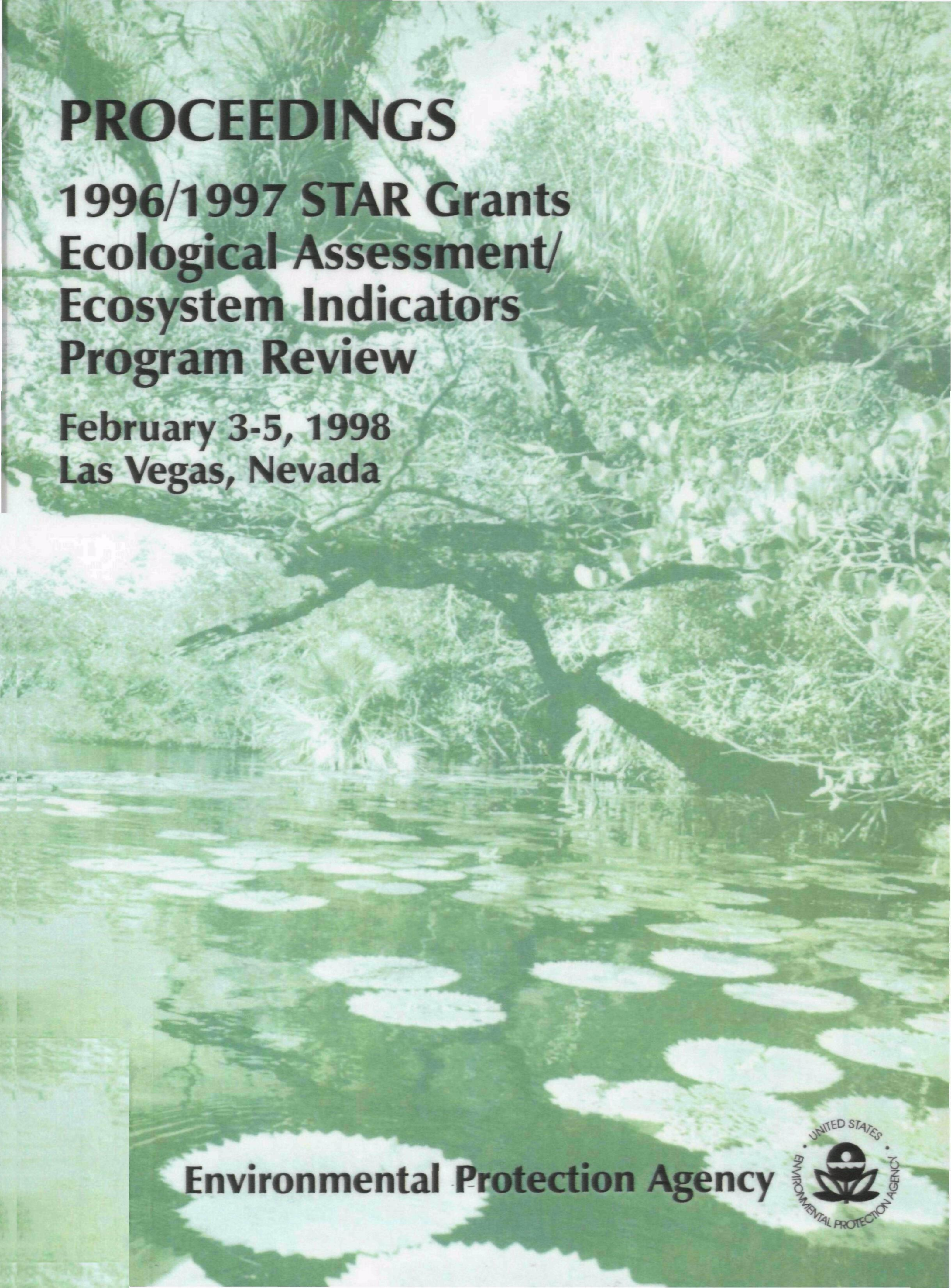

PROCEEDINGS

1996/1997 STAR Grants Ecological Assessment/ Ecosystem Indicators Program Review

February 3-5, 1998
Las Vegas, Nevada

Environmental Protection Agency

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Introduction

The mission of the United States Environmental Protection Agency (EPA) is to protect public health and to safequard and improve the natural environment—air, water, and land upon which life depends. Achievement of this mission requires the application of sound science to the assessment of environmental problems and to the evaluation of possible solutions. The National Center for Environmental Research and Quality Assurance (NCERQA) at EPA is committed to providing the best products in high-priority areas of scientific research through significant support for long-term research.

One high-priority research program identified in the Office of Research and Development's (ORD) Ecological Research Strategy is monitoring research. The monitoring research is focused on biological indicator development at the molecular, community, and landscape levels of biological organization. These indicators will be used for the monitoring of ecosystem condition as well as exposure evaluation. The development of new characterization methods and technologies and improvement of multiscale monitoring designs are also high-priority research components. This research represents the extramural component of ORD's Environmental Monitoring and Assessment Program (EMAP).

In support of the need for monitoring research, NCERQA issued a 1996 Request for Applications (RFA) on Ecological Assessment—Regional Ecosystem Protection and Restoration. The purpose of the solicitation was to request proposals that led to the scientific understanding and techniques required for effective ecological risk assessment and ecosystem protection at a regional ecosystem scale. The 1996 competition resulted in the receipt of 132 applications; 20 passed scientific peer review, and 15 were funded.

In 1997, NCERQA issued another RFA on Ecosystem Indicators. The purpose of this solicitation was to support research that led to the development of techniques and indicators that characterize and quantify the integrity and sustainability of ecosystems at local, regional, national, and/or global scales. The 1997 competition resulted in the receipt of 91 applications; 13 passed scientific peer review, and 9 were funded.

Annual program reviews such as this one will allow investigators to interact with one another and to discuss progress and findings with EPA and other interested parties. If you have any questions regarding the program, please contact the program manager, Barbara Levinson, at 202-564-6911 or levinson.barbara@epamail.epa.gov.

Section 1.

Projects Initiated With Fiscal Year 1997 Support

Foliar Chemistry as an Indicator of Forest Ecosystem Status, Primary Production, and Stream Water Chemistry

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The New York-New England region is the most densely forested region in the United States. In addition, it is one of the most densely populated, and air pollution levels are among the highest in the country. More than 30 million people in the region require potable water, forest products, recreation, and aesthetic renewal from a complex patchwork of forested lands with a rich and diverse history of human use and ownership. The sustainable use of forest resources and the maintenance of surface water quality in forested regions depends on the integrity of biogeochemical cycles within forest ecosystems.

Development of a successful system for monitoring forest and stream biogeochemistry requires two components: (1) a simple, integrative indicator of current biogeochemical status and (2) a method for predicting the influence of short-term climatic and hydrologic changes on this indicator. We hypothesize that forest productivity, soil water chemistry, and foliar chemistry at the whole-stand (not individual tree) level are all tightly linked to the biogeochemical status of a forest ecosystem (see Figure 1). We further hypothesize that the concentration of cations in forest canopies will be measurable by high spectral resolution remote sensing, as has been demonstrated for nitrogen and lignin. Watershed-level stream chemistry, reflecting soil water chemistry, also will be predictable from watershed-level values of canopy chemistry derived by remote sensing.

The White Mountain region of New Hampshire will be used as the primary study site. At the intensive plot scale, a long-term sampling program will be used and augmented at the Hubbard Brook Experimental Forest in New Hampshire, and long-term experimental treatments will be used and augmented at the Harvard Forest in Massachusetts to examine and attempt to predict interannual variations in foliar and soil water chemistry as well as woody and foliar production. Regional subsampling scale measurements will be made of canopy, soil and soil water chemistry, as well as forest productivity in a series of existing experimental and monitoring research sites. Work at the spatially continuous monitoring scale across the White Mountain region will include the development of algorithms for the prediction of canopy cation concentrations using data from NASA's Airborne Visible-Infrared Imaging Spectrometer (AVIRIS).

Monitoring the biogeochemical status of forest and stream ecosystems is a key component of assessing environmental quality in the Northeastern United States. Any monitoring system requiring spatially continuous capabilities will need to use some form of remote sensing. Forest canopies are the only portion of the system accessible to optical reflectance remote sensing instruments, and so they offer the most likely target surface for monitoring forest health in this spatial mode. If successful, the research proposed here will establish the linkages between foliar chemistry and processes controlling forest growth and element loss as well as the methods by which remote sensing can be used to predict canopy chemistry. This would then establish the scientific basis for developing a satellite- or aircraft-based remote sensing program for monitoring forest health and stream water quality.

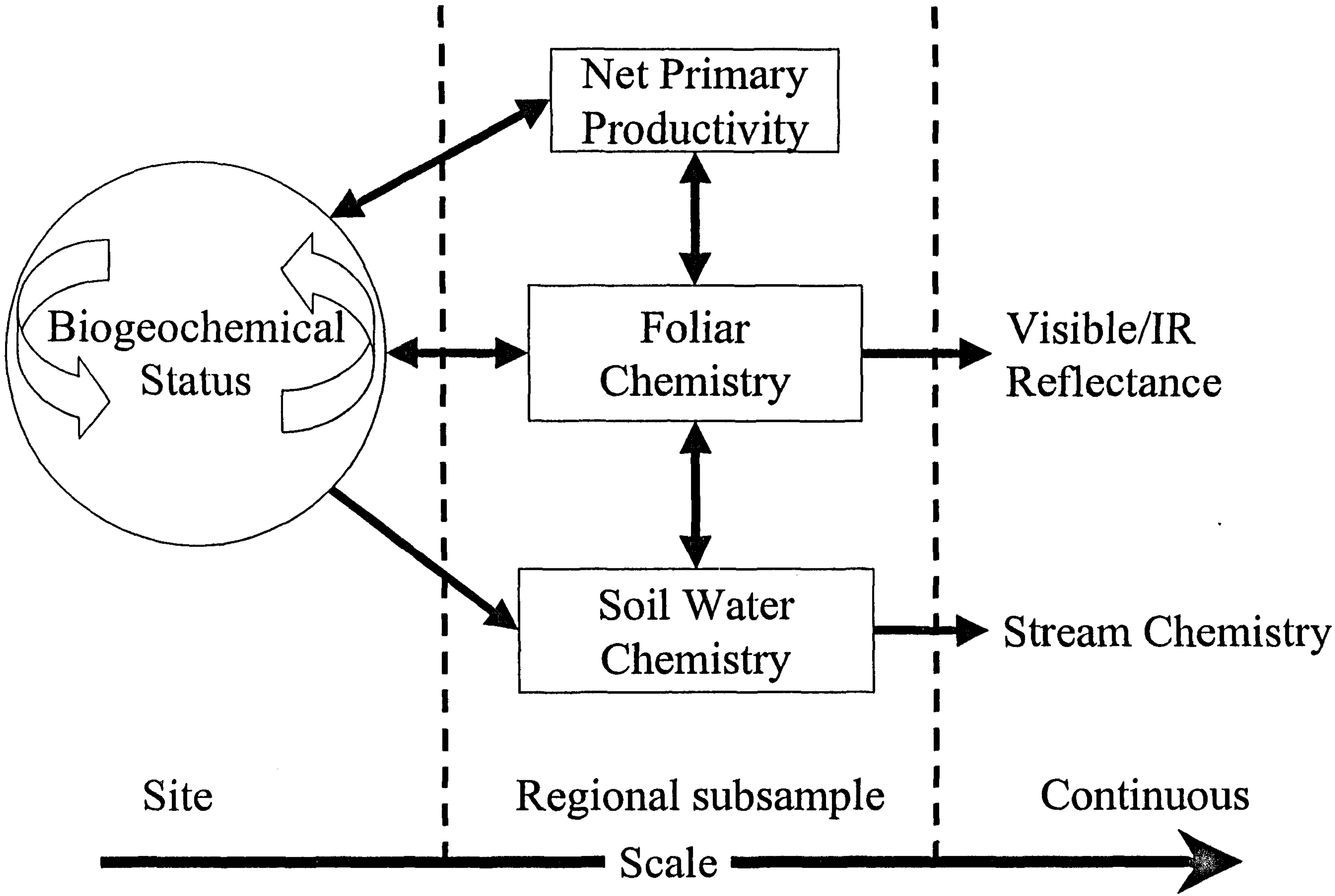

Figure 1. Hypothesized linkages between forest biogeochemical status and variables to be measured at three spatial scales.

