and go. They, the proposals, the panelists, and the reviewers brought in the fresh ideas that kept us up to date with the discipline. The system, though stressed by being underfunded, has always been remarkable for the amount of effort that bright people invest in getting the best possible evaluations of proposals. All rotators I have ever talked to have come away from the agency with a very positive attitude about the level of energy and good faith that goes into the review process and the administration of awards. This attitude of helpfulness and serious attention to ideas always characterized John's office and set the mood for the unit. The young investigator seeking advice for the first proposal, the seasoned senior scientist, and the disappointed recent declinee were all received graciously and given sound advice.

John's original research on the ecology and evolution of freshwater organisms, conducted at Yale before he came to NSF, has had a lasting effect on the field. His best known paper is the one with Stanley Dodson in which they presented their size-efficiency hypothesis (Science **150**:28–35). This paper is a citation classic (has been cited more than 500 times). It was based on an analysis of the fauna and flora of New England lakes, some with and some without an introduced fish (the alewife *Alosa pseudoharengus*). The fish prey selectively on *Daphnia* that are larger than 1 mm, allowing rotifers and smaller cladocera, like *Bosmina,* to predominate in the plankton, and fostering the development of a larger crop of standing algae than would have developed with the *Daphnia* present. The paper illustrates complex relationships that occur in lakes because of size variation, competition, and predation. In many ways it is the ancestor of the current surge of studies on indirect effects in communities and ecosystems.

Another of John's long-standing interests is the history of evolutionary thought. With six months of sabbatical leave from NSF in 1980–1981, he was able to complete a book, published by Columbia University Press in 1984. Entitled "Just Before the Origin: Alfred Russell Wallace's Theory of Evolution," this work is a detailed description of Wallace's development as a naturalist and a collector. It traces Wallace's ideas about evolution as described in his essays between 1848 and 1858 and as inferred from his scientific publications and unpublished manuscripts. Much of this information had not been accessible previously. The final chapters reconstruct the events that led to the reading of the joint Darwin–Wallace paper at the meeting of the Linnean Society of London on 1 July 1858.

John Langdon Brooks has made important contributions to the disciplines of ecology and systematics in three areas: his original research, his dedication to service as an administrator of federal support of basic research, and his scholarly analysis of the historical development of ideas about evolution. The grace with which he has carried out all these activities is continuing to guide his retirement. We look forward to seeing the results of his present writing projects.

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ECOLOGICAL INDICATORS FOR REGIONAL MONITORING

Because we currently lack an integrated approach to monitoring indicators of ecological condition and exposure to pollutants, we cannot determine whether the frequency and extent of the problems are increasing on a regional scale, whether such patterns are warning indicators of significant long-term changes in ecosystem structure or function, or whether they are associated with changes in ambient pollution levels. The need to establish baseline conditions against which future changes can be documented with confidence has grown more acute with the increasing complexity, scale, and social importance of environmental issues such as acid deposition, global atmospheric change, and declining biodiversity. In 1988 the U.S. Environmental Protection Agency (EPA) Science Advisory Board recommended that a program be implemented within EPA to monitor ecological status and trends, as well as to develop innovative methods for anticipating emerging problems before they reach crisis proportions. A recent report from the National Research Council (1990) confirms the need for strengthening regional and national monitoring.

EPA's Office of Research and Development began planning the Environmental Monitoring and Assessment Program (EMAP) in response to the need for better assessments of the condition of the nation's ecological resources. An integrated monitoring network is being designed with the following objectives:

- to estimate current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence;
- to monitor indicators of pollutant exposure and habitat condition and to seek associations between human-induced stressors and ecological condition; and
- to provide periodic statistical summaries and interpretive reports on ecological status and trends to the EPA Administrator and the public.

EMAP is a long-term monitoring program to determine status and trends in ecological resources at regional and national scales. A critical component of the program is the identification of variables to be monitored. This article briefly describes the EMAP indicator identification effort and strategy. The success of this ambitious program requires the participation of other federal agencies and linkages to more intensive monitoring activities. Some agencies are already participating in the program at different levels of effort. Input from the scientific community at an early stage in the program is important, and we welcome ideas and comments.

