., Aug. 8-10, 1973, Oak Ridge, Tenn.

Heath, R. G. 1969. Nationwide residues of organochlorines in wings of mallards and black ducks. Pestic. Monit. J. 3:115-123.

Heath, R. G., and S. A. Hill. 1974. Nationwide organochlorine and mercury residues in wings of adult mallards and black ducks during the 1969-70 hunting season. Pestic. Monit. J. 7:153-164.

Heck, W. 1977. Plants and microorganisms. Pages 437-566 in ozone and other photochemical oxidants. Nat. Acad. Sci., Washington, D.C.

Heck, W., F. Fox, C. Brandt. and J. Dunning. 1969. Tobacco, a sensitive monitor for photochemical air pollution. Nat. Air Pollut. Contr. Admin. Publ. No. AP-55, Cincinnati, U.S. Dept. of Health, Education and Welfare. 23 pp.

Heck, W., and A. Heagle. 1970. Measurement of photochemical air pollution with a sensitive monitoring plant. J. Air Pollut. Contr. Assoc. 20:97-99.

Hem, H. D., C. E. Roberson, C. J. Lind, and W. L. Polzer. 1973. Chemical actions of aluminum with aqueous silica at 25°C. U.S. Geol. Surv. Water-Supply Pap. 1827-E.

Herricks, E. E., and J. Cairns, Jr. 1979. Monitoring and mitigation of aquatic hazards. E. R. Fredericks (ed.). Pages 220-231 in Control of specific (toxic) pollutants. Air Poll. Contr. Assc. Spec. Conf.

Hutchinson, G. E. 1943. Thiamin in lake waters and aquatic organisms. Arch. Biochem. 2:143-150.

Hutchinson, G. E., and J. K. Setlow. 1946. Limnological studies in Connecticut. VII. The niacin cycle in a small inland lake. Ecology 27:13-22.

Lewis, R. A., and C. L. Lewis. 1978. Terrestrial vertebrates as biological monitors of pollution. Contribution to the International Workshop on Monitoring Environmental Materials and Specimen Banking. Berlin, German Federal Republic. October 1978. 36 pp.

Lewis, R. A., M. L. Marton, M. D. Kern, J. D. Chilgren, and E. M. Preston. 1978. The effects of coal-fired power plant emissions on vertebrate animals in southeastern Montana (a report in progress). Pages 213-279 in The biological environmental impact of a coal-fired power plant. Third interim report. EPA-600/3-78-021.

Lombard, L. S., and E. J. Witte. 1959. Frequency and types of tumors in mammals and birds of the Philadelphia Zoological Garden. Cancer Res. 9:127-141.

Mackereth, F. J. H. 1965. Chemical investigations of lake sediments and their interpretations. Proc. R. Soc. (B) 161:295-310.

Mackereth, F. J. H. 1966. Some chemical observations on post-glacial lake sediments. Trans. R. Soc. (B)250:165-213.

McErlean, A. J., C. Kerby, and R. C. Swartz. 1972. Discussions of the Status of knowledge concerning sampling variation, physical tolerances, and possible change criteria for bay organisms. Chesapeake Sci. 13:S42-S54.

Middleton, J. T. 1956. Response of plants to air pollution. J. Air Pollut. Contr. Assoc. 6:7-9.

National Museum of Natural History. 1976. The use of museum speciments for past pollutant documentation--An evaluation. The Smithsonian Institution, Washington, D.C. 204 pp.

National Science Foundation. 1977. Long-term ecological measurements. Report of a Conference, March 16-18, 1977, Woods Hole, Mass. 26 pp.

National Science Foundation. 1978. Report on Second Conference on Long-term Ecological Measurements, Feb. 6-10, 1978, Woods Hole, Mass. 44 pp.

Neal, J. E., and E. G. Olstrum. 1971. Birdlife--An indicator of environmental quality. Ext. Bull. E-707. Nat. Resour. Coop. Ext. Serv., Michigan State University. 4 pp.

Parker, B. C., and M. A. Wachtel. 1977. Seasonal distribution of B. vitamins. Pages 661-695 in J. Cairns. Jr., ed. Aquatic microbial communities. Garland Publishing, Inc., New York.