Environmental Factors That Influence Amphibian Community Structure and Health as Indicators of Ecosystem Integrity

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Amphibian community structure and health may warn of human health hazards and ecological dysfunction because of the following: (1) Amphibian fertilization and development occur in water; therefore, terrestrial juveniles can be examined and collected for detailed study. (2) Dispersal of young results in exposure to synthetic chemicals and landscape alterations. (3) Damage to plants may severely impact amphibian communities. Early life stages require dissolved oxygen from plants; tadpoles feed heavily on algae; and all life stages rely on plant cover. (4) Skin is highly permeable and serves as a major organ of respiration and water uptake. Skin lesions due to chemicals or pathogens may disrupt gas, acid-base, and hydration status. (5) Juvenile and adult amphibians feed on invertebrates, including insect vectors of disease. Substances toxic to insects may harm amphibians directly or deplete their prey. (6) In the summer, tadpole and juvenile numbers may account for much of vertebrate biomass, serving as essential food when reproductive demands of aquatic predators mandate high nutrient intake. (7) All vertebrates share similarities in metabolism and elimination of environmental pollutants. (8) All vertebrates share similar neuroendocrine systems and developmental processes.

This project will examine pond sites from Minnesota through Wisconsin to Illinois to determine the relative influence of large scale and local factors on amphibian community structure and health. This area encompasses a gradient of land uses, from partially forested areas to intensively cultivated regions. Data on land cover, fragmentation, and connectivity of landscape elements, position and density of roads, and water bodies will be derived from satellite images of watersheds and aerial photographs of pond catchments. Locally, the wetland ecosystem structure and function will be assessed. Habitat parameters, water quality, contaminants, and aquatic biota, including amphibian communities as well as organisms that impact amphibians (i.e., algae, macrophytes, snails, other invertebrates, and fishes), will be quantified. In addition, an assessment will be made of amphibian health, including malformation data, histologic lesions, and indicators of parasitism.

Relating these findings, this project will determine if: (1) Wetland ecosystem structure and function are correlated with amphibian diversity and community structure. (2) Agricultural land uses are correlated with a higher prevalence of malformations and lesions in amphibians as well as negatively impact amphibian community structure. (3) Habitat fragmentation adversely affects amphibian community structure and health. (4) Aquatic herbivores and aquatic contamination by herbicides are correlated with amphibian parasitism. (5) Amphibian abundance is inversely related to kidney parasitism. (6) The prevalence of deformed limbs is correlated with encysted parasites in limb bud areas. (7) Limb and ocular abnormalities, intersex gonads, and changes in ratios of males to females are correlated with waterborne contaminants.

Towards a Regional Index of Biological Integrity: The Example of Forested Riparian Ecosystems

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The premise of this project is that measures of ecological indicators and habitat conditions will vary between reference standard sites and reference sites that are impacted, and that these measures can be applied consistently across a regional gradient in the form of a Regional Index of Biological Integrity (RIBI). Six principles are being proposed to guide the development of any RIBI: (1) biological communities with high integrity are the desired endpoints; (2) indicators can have a biological, physical, or chemical basis; (3) indicators should be tied to specific stressors that can be realistically managed; (4) linkages across geographic scales and ecosystems should be provided; (5) reference standards should be used to define target conditions; and (6) assessment protocols should be efficiently and rapidly applied. Four integrative bioindicators can be combined to develop an RIBI for forest riparian ecosystems in the mid-Atlantic states: (1) macroinvertebrate communities, (2) amphibian communities, (3) avian communities, and (4) avian productivity, primarily for the Louisiana waterthrush (*Seirius motacilla*). This species depends on stream macroinvertebrates for food and forest riparian habitats for nesting. As a common top predator and the only obligate avian species of this ecosystem in the Eastern United States, it is an ideal calibrator for an index of headwater ecosystems.

Measuring the population parameters of the Louisiana waterthrush requires a substantial investment, but once completed, provides a means to calibrate the other indicators, thus linking them across scales. Each bioindicator is most strongly associated with measures of habitat at a particular scale. Measuring productivity for the Louisiana waterthrush relates primarily to the quality of riparian habitat, but it is also dependent on the availability of macroinvertebrates as food. Biomass and composition of macroinvertebrate and amphibian communities relate to instream and wetland habitat and measures of water chemistry and sedimentation. Avian communities relate primarily to landscape metrics. However, by combining measures of nest productivity, territory density, and survey abundance, attributes of the Louisiana waterthrush span the widest range of scale. Once tested between reference and impacted sites and then calibrated across scales, a set of indicators could be combined into an RIBI for the Mid-Atlantic Integrated Assessment. By providing a reliable expression of environmental stress or change, an RIBI can help managers reach scientifically defensible decisions.

Assessment of Forest Disturbance in the Mid-Atlantic Region: A Multiscale Linkage Between Terrestrial and Aquatic Ecosystems

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Alan T. Herlihy
Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR

The objective of this 3-year project is to develop, test, validate, and demonstrate an analytical framework for assessing regional-scale forest disturbance in the mid-Atlantic region by establishing a multiscale linkage between forest disturbance and forest nitrogen (N) export to surface waters. Excessive nitrogen leakage (export) from forested watersheds is a potentially useful, integrative "indicator" of a negative change in forest function, which occurs in synchrony with changes in forest structure and species composition. The research focuses on forest disturbance associated with recent watershed defoliations by the gypsy moth larva at spatial scales ranging from small watersheds to the entire region.

Three research hypotheses will be tested: (1) N export from forested watersheds in the mid-Atlantic region is primarily attributable to forest disturbances, operating at both the local and regional scales; (2) changes in forest species composition in the mid-Atlantic region—such as declines in dominance of oak species and increases in shade-tolerant species—have been induced or exacerbated by gypsy moth defoliation; and (3) if both N export and rapid forest succession are largely disturbance-induced by gypsy moth defoliation in the region, then broad-scale patterns of dissolved N leakage, forest succession, and forest disturbance should be spatially and temporally well-correlated.

There are five carefully linked tasks associated with this project's objective that will allow testing of the stated hypotheses. These are: (1) characterizing forest composition, recent disturbance history, and annual N export (see Figure 1) for intensively studied watersheds; (2) modeling N export from intensively studied watersheds due to disturbance; (3) verifying N export as an indicator of disturbance at subregional scales; (4) scaling forest point data to landscape scales; and (5) correlating spatial and temporal patterns of N export and forest species composition changes with forest disturbance at the regional scale.

Tasks 1 and 2 will largely be accomplished using conventional methods appropriate for small watershed studies by cost-effectively taking advantage of a plethora of data for small watersheds in the region that were collected for other projects. In Task 2, data assembled during completion of Task 1 will be used to parameterize an empirical model of N export from these watersheds due to disturbance—a unit N export response function (UNERF) model (which is completely analogous to the widely used linear unit hydrograph model in watershed hydrology); an important input to the model is a time series of gypsy moth defoliation data for each watershed (obtained from statewide aerial mapping programs). Task 3 will result in the subregional verification of the UNERF model by comparing predictions and observations of N export for a group of watersheds not examined during Task 2. Task 4 will use a geographic information system (GIS), extrapolative techniques of landscape ecology, remotely sensed imagery, regional forest species composition data, and a limited number of on-the-ground measurements to describe forest composition and changes in forest species composition at the landscape scale. In Task 5, using spatial patterns and statistical distributions of forest composition from Task 4 and time-varying gypsy moth defoliation maps as inputs to a GIS-linked version of the UNERF model, spatial and temporal patterns of N export from forested lands in the mid-Atlantic region (and for important subregional units such as the Chesapeake Bay watershed) will be predicted.

The primary output from the project will be a regional assessment of the effects of forest disturbance in the form of gypsy moth defoliation on forest health and water quality in the mid-Atlantic region based on the establishment of a multiscale linkage between forests and surface waters through a relatively simple, but useful, modeling approach. The demonstration of a viable approach to spatially extrapolating (and validating the extrapolation) forest composition information to the landscape or watershed scale must be recognized as a major contribution of the project and one that will lay the groundwork for future assessments of changes in other types of terrestrial ecosystems. In addition, the ability to derive statistical distributions of N export from forested lands to the Chesapeake Bay represents a major benefit to the existing Environmental Protection Agency Chesapeake Bay Program.

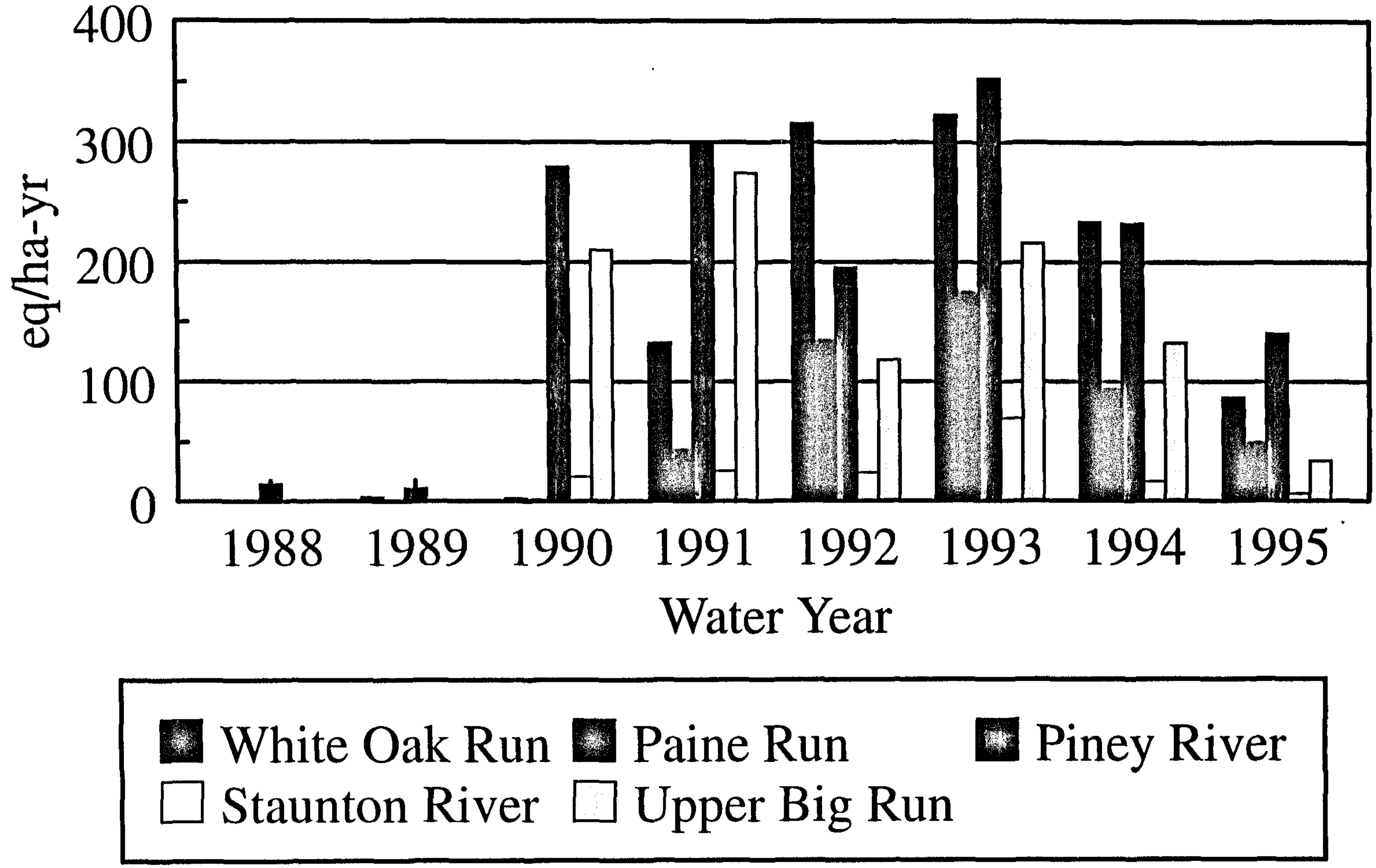

Figure 1. Annual dissolved N export from five mid-Atlantic forested watersheds during water years 1988-1995. Note the synchrony of the N export response to defoliation, first observed in the region in 1989.