EMAP consists of five principal activities: (1) strategic evaluation, development, and testing of indicators; (2) design and evaluation of integrated statistical monitoring frameworks and of protocols for collecting data; (3) nationwide characterization of the extent and location of ecological resources; (4) demonstration studies and implementation of integrated sampling designs; and (5) development of data handling, quality assurance, and statistical analytical procedures. A report entitled "Ecological Indicators for the Environmental Monitoring and Assessment Program" (Hunsaker and Carpenter, editors. 1990) will be available in August 1990. This document is an interim conceptual plan for the indicator component of EMAP and has the following purposes:

- inform potential data users of the approach proposed to describe ecological conditions,
- outline a framework for selecting and evaluating indicators for further testing, and
- seek expert advice and ecological data sets that might aid in further evaluations.

Indicators include measurements related to ecosystem "health" or "integrity," pollutant exposure, habitat condition, and human-induced stress. The initial set of indicators identified as appropriate research indicators for EMAP is listed in Tables 1 and 2. At the grossest level EMAP has addressed ecological resources according to six resource categories: near-coastal areas, inland surface waters, wetlands, forests, arid ecosystems, and agroecosystems. Indicators have been proposed as appropriate for these; however, some indicators are appropriate to multiple resources.

EMAP is being designed to answer critical questions for policy-makers and the public: What are the current extent and location of major ecological resource classes? Which resources are degrading, where, and at what rate? Are degraded resources improving in response to control and mitigation programs? EMAP monitoring networks will provide statistically unbiased estimates of status, trends, and relationships among indicators with quantifiable confidence limits over regional and national scales for periods of years to decades. EMAP is adopting a risk assessment approach. The term **assessment endpoint** is used to describe an assessable environmental entity that has value to the public and is biologically relevant to the hazard of interest.

Overall ecosystem health, used in the same sense as human health, is an obvious as-

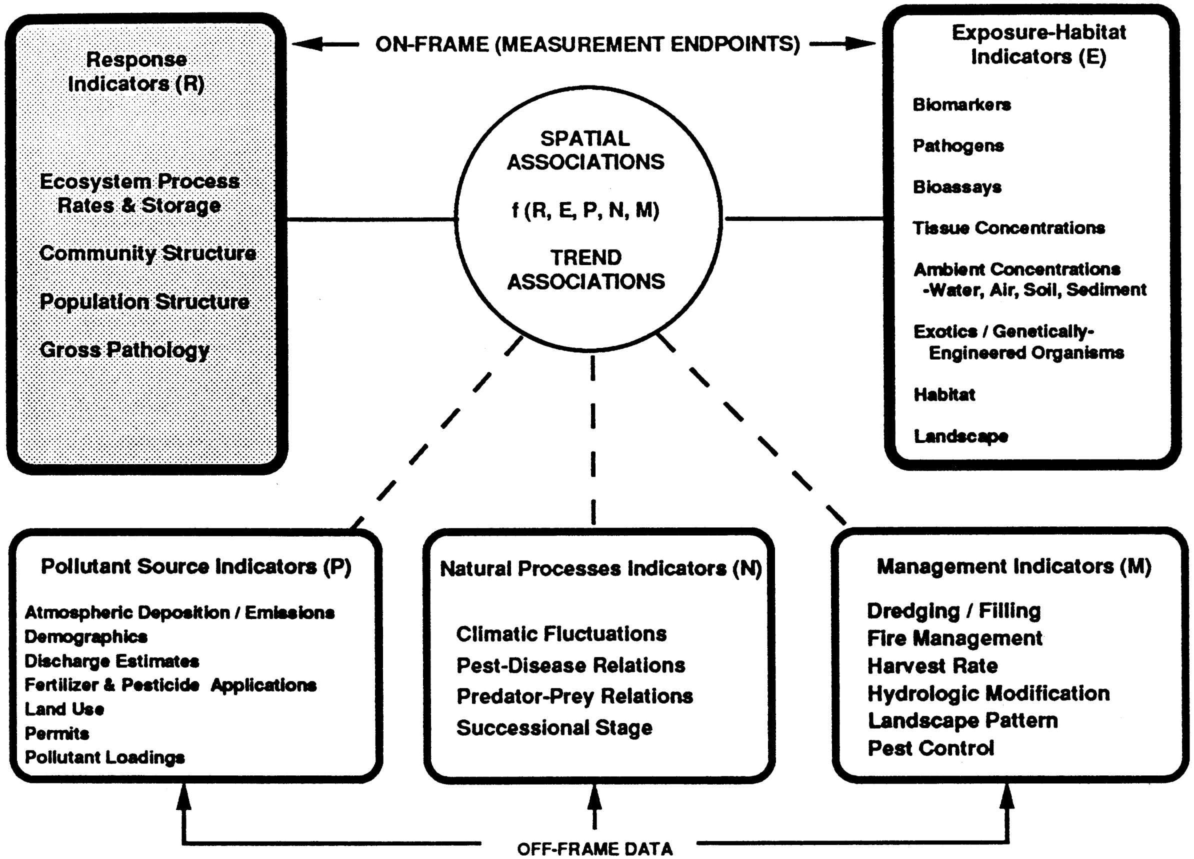

Fig. 1. Diagram of EMAP conceptual indicator strategy showing indicator types and those indicators that will be measured on the EMAP sampling frame. The circle indicates that analysis is by statistical association, rather than explicitly (causal) mathematical relationships.