Patrick, R., and R. R. Kiry. 1976. Estuarine surveys, biomonitoring, and bioassays. Contrib. Dep. Limnol. Acad. Nat. Sci., Philadelphia. 62 pp.

Patrick, R., and D. Strawbridge. 1963. Methods of studying diatom populations. J. Water Pollut. Contr. Fed. 35(2):151-160.

Pequegnat, W. 1978. Combined field-laboratory approaches to detecting impacts of waste materials on organisms. Third Annual Conference on Treatment and Disposal of Industrial Wastewaters and Residues, Apr. 18-20, 1978, Houston, Tex.

Rhoades, D. F. 1979. Evaluation of plant chemical defense against herbivores. Pages 3-34 in Rosenthal, G. A., and D. H. Janzen, eds. Herbivores: Their interaction with plant secondary metabolites. Academic Press, New York.

Robel, R. J., C. D. Stalling, M. E. Westfahl, and A. M. Kadoum. 1972. Effects of insecticides on populations of rodents in Kansas--1965-69. Pestic. Monit. J. 6:115-121.

Robinson, W. O., H. Bastron, and K. J. Murata. 1958. Biogeochemistry of the rare earth elements with particular reference to hickory leaves. Geochim. Cosmochim. Acta 14:55-67.

Robinson, W. O., R. R. Whetstone, and B. F. Scribner. 1938. Presence of rare earths in hickory leaves. Science 87:470.

Rood, H. L., and G. M. Goldstein. 1977. Recommendations of the EPA/NBS Workshop on the National Environmental Specimen Bank. U. S. Environmental Protection Agency Rep. EPA-600/1-77-020, Environmental Health Effects Res. Ser. 54 pp.

Stephens, C. R., E. F. Darley, O. C. Taylor, and W. E. Scott. 1961. Photochemical reduction products in air pollution. Int. J. Air Pollut. 4:79-100.

Snyder, R. L., and H. L. Ratsliffe. 1969. Primary lung cancer in birds and mammals of the Philadelphia Zoo. Cancer Res. 26:514-518.

Swartz, R. C. 1972. Biological criteria of environmental change in the Chesapeake Bay. Chesapeake Sci. 13: S17-S41.

Takemoto, K. 1972. Air pollution of the lungs of dogs and birds. Pages 19-23 in Histopathological studies of the human being affected by air pollution.

Takemoto, K., H. Katayama, K. Namie, R. Endo, and K. Tashiro. 1974. Effects of air pollution on the ornithorespiratory system. Part IV. Pathology of doves lung. (In Japanese) Nippon Eiseigaku Zasshi 29:106.

Tashiro, K., K. Namie, K. Takemoto, and E. Hisazumi. 1974. Effects of air pollution on the respiratory system of animals in a zoological garden. (In Japanese) Nippon Eiseigaku Zasshi 29:107.

van der Schalie, W. H., K. L. Dickson, G. F. Westlake, and J. Cairns, Jr. 1979. Fish bioassay monitoring of waste effluents. Environ. Manage. 3(3):217-235.

Warren, H. V., and R. E. Delavault. 1960. Observations on the biochemistry of lead in Canada. Trans. R. Soc. Can. Ser. 54:11-20.

Warren, H. V., and R. E. Delavault. 1967. A geologist looks at pollution--mineral variety. West. Miner 40:22-32.

White, T. C. R. 1974. A hypothesis to explain outbreaks of looper caterpillars, with special reference to populations of *Selidosema suavis* in a plantation of *Pinus radiata* in New Zealand. Oecologia 16:279-302.

White, D. H., and R.G. Heath. 1976. Nationwide residues of organochlorines in wings of adult mallards and black ducks. Pestic. Monit. J. 9:176-185.

Weinstein, L., and D. McCune. 1970. Field surveys, vegetation monitoring. Pages G1-G4 *in* Recognition of air pollution injury to vegetation: A pictorial atlas. Air Pollut. Contr. Assoc., Pittsburgh, Pa.

Yamaoka, S., M. Fukuda, and M. Oka (O. Fukase). 1973. Experiments of exposing animals to urban polluted air, Part I. (In Japanese) Rep. Oaka Municipal Inst. Hygiene 35:134-135.