Microbial Indicators of Biological Integrity and Nutrient Stress for Aquatic Ecosystems

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Several chemical and biological variables will be examined, which may provide a broadly applicable approach to understanding the biological consequences of nutrient loading in aquatic systems and predictions of the resulting community structure. This approach is based on recent advances in aquatic microbial ecology and on theory developed in the rapidly expanding field of ecological stoichiometry. The indicators that will be examined include: (1) seston C:N:P ratio; (2) species-level responses of algae to nutrient bioassays; (3) community-level responses of bacteria to nutrient bioassays; (4) community structure of algae; (5) community structure of bacteria; and (6) the estimated ratio of algal- to bacterial-specific growth rates. The general hypothesis is that these indicators will reflect nutrient-related stresses, including eutrophication and alterations of nutrient loading ratios (see Figure 1).

This general hypothesis is further elaborated by testing the following seven specific hypotheses: (1) indicators based on seston stoichiometry and nutrient bioassays will agree; (2) limitation by a single nutrient will be negatively associated with algal community diversity and equitability; (3) colimitation by two nutrients will be positively associated with algal community diversity and equitability; (4) bacterial community structure will shift in response to nutrient limitation; (5) bacterial nutrient limitation will be negatively associated with loss rate to micrograzers; (6) degrees of algal and bacterial nutrient limitation will be positively associated; and (7) algal nutrient limitation will be associated with low algal productivity and growth relative to bacteria.

A standard protocol will be employed consisting of sampling standard water quality parameters, chemical analysis of particulate matter, and algal and bacterial bioassays to identify nutrient limitation and to estimate *in situ* growth rate. Over 3 years, this protocol will be applied in two warm temperate reservoirs in Texas and in two cool temperate lakes to enable inter-regional comparisons.

There is some evidence that algal growth in one of the Texas Reservoirs is strongly nitrogen limited, while growth in the other is colimited by nitrogen and phosphorus in the warm growing season. One of the Canadian lakes is an unmanipulated reference lake, while the other is experimentally eutrophied by phosphorus additions. In this second lake, recent research demonstrated large shifts in algal composition and food web dynamics associated with shifts of nitrogen and phosphorus dynamics.

This project will demonstrate that the proposed indicators sensitively reveal seasonal shifts in nutrient limitation, interannual, interlake, and regional differences in nutrient stress and loading. The microbial indicators proposed should have wide applicability in nearly all aquatic habitats and are based on ecosystem components with very rapid responses to environmental changes. These indicators are short-term, and thus feasible to repeat at larger temporal and spatial scales. This study will reveal whether these short-term indicators adequately reflect whole-lake and larger scale responses to nutrient stresses.

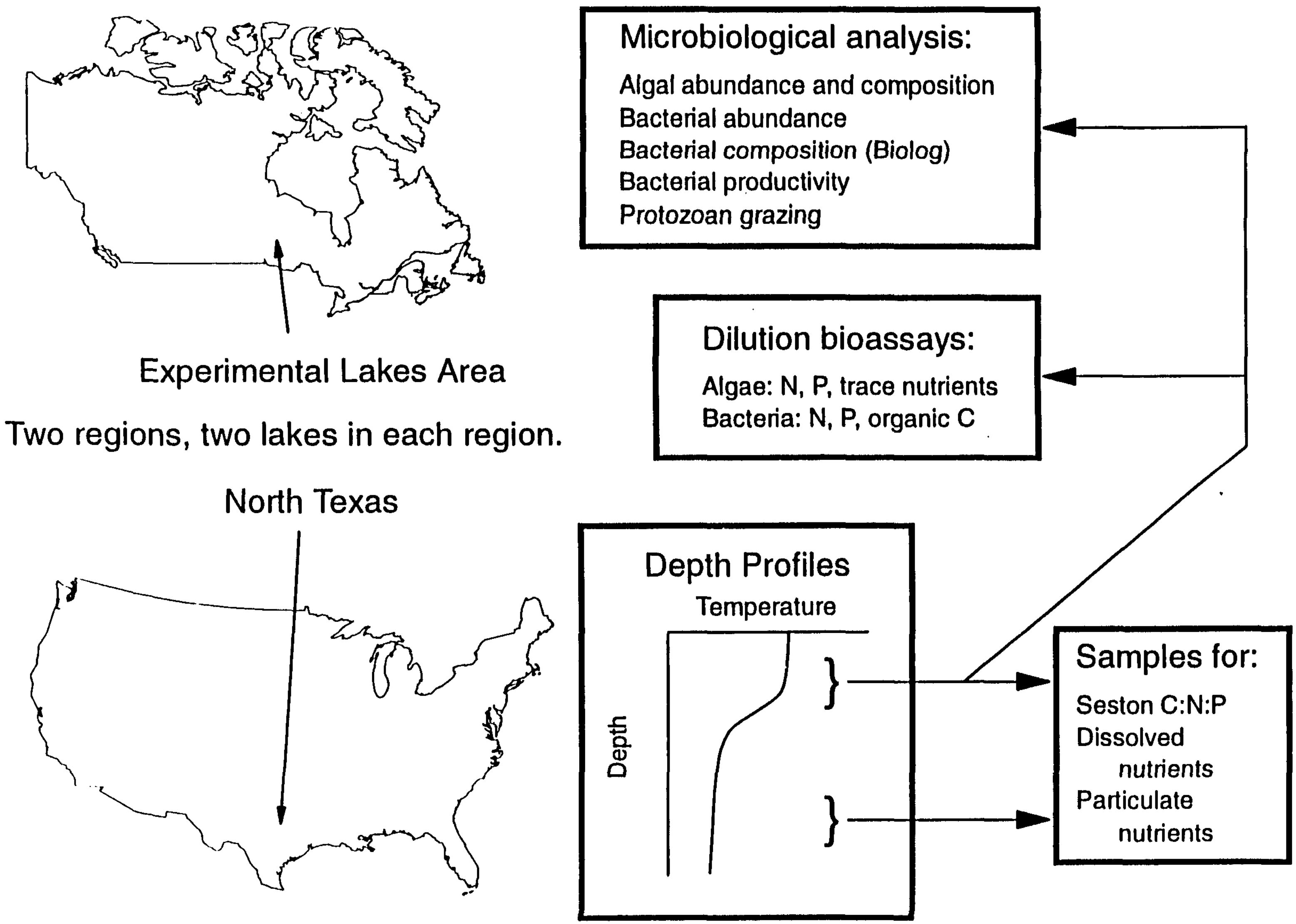

Figure 1. Microbial indicators of biological integrity and nutrient stress for aquatic systems.

Foraminifera as Ecosystem Indicators: Phase 1—A Marine Benthic Perturbation Index; Phase 2—Bioassay Protocols

Pamela Hallock Muller
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Foraminifera are by far the most useful group of paleoenvironmental indicators used by geoscientists for the following reasons: (1) their shells are important sediment constituents; (2) they are small and widely abundant; (3) different taxa have evolved to exploit most environments, substrates, and nutritional modes in marine systems; and (4) their shells morphologically and geochemically record environmental conditions. This project will develop techniques for routine use of foraminifera as indicators of biological integrity in both field and laboratory settings.

In Phase 1, an index is being developed and tested for assessing perturbations of marine benthic ecosystems, which is based on changes in key taxa of foraminifera and that can be applied worldwide using historical, sediment-core, and surface-sediment data sets. This technique will provide an index for assessing how benthic communities have changed under human influence as compared with the natural variability in preanthropogenic times or in unaffected areas. The procedure requires minimal technology and can be applied by technicians with modest training. The model ranks relative abundances of key foraminiferal taxa, morphogroups, and total abundances, generating an index value when foraminiferal assemblages are compared temporally or spatially. The model will be adaptable to local and regional biotas and can incorporate other environmental or taxonomic data that can be scaled to the model.

In Phase 2, bioassay protocols will be developed for foraminifera in laboratory studies on the effects of key stressors in marine benthic environments. In addition, Phase 2 will use *Amphistegina spp.*, which are reef-dwelling foraminifera with algal endosymbionts. Known stressors in culture include temperature shock, salinity change, slight increases in UV-B radiation, algal overgrowth, and chemical pollutants. Specific protocols will be developed by using visual, cytological, and biochemical responses to enable routine experimentation with the protists. Besides being globally important in their own right, these foraminifera can provide a model calcifying symbiosis for testing stressors that threaten the ecological integrity of coral-reef ecosystems. Protocols also will be adaptable to other cultivable foraminifera from other ecosystems.

For Phase 1, the preliminary iteration of the index (see Table 1) has been tested on historical (1960) and recent (1992) data sets from surface sediments collected off Key Largo in the Florida Keys, with results indicating a significant change in the benthic community over that time. In addition, published data sets from Florida Bay have been requested from the U.S. Geological Survey; tests of those data sets using the preliminary index will be presented.

Preliminary tests indicate the potential for providing an index for quantifying change in marine sediments that can be directly useful in interpreting environmental change under anthropogenic influence. This work has only just begun. For Phase 1, collection and analysis of sediment cores from the Florida Keys is planned for 1998. Data sets are being sought from temperate locations, specifically Nova Scotia and San Francisco Bay, to expand applicability. For Phase 2, experiments will be initiated in early 1998.

Classification Categories	Taxonomic/Morphogroup Rankings
Local opportunists Other agglutinates Larger miliolines Other miliolines Large rotaliines Other rotaliines Other key taxa or morphogroups Morphological anomalies	0 - Not recorded in region or no data 1 - Rare (≤ 1%) 2 - Uncommon (1% < ≤ 5%) 3 - Common (5% < ≤ 20%) 4 - Abundant (20% < ≤ 40%) 5 - Very abundant (40% < ≤ 60%) 6 - Dominant (> 60%)
# forams/gm of sediment Other parameters	Ranked as $\log_{10}$ values Ranked as a 0-6 scale

Example: Inshore station near Key Largo, Florida

Classification Categories	Sample A M-1961	Sample B M-1992	Difference $D = \lvert A_i - B_i \rvert$	Change Factor (CF)[1]
1. Known opportunists	1	1	0	0
2. Other agglutinates	1	2	1	0
3. Larger miliolines	6	3	3	2
4. Other miliolines	3	5	2	1
5. Large rotaliines	1	1	0	0
6. Other rotaliines	2	3	1	0
7. # forams/gm of sediment	0	3.9	0	No data
8. Other catagories	0	0	0	No data

$$MBPI = \frac{[\sum \lvert A_i - B_i \rvert - (\lvert A_i - B_i \rvert - 1)]}{N^*} = \frac{7+3}{6} = 1.7$$

[1]CF = $(\lvert A_i - B_i \rvert - 1)$ where $\lvert A_i - B_i \rvert \geq 1$; CF = 0 where $\lvert A_i - B_i \rvert = 0$.