Table 1. Proposed response indicators for EMAP by ecological resource category and indicator type.

RESPONSE	NEAR-COASTAL	INLAND SURFACE WATERS	WETLANDS	FORESTS	ARID ECOSYSTEMS	AGROECOSYSTEMS
Ecosystem Process Rates and Storage	• **Dissolved Oxygen (A.1)** • Biological Sediment Mixing Depth (A.3) • Extent/Density of Submerged Aquatic Vegetation (A.4)	• **Lake Trophic Status (B.1)**	• **Organic Matter/ Sediment Accretion (C.1)** • **Wetland Extent/ Type Diversity (C.2)**	• Nitrogen Export (D.3) • Litter Dynamics (D.4) • Microbial Biomass and Respiration in Soils (D.5)	• **Vegetation Biomass (E.1)** • **Riparian EcosystemExtent (E.2)** • **Energy Balance (E.3)** • **Water Balance (E.4)** • **Soil Erosion (E.5)** • Charcoal Record (E.6)	• **Nutrient Budgets (F.1)** • **Soil Erosion (F.2)** • **Soil Microbial Biomass (F.3)** • **Land Use/ Extent of Noncrop Vegetation** (F.4)
Community Structure	• **Benthic Abundance Biomass, and Species Composition (A.2)** • Fish Abundance/Species Composition (A.5)	• **Fish Index of Biotic Integrity (B.2)** • **Macroinvertebrate Assemblage (B.3)** • **Diatom Assemblage in Lake Sediments (B.4)** • **Relative Abundance of Semiaquatic Vertebrates (B.5)**	• **Vegetation Species Composition and Diversity (C.3)** • **Relative Abundance of Selected Animal Species (G1.1)** • Leaf Area, Solar Transmittance, Greeness (C.4) • Macroinvertebrate Abundance, Biomass, Species Composition (C.5) • Soil/Aquatic Microbial Community Structure (C.6)	• **Relative Abundance of Selected Animal Species (G1.1)** • Vegetation Species Composition and Diversity (C.3)	• **Species Composition/ Ecotone Location of Vegetation (E.7)** • **Abundance/Species Composition of Lichens/ Cryptogamic Crusts (E.8)** • **Relative Abundance of Selected Animal Species (G1.1)**	• **Relative Abundance of Animal Species (G1.1)**
Population Structure	• Presence of Large Indigenous Bivalves (A.6)	• **Top Carnivore Index: Fish (B.6)**	• Demographics for Animal Species (G1.2) • Morphological Asymmetry: Animals (G1.3)	• **Tree Growth Efficiency (D.1)** • Demographics of Animal Species (G1.2) • Morphological Asymmetry: Animals (G1.3)	• **Dendrochronology: Trees and Shrubs (E.9)** • **Pollen Record (E.10)** • **Woodrat Midden Record (E.11)** • Demographics of Animal Species (G1.2) • Morphological Asymmetry: Animals (G1.3)	• **Crop Yield (F.5)** • **Livestock Production (F.6)** • Demographics of Animal Species (G1.2) • Morphological Asymmetry: Animals (G1.3)
Pathology	• Fish Gross Pathology (A.7)	• **External Pathology: Fish (B.7)**		• **Visual Symptoms of Foliar Damage : Trees (D.2)**		• **Visual Symptoms of Foliar Damage: Crops (F.7)**

sessment endpoint. Additional assessment endpoints for EMAP include sustainability, aesthetics, species extinction, and biodiversity. An assessment endpoint includes an entity and the descriptor or quality of the entity such as a 25% reduction in forest productivity or loss of natural flood protection by wetland extinction. Many assessment endpoints are difficult to define and/or are subject to changing expectations of the public. Therefore, we use **measurement endpoints** or **indicators** that are quantitative summaries of the results of monitoring such as a toxicity test, community index, or number of vertical habitat layer.