N* = Number of categories in which both A and B > 1 (i.e., taxa occur in area and data were collected).

Preliminary tests indicate:

- MBPI < 1 No significant change in benthic community.
- 1 < MBPI < 2 Perceptible change in benthic community.
- MBPI < 2 Dramatic change in benthic community.

Table 1. Proposed marine benthic perturbation index.

Development and Evaluation of Multiscale Mechanistic Indicators for Assessing the Integrity of Regional Landscapes

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In this project, suites of ecological indicators will be developed that cross spatial scales, mechanistically reflect ecosystem states and processes, are statistically robust, and are applicable across regional landscapes. In addition, these indicators will be based on readily accessible information available in a real-time framework (e.g., Landsat data). To accomplish this, the following objectives are proposed: (1) develop predictive models that integrate landscape-scale factors with reach-scale physical and chemical stream attributes to quantify key compositional and structural attributes of stream biota and derive ecosystem indicators at multiple spatial scales; (2) evaluate the appropriate scale of terrestrial and aquatic data necessary to resolve regional and local aquatic resource questions; (3) improve the ability to distinguish and quantify natural variation in indicators from that derived from anthropogenic stressors; (4) assess the extent to which regional and local-scale indices (including standard indices of ecological integrity such as the Index of Biological Integrity) reflect fundamental ecosystem processes and structural properties of stream habitats and biota; and (5) quantify confidence limits and evaluate the geographic transferability of regional and local-scale indicators developed above.

To develop, evaluate, and integrate indicators across multiple spatial scales, a multitiered sampling and modeling strategy will be employed, integrating data collected at regional scales via satellite imagery, local scales via low-altitude imagery, and site scales via field sampling (see Figure 1). Relationships among these hierarchically nested scales will be quantified using an integrated series of empirical and process models. These data will be used to identify indicators at each scale that reflect a critical ecosystem process or state variables related to the integrity and sustainability of those ecosystems. Indicators representing fundamental driving variables and processes will be developed and tested and then integrated into a system for identifying positive or negative trends in the health of ecosystems in regions that are heavily dominated by agriculture and mixed land uses.

The results of this research will significantly increase the ability to quantify features of terrestrial ecosystems in strongly altered landscapes. Models of processes that integrate features at different scales will be developed. A sampling design that incorporates natural and anthropogenic features of landscapes and streams at regional, watershed, and local scales will be evaluated to determine the transferability of these methods among ecoregions. Extensive databases, previously developed through EPA-funded research, will be used to validate the use of statistical and methodological techniques.

By decomposing variance in ecosystem parameters associated with factors such as land use patterns and practices versus "natural" processes (e.g., geomorphology, topography), managers and policy-makers can concentrate scarce resources on those factors that have an influence on the ecological endpoints and that can be managed or manipulated. The proposed research will assist risk assessors to prioritize landscape and local features of terrestrial and aquatic ecosystems that influence aquatic ecosystem integrity. Finally, a rigoous analysis of the uncertainty associated with indices at all spatial scales, including natural stochasticity, measurement error, parameter error, and model error, will be provided. These estimates of statistical confidence will greatly improve the utility of ecological indicators for use in local and regional assessments.

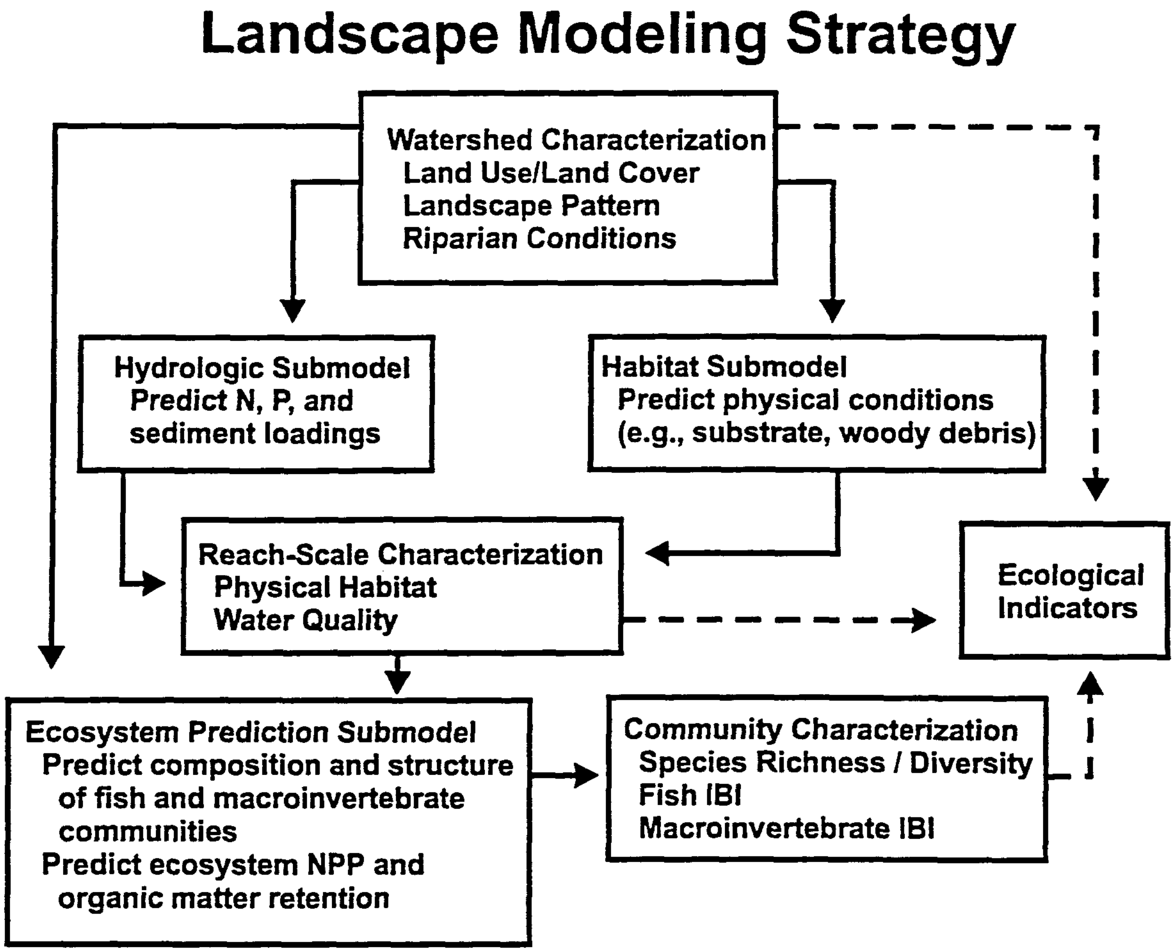

Figure 1. Conceptual model illustrating the organization of mechanistic factors operating at multiple spatial scales. Components summarize the development of predictive models, ecosystem attributes, and fundamental ecosystem processes. Indicators are derived at all spatial scales.

Development and Evaluation of Ecosystem Indicators for Urbanizing Midwestern Watersheds

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Urban areas are spreading over much of the Eastern United States, and yet our understanding of their impact on ecosystem processes is very poor. Understanding and managing the responses of these systems to urbanization requires a multidisciplinary effort ranging from site-specific to large-scale regional studies. The use of ecosystem indicators allows for the development of practical management approaches in the absence of detailed monitoring of the complete system. Although urbanization usually has negative impacts on stream ecosystems, the causal relationships have not been well studied. Simple empirical indicators may actually be misleading if they are not based on specific system characteristics. The focus of this project is on the development of predictive indicators of urbanization that are applicable to midwestern watersheds and stream ecosystems and, more importantly, to illustrate an objective methodology for developing and testing such ecosystem indicators.

This project's objectives are to: (1) quantify the impacts of urbanization on hydrologic regimes, water quality, and habitat structure of stream ecosystems using paired experimental watersheds, and to develop linked models that accurately predict these impacts; (2) use the linked models as a virtual laboratory within which to generate and test indicators of urbanization and hydrologic change in terms of responses of fish and macroinvertebrate communities; and (3) use these models and indicators in assessing the response of stream communities to alternative urbanization scenarios with extension to larger watersheds in the region.

This project will examine watersheds in transition from rural to urban. The initial study site is a 216 km^2 set of paired experimental watersheds encompassing two adjacent third-order streams. The watersheds typify drainages in the corn belt ecoregions; however, one is urbanizing more rapidly than the other, with substantial new housing developments planned in the next few years. Stream flow, water quality, and aquatic biota have been intensively monitored since 1991, allowing the interpretation of temporal trends. A detailed geographic information system (GIS) database is available for spatial analysis. The investigators hope to establish linked process models that address the impact of land use change on the physical and chemical characteristics of runoff, stream flow, water quality, and habitat quality, and which then link changes in such stream variables to changes in aquatic community structure. A set of environmental indicators will be generated and tested based on these relationships. The predictive relationships among indicators will then be evaluated for a range of larger and more urbanized watersheds in the region. Thus, indicator behavior will be examined over a range of scales and physical settings under alternate urbanization scenarios.

Water quality and flow regimes are currently being evaluated for significant trends in the paired streams. Significant differences in flow, chloride, nitrate, total phosphorus, dissolved oxygen, and fish diversity have been identified. In addition, the initial steps in the modeling process focusing on temperature/oxygen levels and land use classification also are under way.

This project will provide a sound basis for the use of specific indicators as tools in regional planning of watershed development. The risk analysis portion of the work will provide a probabilistic measure as to whether a potential urbanization scenario can achieve stream water quality and biological targets.

Characterization of Ecological Integrity of Commercially Grazed Rangelands Using Remote Sensing-Based Ecological Indicators

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Rangelands involve vast areas of the Western United States with arid to semi-arid climates. Their low biological productivity has made point-based monitoring of the ecological status difficult to economically justify. Several remote sensing (RS) based synoptic means of characterizing changes in the integrity of lands will be tested on one large ranch in northern Utah. Also, the applicability of a transition threshold conceptual model will be tested by using satellite remote sensing and geographic information systems (GIS) to characterize rangeland conditions and trends.

The proposed research will use 21 years of Landsat satellite imagery; a GIS database of site biological, physical, historical, and current ranch management records; and multiple-time by nested multiple-scale experimental design to establish causal links between possible threshold response and human management interventions to assess the ecological integrity of ecosystems within a Western Intermountain Sagebrush Steppe-dominated landscape subject to commercial livestock and big game animal grazing.

The assessment will occur at multiple scales, including: landscape, watershed, administrative (i.e., public versus private land), individual paddock, ecological site, and piosphere (waterpoints). Watersheds and sub-basins will be delineated by using digital elevation models and GIS-based hydrological modeling algorithms. The resulting landscape stratification of geomorphological source, sink, and transfer zones will be statistically related to satellite image-derived indices of vegetation cover and composition, soil erosion, and landscape configuration metrics and will result in an overall measure of site ecological integrity and sustainability.

The proposed research will result in the following: (1) new RS-based ecological indices for assessing ecological integrity; (2) a synthesis of the new transition threshold concept in rangeland ecology, landscape ecology, and ecosystem science, which will link spatio-temporal changes in ecosystem structure and pattern to changes in rangeland condition and trend; (3) a general methodology for using satellite RS and GIS technologies with current ecological assessment concepts for monitoring semi-arid landscapes at multiple spatial scales; and (4) a validation of the utility of remote sensing-based piosphere indices in North America through the use of the developed GIS database.

Section 2.

Projects Initiated With Fiscal Year 1996 Support

Health Indicators for Salt Marsh Estuaries of the South Atlantic Bight

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This project examines simple, inexpensive, and rapid methods for assaying and monitoring the general health of salt marsh ecosystems in the Southeastern United States. It examines a suite of indigenous salt marsh organisms to determine if biological processes that occur on relatively short time scales (days-months) can be used as measures of salt marsh health and effectiveness of remediation strategies.

The research project involves laboratory and field components. However, the project emphasizes field studies. Paired sites at contaminated and control locales are chosen for field sampling. In the first year of the project, the sites included the LCP Superfund site in Brunswick, Georgia, and a relatively pristine site on Sapelo Island, Georgia. Years 2 and 3 will include another paired site in Georgia and several sites in Georgia and South Carolina, respectively. The basic concept includes: (1) evaluating critical rates within the macrophyte community, focusing on sublethal impacts; (2) determining the efficacy of reproductive potential of three species of estuarine crustaceans as another measure of sublethal stress; and (3) evaluating physiological bioassays using marine microorganism indicators.

Samplings at the LCP and Sapelo sites have been conducted. Samples are in various states of processing, analyses, data collection, and evaluation. Preliminary results indicate that the bioassays tested on impacted sites show no differences relative to reference sites. However, the preliminary nature of these results must be stressed, and it is inappropriate to draw conclusions at this time.

Samples from year 1 will continue to be analyzed. Data will be combined with that already collected and prepared for presentation and publication. Sites having potential impacts of chromium (Charleston, South Carolina), insecticides (known toxaphene site, Brunswick, Georgia), and arsenic/creosote (Escambia Superfund Site, Brunswick, Georgia) are currently being evaluated for extensive sampling during the coming year. Site selection also will begin in South Carolina and possibly Florida for year 3 project objectives.

Trophic Transfer of Atmospheric and Sedimentary Contaminants Into the Great Lakes Fisheries: Controls on Ecosystem Scale Response Times

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The purpose of this study is to quantify the absolute and relative magnitudes of polychlorinated biphenyls (PCBs) transfers into the Great Lakes fisheries from three exposure routes: (1) atmospheric deposition transferred through the pelagic food web; (2) atmospheric deposition transferred, via rapidly settling particles, through the benthic food web; and (3) transfer from historically contaminated, in-place sediments through the benthic food web. This will be accomplished by using stable isotopes and PCBs as tracers of carbon and bioaccumulative contaminants, respectively, through the water column and food web of Grand Traverse Bay, an embayment of Lake Michigan. Each of these three routes differ both in their efficiencies of contaminant transfer and in their characteristic response times. This study will result in a quantitative, process-driven model of contaminant transfers in the Great Lakes food webs that distinguishes between "new" (i.e., regional atmospheric deposition) and "in-place" (i.e., recycling from contaminated sediments) sources of contaminants that support the slowly changing contaminant inventories in the highest trophic levels of the Great Lakes.

This project's objective is to quantify the absolute and relative flows of bioaccumulative organic contaminants through the pelagic, epibenthic, and benthic food webs of the northern Great Lakes (see Figure 1). Efficient scavenging of atmospheric-derived contaminants from surface waters delivers large chemical fluxes seasonally to the epibenthic food web, and this process "pumps" recent atmospheric loadings into the Great Lakes fisheries. Specific objectives include: (1) quantifying the fluxes of organic carbon on a seasonal basis and associated contaminants from the surface waters to near the sediment-water interface; (2) quantifying trophic transfers of carbon and PCBs through the pelagic, epibenthic, and benthic foodwebs, with emphasis on the episodic deposition of particles to the benthic environment in the spring and the relative importance of infauna, amphipods, and mysids in contaminant transfer to Great Lakes fish; and (3) quantifying, through statistical analysis of contaminant "fingerprints" and bioenergetics modeling, the relative magnitudes of exposure to sedimentary and atmospherically derived contaminants in the Great Lakes fisheries.

To meet this project's objectives, an extensive field sampling effort in Grand Traverse Bay was successfully initiated and completed in 1997. Virtually all major species were collected, characterizing the lake trout food web on a seasonal basis. Sediment traps were deployed, retrieved, and redeployed during 1997 to characterize seasonal PCB and carbon settling and recycling dynamics. Vapor and dissolved PCB samples were collected on a monthly basis to determine atmospheric loadings. In addition, bottom sediment grabs and bottom water (~ 2 meters off the bottom) dissolved, and particulate samples were collected. Preliminary PCB concentrations in water, air, sculpin, and lake trout suggest that Grand Traverse Bay will be an appropriate surrogate for quantifying contaminant transfers into northern Great Lakes fisheries.

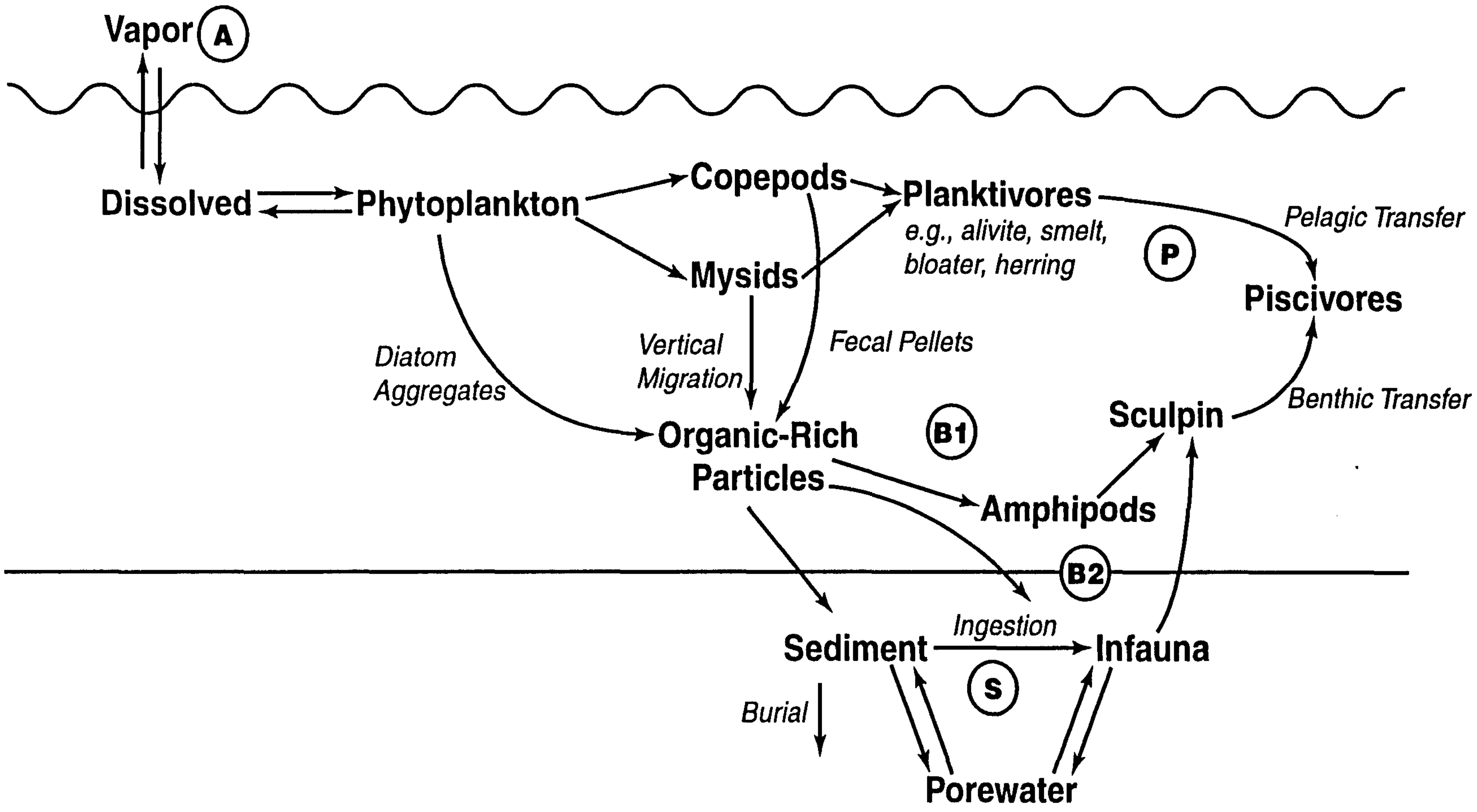

Figure 1. Food web structure and flows of bioaccumulative contaminants in the northern Great Lakes. Diffusive uptake of dissolved contaminants by higher trophic levels was omitted for clarity.

Multiscaled Assessment Methods: Prototype Development Within the Interior Columbia River Basin

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This project's goal is to investigate multiscaled relationships among biophysical variables and biological features of terrestrial and aquatic systems of critical value in the use of ecological assessment data. Extensive abiotic and biotic databases compiled for the Interior Columbia River Basin (ICRB) are employed to address six primary objectives: (1) link biophysical and biological patterns associated with terrestrial and aquatic systems at different scales; (2) quantify the scaled relations of linked biophysical and biological systems; (3) develop methods for predicting broad and fine scale patterns over areas of varying sizes; (4) classify landscapes at different scales based on biophysical and biological characteristics and define probabilities of response of the biotic components of landscapes; (5) test the effectiveness of classifications based on indirect variables (e.g., elevation, lithology, landforms) for predicting bioenvironments (e.g., groups of direct variables such as climatic variables) and biological characteristics of areas of varying sizes for evaluating alternative land management strategies and conservation; and (6) develop prototype multiscaled, representativeness assessments for evaluating alternative land management strategies using products from objectives 1-5.

To meet the above-mentioned objectives, nine steps are followed: (1) identify fine scale patterns of interest (biotic and abiotic) to be predicted by classification, maps, and models; (2) associate indirect and direct biophysical variables with each study ecological scale; (3) sample fine scale patterns across coarser scale biophysical environments; (4) determine the biophysical variables that most influence finer scale features (biotic and abiotic); (5) use numerical techniques to develop ecological classifications and maps based on a reduced number of indirect and direct biophysical variables; (6) determine relationships between biotic components and biophysical environments; (7) determine how accurately classes developed using direct biophysical variables can be predicted using indirect variables and vice versa; (8) determine whether the hierarchical structure of biophysical environments constrains biotic distributions and, as a consequence, constrains the hierarchical structure of biotic communities; and (9) test the effectiveness of classifications, maps, and models in assessing the representativeness of areas for regional conservation planning.

The project started on March 1, 1997. Since then, step 1 has been completed, and step 2 is near completion. All existing relevant spatially referenced databases covering the ICRB have been acquired and processed, and new databases are being developed. Thorton's DAYMET model generating biophysical variables has been tested at a 30 meter scale in a subbasin of the Flathead National Forest, Montana. A total of 35 variables representing geographic coordinates, topography, climate/hydrology, geology, disturbance, and management have been attributed to 27,000 vegetation plots for analyses of regional biotic distribution. Preliminary work on steps 4, 5, and 6 is under way in four areas: (1) testing the effectiveness of three multiscaled ecological classifications in predicting vegetation patterns and disturbances across scales; (2) conducting a regional gradient analysis of vegetation and a study of species diversity patterns over the ICRB; (3) studying the effect of sub-grid variation on estimation of diversity patterns; and (4) development of preliminary predictive statistical models to define regional probabilities of environmental response for species (see Figure 1) and community types.