The conceptual strategy for indicators defines categories of indicators–response, exposure, habitat, and stressor (Figure 1). **Response indicators** are the primary measurement endpoints for EMAP and should quantify the overall biological conditions of ecosystems by measuring either organisms, populations, communities, or ecosystem processes as they relate to assessment endpoints. **Exposure indicators** are measures of ecosystem exposure to toxics, nutrients, heat, acidity, and ionizing or electromagnetic radiation, to name a few examples. **Habitat indicators** represent conditions on a local or landscape scale that are necessary to support a population or community (e.g., availability of snags, extent and spatial pattern of vegetation cover, and vertical layers of vegetation). **Stressor indicators** reflect activities or occurrences that cause changes in exposure or habitat conditions and include pollutant, management, and natural process indicators (e.g., number of wastewater discharges, proximity to urban areas, and introduction of exotic species). Stressor indicators will not be measured on the EMAP sampling frame but will be obtained from external sources (an exception may be atmospheric stressors).

Indicators were identified that look promising for annual sampling during an index period and for which methodology is sufficiently well developed that monitoring could be implemented within two to five years. The National Research Council (1990) identifies two important issues in the choice of variables to monitor. The first relates to the depth of knowledge about a particular system (e.g., specificity and reliability of responses), and the second, to the statistical efficiency of sampling alternative variables (e.g., the signal-to-noise ratio). Desirable EMAP indicators characteristically:

- Correlate with changes in processes or other unmeasured components such as stressors of concern or management strategies;
- are appropriate for regional monitoring and apply to a broad range of resource classes;
- can integrate effects over time and space;
- are unambiguously and monotonically related to an endpoint, a relevant exposure or habitat variable, or a stressor;
- can be quantified by synoptic monitoring (low natural variability) or can be automatically monitored in a cost-effective manner;
- can be related to the overall structure and function of ecosystems;
- are responsive to stressors of concern or management strategies;
- should have a standard method of measurement;
- have low measurement error;
- would have a historical data base or accessible data for development of a data base; and
- are cost effective (low cost/high information value).

Because of ecosystem complexity and the interactive and cumulative effects of contaminants and habitat alteration on ecosystem structure and function, EMAP will focus on response indicators to define ecological condition. EMAP must also provide information to interpret what constitutes "healthy/unhealthy" or nominal/subnominal conditions of indicators. Unfortunately, it is difficult to describe, a priori, the characteristics of a nominal ecosystem. The most promising approach appears to be use of regional reference sites. Indicators could be measured on groups of sites that are "geographically typical" of a region and that appear to be well managed. Indicator values at these reference sites could then be used to define nominal/subnominal boundaries. EMAP will also seek to determine associations between indicators of resource response and indicators of environmental stress and exposure. However, EMAP does not propose to provide answers about cause and effect.

Following the publication of proposed research indicators in the Indicator Report, the next step in the strategy is to evaluate these

Table 2. Proposed exposure/habitat indicators for EMAP by ecological resource category and indicator type.

EXPOSURE/ HABITAT	NEAR-COASTAL	INLAND SURFACE WATERS	WETLANDS
Biomarkers	• DNA Alteration: - Adduct (G2.1) - Secondary Modification (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accumulation (G2.6) • Histopathologic Alterations (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)	• DNA Alteration: - Adduct (G2.1) - Secondary Modification (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accumulation (G2.6) • Histopathologic Alterations (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)	• DNA Alteration: - Adduct (G2.1) - Secondary Modification (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accumulation (G2.6) • Histopathologic Alterations (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)
Pathogens		• Water Column Bacteria (B.12)	
Bioassays	• **Acute Sediment Toxicity (A.8)** • Water Column Toxicity (A.11)	• **Water Column and Sediment Toxicity (B.8)**	•Bioassays (C.10)
Tissue Concentrations	• Chemical Contaminants in Fish and Shellfish (A.12)	• **Chemical Contaminants in Fish (B.12)**	• Chemical Contaminants in Tissues (C.11)
Ambient Concentrations	• **Chemical Contaminants in Sediments (A.9)** • **Water Clarity (A.10)** • Dissolved Oxygen (A.13)	• **Routine Water Chemistry (B.10)** • Heavy Metals/Man-made Organics (Toxics) (B.13)	• **Nutrients in Water and Sediments (C.7)** • **Chemical Contaminants in Water and Sediments (C.8)**
Exotics-GEOs			
Habitat	• Extent and Density of Submerged Aquatic Vegetation (A.4)	• **Physical Habitat Quality (B.11)**	• **Hydroperiod (C.9)** • **Abundance/Density of Key Physical Features (G3.1)** • **Linear Classification and Physical Structure of Habitat (G3.2)**
Landscape			• **Habitat Proportions (Cover Types) (G3.3)** • **Patch Size/Perimeter to Area Ratio (G3.4)** • **Fractal Dimension (G3.5)** • **Contagion/Habitat Patchiness (G3.6)** • Gamma Index of Network Connectivity (G3.7) • Patton's Diversity Index (G3.8)

Table 2. Continued.