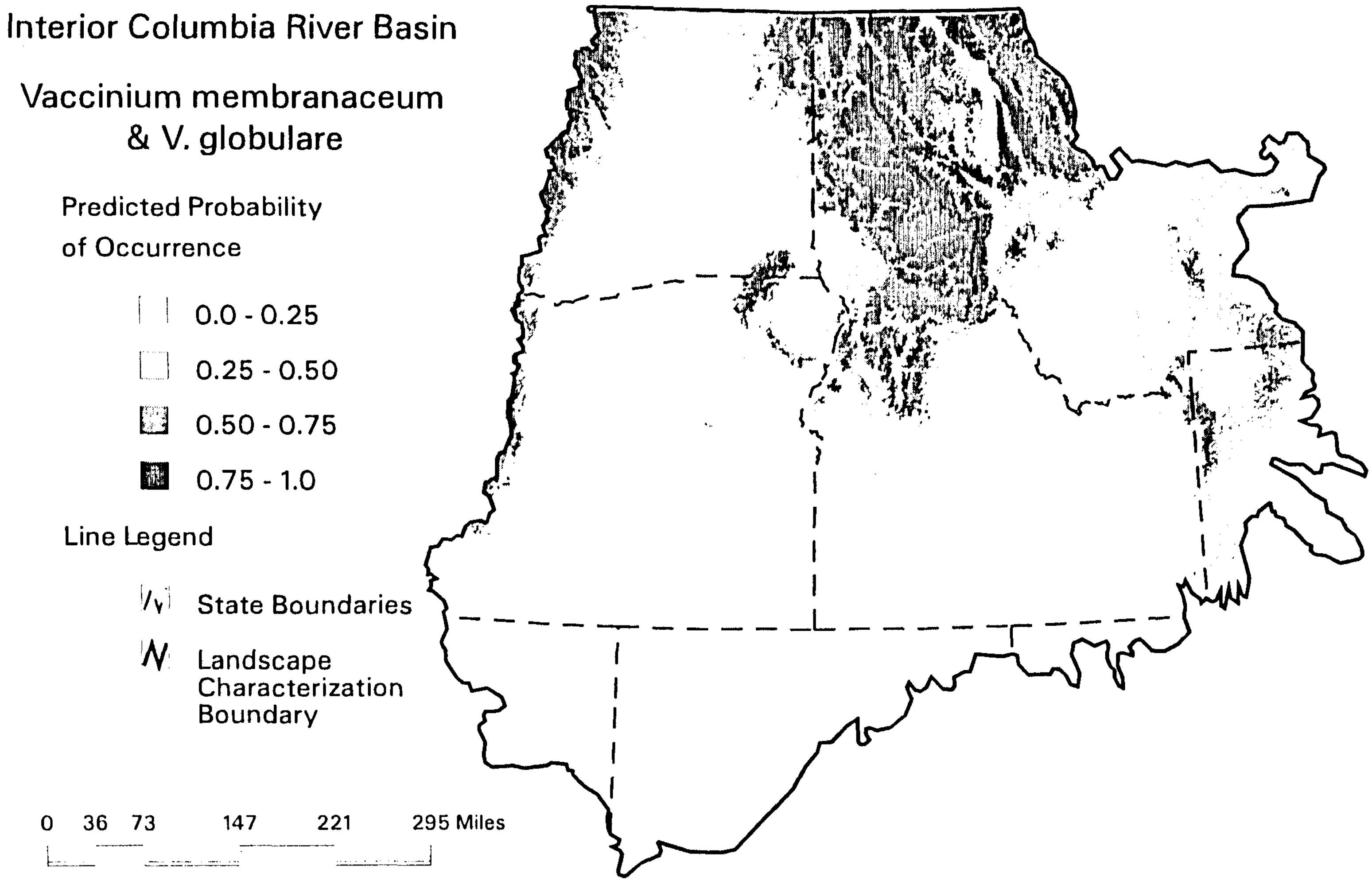

Figure 1. Interior Columbia River basin.

Multiscale Assessment of the Population Status of *Thalassia Testudinum* (Turtle Grass): A New Approach to Ecosystem Assessment

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Seagrasses are vital components of the near-shore ecosystem, providing food and shelter for part or all of the life cycle of many economically important fish and shellfish species. However, drastic declines in the distribution and abundance of estuarine seagrass and submerged aquatic vegetation (SAV) communities have occurred in many estuaries throughout the world during the past 50 years. In most cases, concurrent declines in water quality have been blamed for seagrass loss.

Because seagrasses are sensitive to even slight decreases in water clarity, they are ideal sentinel species for biological monitoring of water quality. This project's goal is to test the utility of demographic, morphological, physiological, and chemical characteristics of turtle grass (*Thalassia testudinum*) as indicators of chronic stress. The investigators also are trying to determine the most effective sampling design and scale for assessing the impact of natural and human impacts on seagrass beds. Turtle grass was selected for three reasons: (1) It is abundant along the Gulf coast. (2) Because it has a large investment in nonphotosynthetic tissue (roots and rhizomes), it is particularly sensitive to stress. (3) In estuaries like Tampa Bay, it has proven more vulnerable than other seagrass species to human impacts.

In the first year, nine sites were sampled from the Chandeleur Islands to the Florida Keys, using a hierarchical sampling design based on tesselated hexagons. At each site, 30 stations at each of three (small—100 m^2, medium—10,000 m^2, and large—1,000,000 m^2) scales were sampled (see Figure 1). At each of the stations, seagrass cover and community structure were assessed visually in 0.25 m^2 quadrats. Plant samples were collected for demographic analysis by reconstructive aging and for structural indices such as leaf width, length, shoot-specific leaf area, and leaf area index. Rhizome samples were collected for elemental (C:N:P) and stable isotope (del C-13, del N-15, and del S-34) analyses.

The first sampling was carried out in fall 1997, so data have not yet been analyzed. However, the following responses to stress gradients based on our pervious work in Florida Bay and other estuaries are anticipated: (1) *T. testudinum* populations will exhibit changes in age structure. The number of new rhizome apices and very old shoots are both expected to decline along stress gradients. Plastochrone intervals (blade turnover rates) will increase. (2) Spatial patterns of elemental (C:N:P) ratios will reflect nutrient sources for each system. Stable nitrogen isotopes, in particular, will reflect gradients in anthropogenic and natural (fixed nitrogen) supplies. (3) Morphological characteristics of *T. testudinum* also will reflect cronic stress effects: leaf blades will be narrower; shoot density and leaf area index will decline. (4) Physiological reserves, such as rhizome starch, will be depleted by the metabolic cost of response to chronic stress.

Anclote, Scale 3, 1997

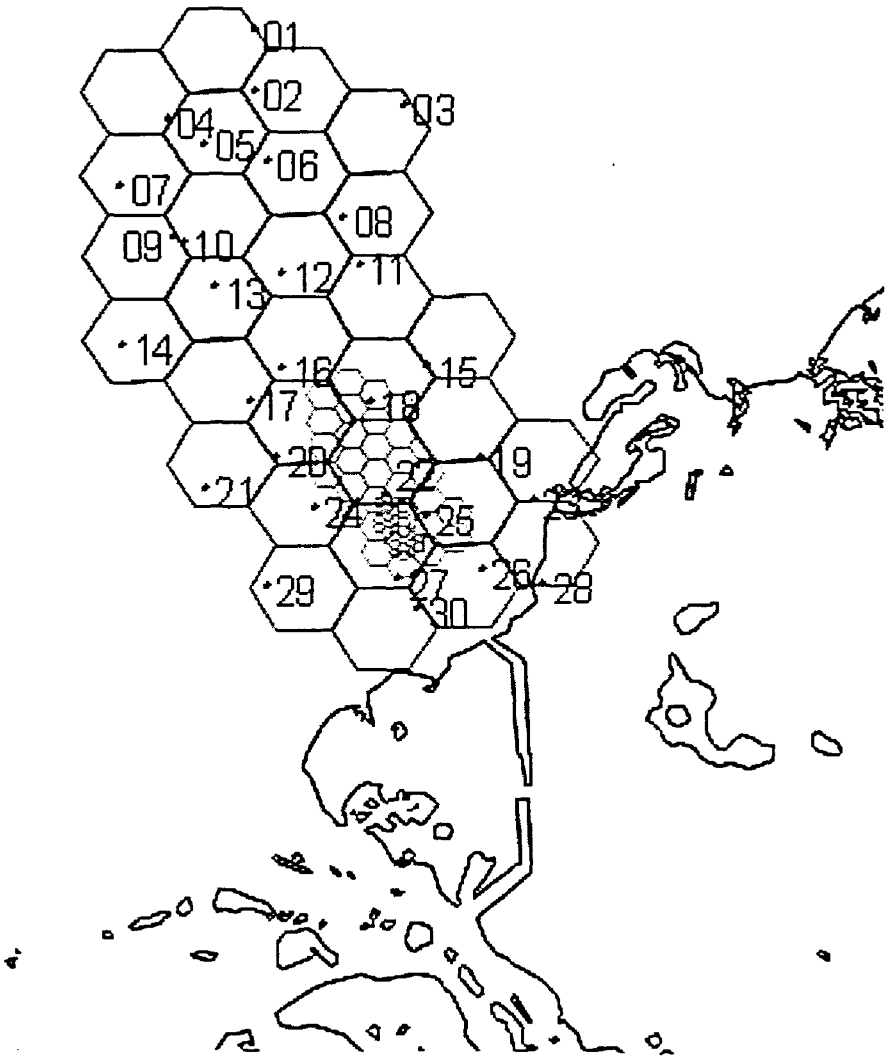

Figure 1. Multiscale seagrass sampling grid. Tesselated hexagons (30 at each scale) distribute sampling points over small (100 m²), medium (10,000 m²), and large (1,000,000 m²) scales at each site. The orientation and proportions of grids are adjusted to the impact gradient at each site.

Modeling Spatial and Temporal Dynamics of Montane Meadows and Biodiversity in the Greater Yellowstone Ecosystem

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This project's goal is to examine ecological dynamics in the Greater Yellowstone Ecosystem (GYE), concentrating specifically upon the spatial and temporal dynamics of montane meadow communities. The abiotic aspects of these communities as well as the biodiversity of plant, bird, and butterfly communities are being examined. This involves using intensive, local field sampling to test for relationships between species distribution patterns and remotely sensed data (see Figure 1). This project's long-term goal is to develop predictive species assemblage models based on landscape-level habitat analysis. This research involves several steps: (1) quantifying the spatial and temporal variability in montane meadow communities; (2) developing a spectrally based, spatially explicit model for predicting plant and animal species diversity patterns in montane meadows; and (3) testing the spectrally based, spatially explicit model for predicting plant and animal species diversity patterns in montane meadows.

A time series of satellite imagery is being used for monitoring the extent, condition, and spatial pattern of montane meadows on a seasonal and interannual time scale. Spectrally based, spatially explicit models are being developed for six meadow types using a geographic information system to stratify the study area by topography and geology. Two regions of the ecosystem have been sampled: the northern part of the ecosystem, hereafter termed the Gallatin study area, which included the Gallatin National Forest and northwestern portion of Yellowstone National Park; and the southern part of the ecosystem, hereafter termed Teton study area, which included Grand Teton National Park. Twenty-five sample sites were located in the Tetons, and 30 sample sites were located in the Gallatins. Birds, butterflies, and plants were surveyed at each of the sites. All species were identified in the field or given appropriate field names. Voucher specimens were collected. Species that were difficult to identify are being reviewed by experts in the field.

Data entry for the 1997 field season is nearing completion. Quality control of the data will follow. It is already becoming apparent that there are many species of birds, butterflies, and plants that show strong affinities for one or more spectrally defined habitat classes. A data matrix of species as well as functional and ecological traits is being compiled. In addition, analysis during the next several months will focus on assessing temporal variation in reflectance values for each sample site and conducting statistical analyses of relationships between spectral reflectance and field-sampled species distribution and biophysical data. Next spring and summer data from all of the sites will be collected again, following the above procedures. The third year will be spent primarily on data analysis. If there are sufficient funds, the collection of additional field data will occur.

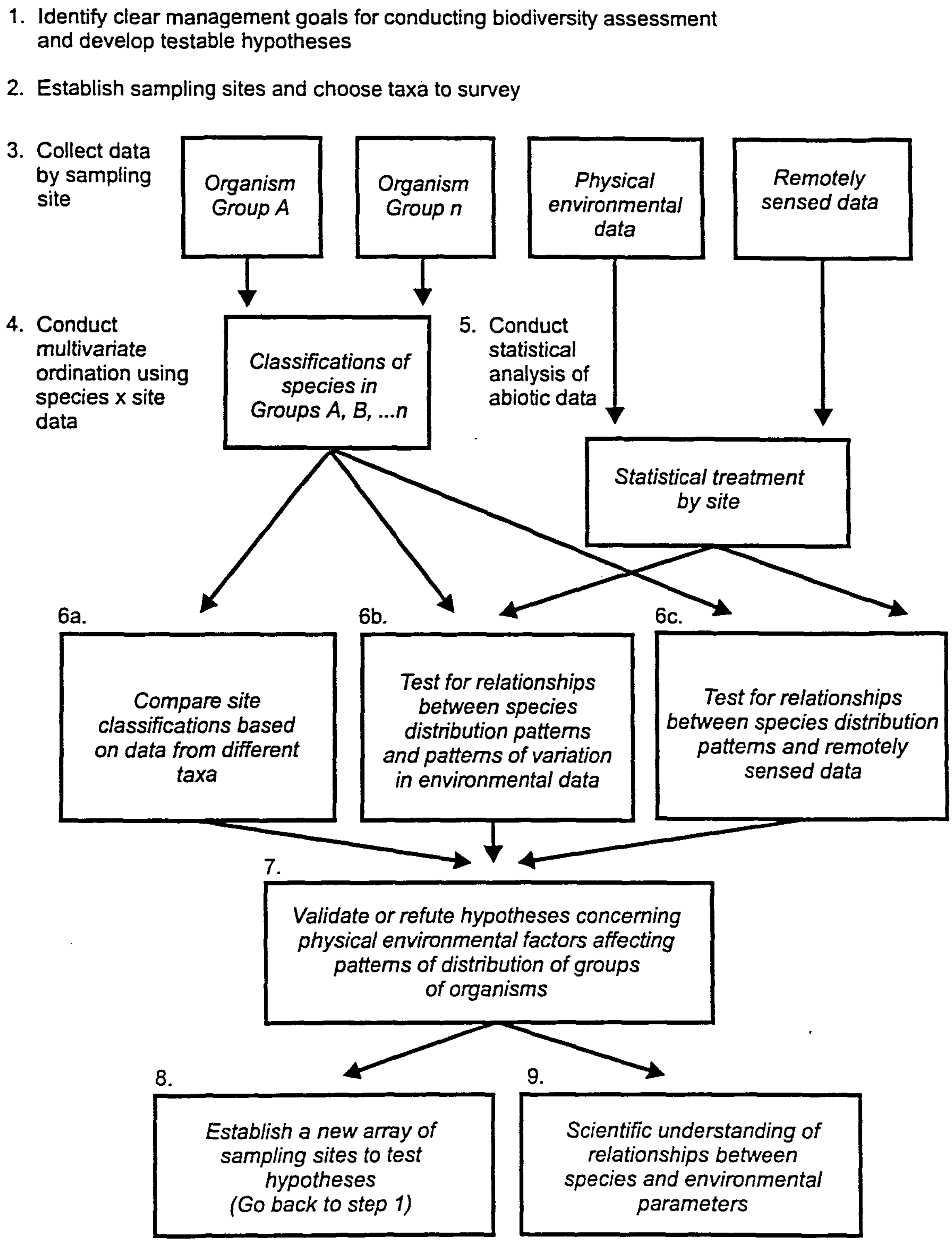

Figure 1. Research design for biological diversity assessment as seen in Debinski, D.M. and P.S. Humphrey. 1997. An integrated approach to biological diversity assessment. *Natural Areas Journal* 17 (4): 355-365.

Modeling and Multiobjective Risk Decision Tools for Assessment and Management of Great Lakes Ecosystems

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This project addresses restoration and protection of the Lake Erie ecosystem. Lake Erie's successes of the 1980s—nutrient controls, rebounding fisheries—have not continued into the 1990s. Fish populations are once again in decline. Contaminant body burdens are no longer decreasing, and the invasion of exotic species threatens to further destabilize the ecosystem. Possible climate warming would alter habitats.

Gaps in understanding the consequences of management actions and the lack of tested techniques for integrating multiple objectives and risk in decision-making hamper efforts to deal with these new challenges. The 1994 State of the Lakes Ecosystem Conference recommended that an ecosystem approach be adopted for studying ecosystem problems and the stresses that cause them; that well-defined ecosystem objectives be used to measure success in restoring ecosystem integrity; and that roundtable and interdisciplinary approaches to decisionmaking be taken that aim for consensus among stakeholders. This project attempts to respond to those recommendations.

In particular, the project's goal is to develop and test an integrated ecological assessment and decision methodology for the Lake Erie ecosystem. The purpose of the methodology is to assist managers and stakeholders, who are involved in the Lake Erie Lakewide Management Plan (LaMP) and other Lake Erie management processes, to define objectives and evaluate tradeoffs and risks associated with future uses. The research plan addresses the following issues: (1) the interaction of invasions of exotic species, nutrient reductions, and fishery harvests; (2) the influence of near-shore and tributary habitat on the offshore community structure and productivity; (3) the effects of alteration of the offshore community on contaminant body burdens of Lake Erie fish; and (4) the sensitivity of emerging ecosystem objectives to climate change.

The products of the research will include the following: (1) an expanded Lake Erie Ecosystem Model (LEEM), with modifications to habitat, hydrology, and climate change components; (2) the development and application of methodologies for decision-making under multiple objectives and uncertainty; and (3) workshops in which Lake Erie managers, who participate in the Lake Erie LaMP, apply and evaluate the model and methods.

The accomplishments during the first year of the project include enhancements to LEEM, analyses of ecosystem response to selected issues, and framing of a high-priority management problem for analysis by multiobjective risk methods.

Habitat has been linked to LEEM through the use of Habitat Suitability Indices (HSIs), which modify recruitment and predator-prey interactions. Alternative models have been developed for relating HSIs for wetlands to changes in the mean and variation of Lake Erie levels that could result from climate change. This was accomplished by adapting the Case Western Reserve University Great Lakes climate change model. Presently, an inventory of habitat supply for egg and larval stages is under way for the lake and will be linked to LEEM. Initial analyses using the modified LEEM have explored the relative importance of alternative stressors (habitat loss, phosphorus, and exploitation) upon the Lake Erie ecosystem. Changes in habitat were found to alter total biomass and walleye populations more than changes in P loadings.

In consultation with Region V of the U.S. Environmental Protection Agency, the issue of phosphorus management has been identified as the first management problem to be addressed by the multi-objective and risk methodologies. In particular, there appear to be fundamental tradeoffs between lake productivity (especially of the recreational and commercial fisheries of walleye, yellow perch, and smelt) and the taste, odor, and visual problems resulting from eutrophication. As a result, whether or not it is desirable to modify phosphorus loadings in part depends on the relative weight placed on those objectives. Further, ecosystem structure changes resulting from the zebra mussel invasion have made it more difficult to assess the relative contribution of habitat changes, species invasion, and decreases in phosphorus loadings to the recent decreases in walleye and yellow perch populations.

LEEM will be used, together with Monte Carlo risk-propagation methods, to characterize the effect of alternative phosphorus targets upon the objectives and the uncertainties surrounding those effects. Decision trees will be used to structure the information. Figure 1 shows the general framework of the analysis.

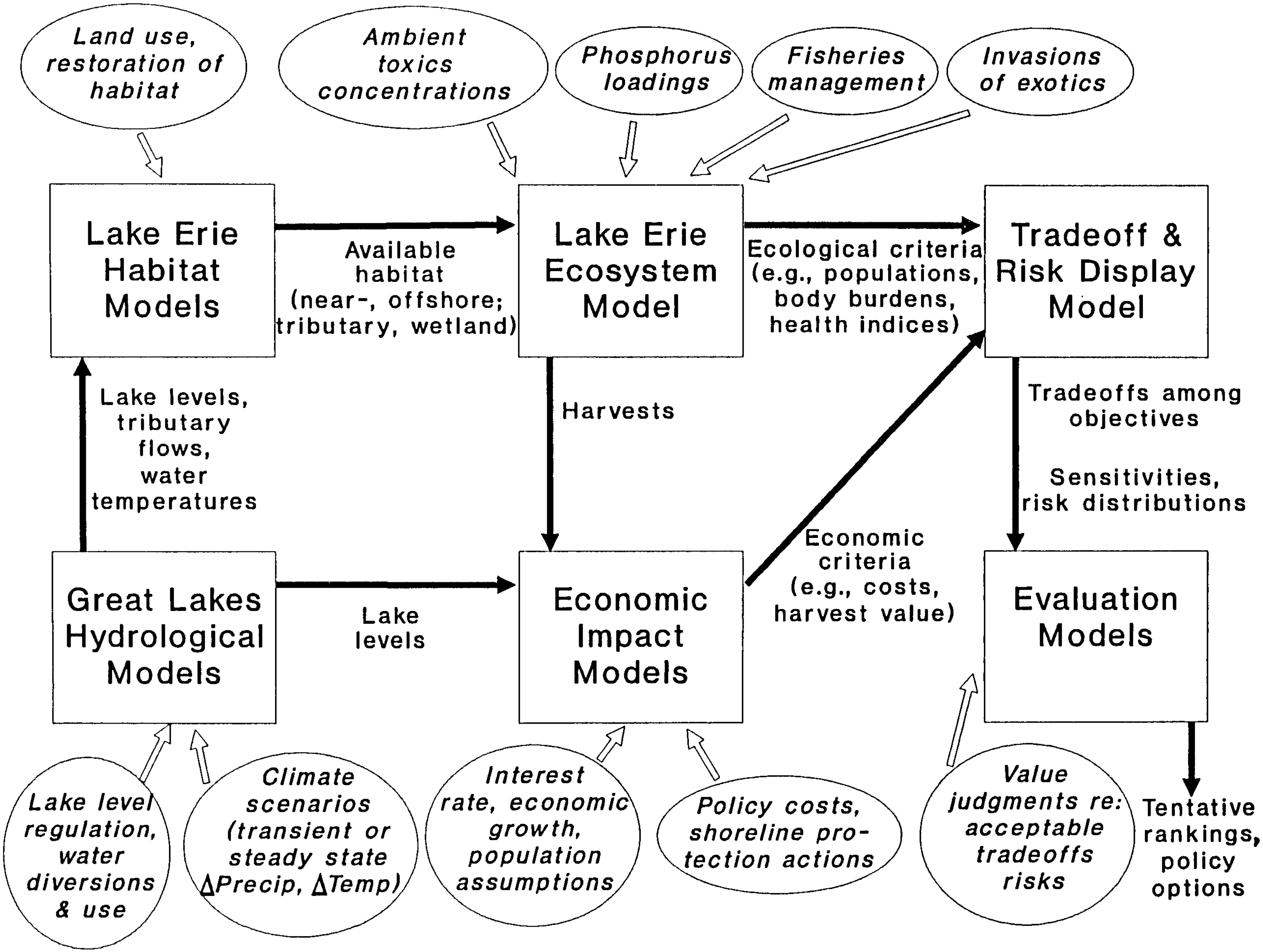

Figure 1. Lake Erie ecosystem management model structure.