EXPOSURE/ HABITAT	FORESTS	ARID ECOSYSTEMS	AGROECOSYSTEMS
Biomarkers	• Stable Isotopes (D.9) • Carbohydrates/Secondary Chemicals: Trees (D.10) • DNA Alteration: - Adduct (G2.1) - Secondary Modif. (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accum. (G2.6) • Histopathologic Alter. (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)	• DNA Alteration: - Adduct (G2.1) - Secondary Modification (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accumulation (G2.6) • Histopathologic Alterations (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)	• DNA Alteration: - Adduct (G2.1) - Secondary Modification (G2.2) - Irreversible Event (G2.3) • Cholinesterase Levels (G2.4) • Metabolites of Xenobiotic Chemicals (G2.5) • Porphyrin Accumulation (G2.6) • Histopathologic Alterations (G2.7) • Macrophage Phagocytotic Activity (G2.8) • Blood Chemistry (G2.9) • Cytochrome P-450 Monooxygenase System (G2.10) • Enzyme-Altered Foci (G2.11)
Pathogens	• **Visual Symptoms of Foliar Damage: Trees (D.2)**		• **Visual Symptoms of Foliar Damage: Crops (F.7)** • **Agricultural Pest Density (F.8)**
Bioassays	• Bioassays: Mosses and Lichens (D.11)		• **Lichens, Mosses, Clover, Earthworm Bioassays (F.9)**
Tissue Concentrations	• **Nutrients in Tree Foliage (D.6)** • **Chemical Contaminants in Tree Foliage (D.7)**	• **Foliar Chemistry (E.12)**	
Ambient Concentrations	• **Soil Productivity (D.8)**	• **Soil Chemistry and Structure (E.13)** • Chemical Contaminants in Wood (E.18)	• **Nutrient Budgets (F.1)** • **Quantity/Quality of Irrigation Waters (F.10)** • **Soil Productivity Index (F.11)**
Exotics-GEOs		• **Exotic Plants (E.14)** • **Livestock Grazing (E.15)**	
Habitat	• **Abundance/Density of Key Physical Features (G3.1)** • **Linear Classification and Physical Structure of Habitat (G3.2)**	• **Soil Chem. /Structure (E.13)** • **Fire Regime (E.16)** • **Mechanical Disturbance of Soils and Vegetation (E.17)** • **Abundance/Density of Key Physical Features (G3.1)** • **Linear Classification and Physical Structure of Habitat (G3.2)**	• **Land Use/Extent of Noncrop Vegetation (F.4)** • **Abundance/Density of Key Physical Features (G3.1)** • **Linear Classification and Physical Structure of Habitat (G3.2)**
Landscape	• **Habitat Proportions (Cover Types) (G3.3)** • **Patch Size/Perimeter to Area Ratio (G3.4)** • **Fractal Dimension (G3.5)** • **Contagion/Habitat Patchiness (G3.6)** • Gamma Index of Network Connectivity (G3.7) • Patton's Diversity Index (G3.8)	• **Habitat Proportions (Cover Types) (G3.3)** • **Patch Size/Perimeter to Area Ratio (G3.4)** • **Fractal Dimension (G3.5)** • **Contagion/Habitat Patchiness (G3.6)** • Gamma Index of Network Connectivity (G3.7) • Patton's Diversity Index (G3.8)	• **Habitat Proportions (Cover Types) (G3.3)** • **Patch Size/Perimeter to Area Ratio (G3.4)** • **Fractal Dimension (G3.5)** • **Contagion/Habitat Patchiness (G3.6)** • Gamma Index of Network Connectivity (G3.7) • Patton's Diversity Index (G3.8)

indicators by using field trials and existing data sets to test their performance and applicability under the proposed sampling design. An international symposium on ecological indicators is scheduled for 16–19 October 1990 in Miami Beach, Florida. For more information on EMAP indicators, contact the EMAP Indicator Coordinator, U.S. EPA, 200 S.W. 35th Street, Corvallis, OR 97333.

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