Use of Multiscale Biophysical Models for Ecological Assessment: Applications in the Southeastern United States

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This project's goal is to develop an integrated set of landscape analysis and computer modeling tools that can predict natural patterns of spatial and temporal variability in the major ecological properties, which are used for environmental assessment. The capability to predict natural patterns of variability in these properties is a prerequisite for determining whether these ecological properties are actually changing, either in response to anthropogenic impacts or to natural environmental change.

The conceptual framework for this work is to use the interaction of climate and geomorphology to predict spatial and temporal variation in environmental processes that influence the growth rates of organisms (i.e., net primary productivity) and the frequency and severity of disturbances that cause mortality. The specific ecological properties that are being analyzed and modeled include: (1) spatial and temporal (interannual) variation in primary productivity; (2) spatial and temporal (decadal) variation in soil carbon and hydrologic storage capacity; (3) spatial and temporal (interannual to decadal) variation in the species diversity of selected functional types of organisms; and (4) spatial and temporal variation (interannual) in the population size and dynamics of selected plant and animal species.

The biophysical modeling approach being used combines tools for visualizing and extracting landscape scale data from digital elevation models and vegetation maps (see Figure 1) with tools for: (1) analyzing point samples from field data collection in the context of landscape scale data from the geographic information system (GIS) applications and (2) modeling hydrological and ecological processes across landscapes using digital elevation models and other information. The data analysis and modeling are focused on three areas that represent different spatial scales of pattern and processes in the Southeastern United States: the Oak Ridge National Environmental Research Park, 150 km^2; the Great Smoky Mountains National Park, 2,000 km^2, serving as a prototype; and the Southern Appalachian Region, 150,000 km^2. Within each of these areas, preexisting data are being used for the analyses, with some limited field work to address specific issues where adequate data are not available.

Work during the first year of the project has concentrated on the smallest spatial scale. Examples of current projects illustrating the range of processes that are being integrated through geomorphological modeling include: (1) analysis of environmental monitoring data for fish and benthic insect diversity in streams on the Oak Ridge Research Park; (2) development of a topographically based hydrologic model for the Oak Ridge Research Park; (3) tree-ring analysis to determine historical patterns of spatial variation in interannual growth increments in tulip poplar; (4) field sampling and computer modeling of the impact of ice storms on forests in the Southern Appalachian region; and (5) development of an individual-based model of black bears for predicting bear population dynamics in the Smokies.

Watershed Topography Drives Both Hydrologic and Soil Carbon and Nitrogen Dynamics

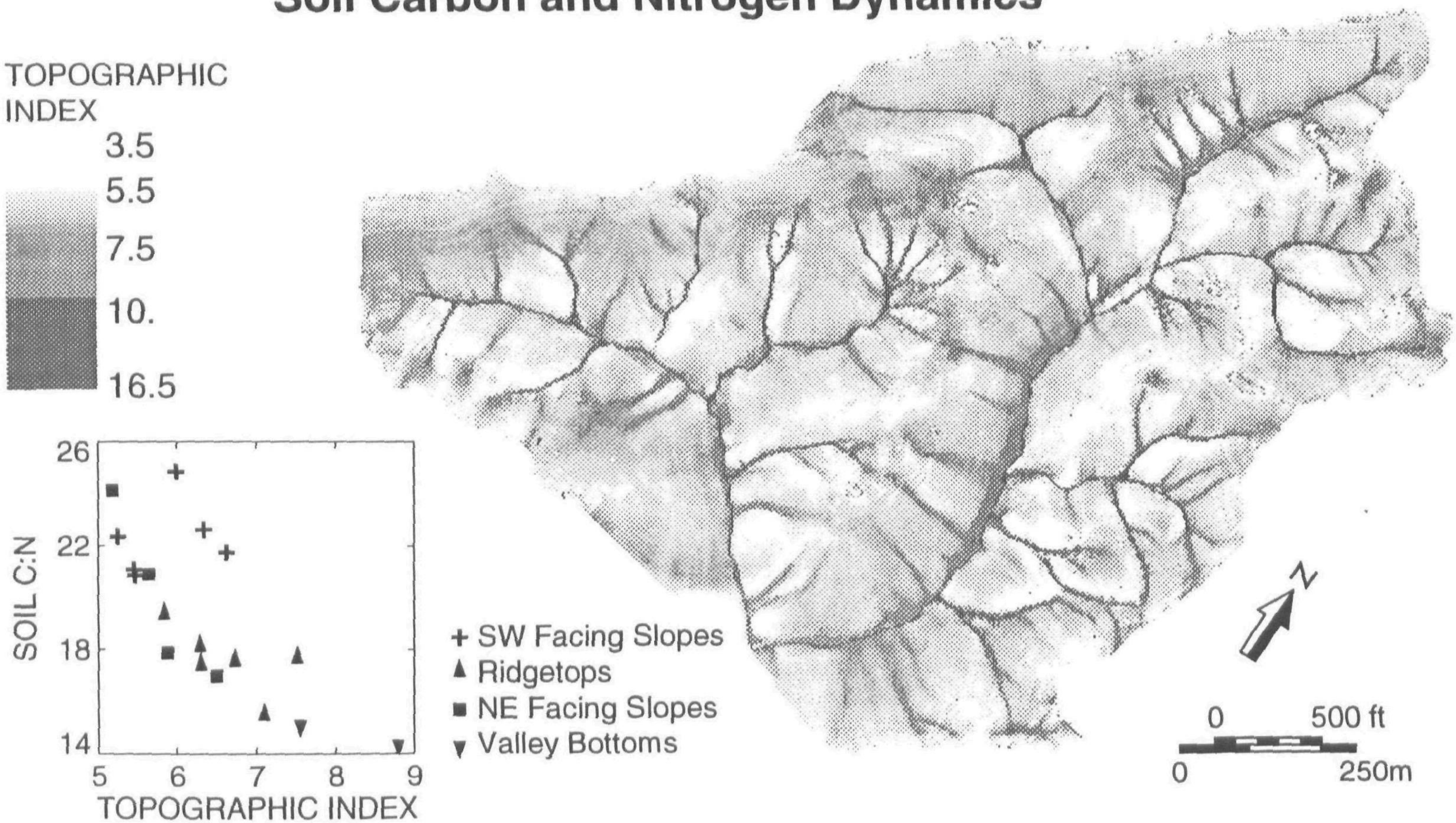

Figure 1. The carbon:nitrogen ratio in soil is an important indicator of soil nitrogen dynamics, which have a strong effect on plant growth and net primary productivity. The inset map of Walker Branch Watershed on the Oak Ridge National Environmental Research Park was developed from a high-resolution digital elevation model (DEM) and is shaded using a hydrologic wetness index based on drainage area and slope. High values of the index (darker colors) indicated wetter than average soil conditions. The inset graph shows the strong correlation between soil C:N and the topographic (wetness) index, indicating that topography alone is a good predictor of this important soil property (based on C.T. Garten, M.A. Huston, and C. Thoms. 1994. Topographic variation of soil nitrogen availability at Walker Branch Watershed, Tennessee. *Forest Science* 40: 497-512).

Monitoring and Restoring Hydropatterns in South Florida Ecosystems

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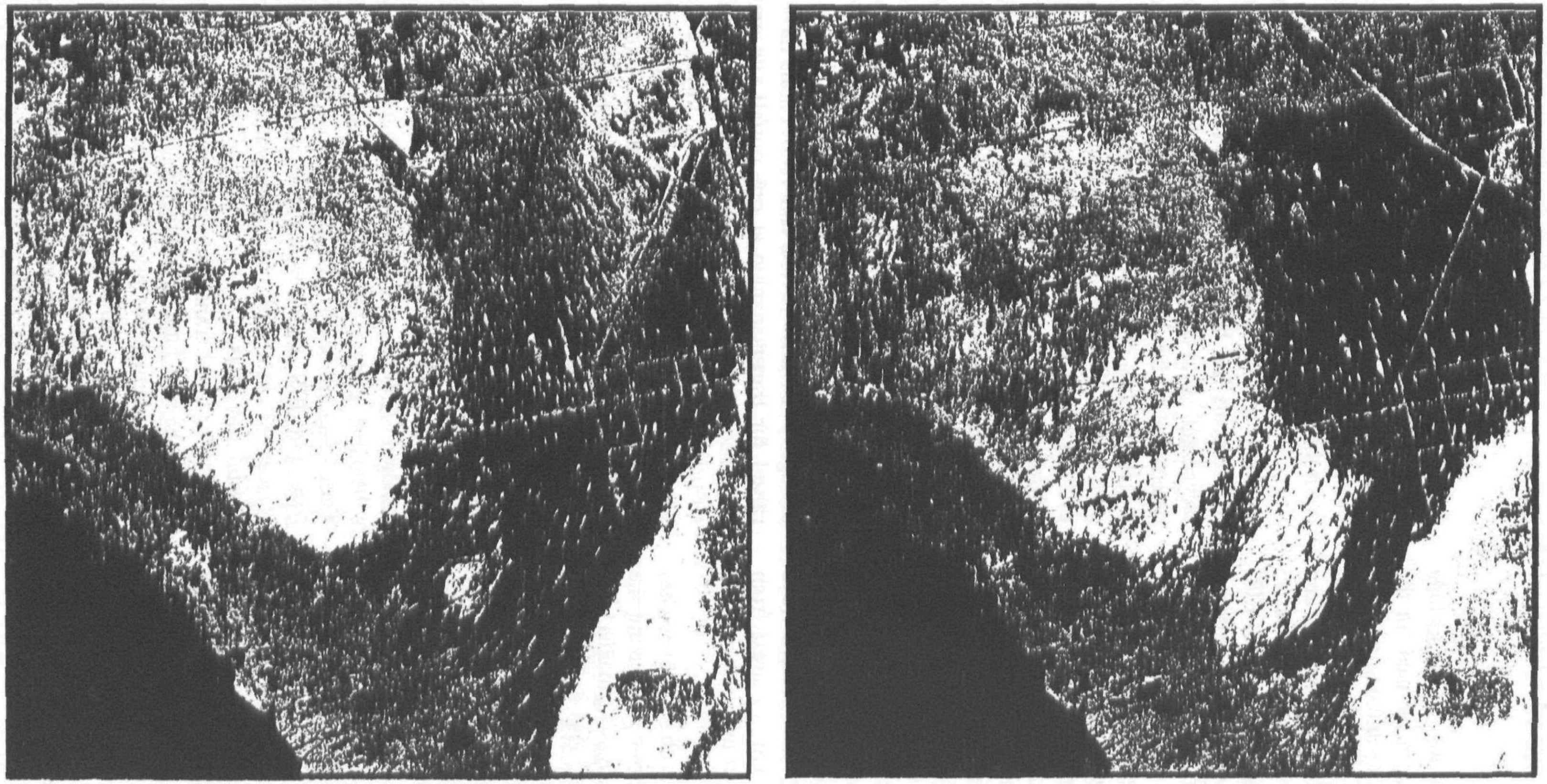
This project's goal is to develop and evaluate new methods to monitor and predict the spatial and temporal patterns of surface water inundation (hydropatterns) in the different wetland ecosystems found throughout the greater South Florida Ecosystem. The objectives of the research are three-fold: (1) to develop approaches to use space-borne imaging radar systems to monitor variations in relative soil moisture and surface water inundation in the study area; (2) to implement hydrologic models that can be used to estimate the expected patterns of surface water inundation (hydropatterns) in specific test sites and the influence of anthropogenic activities (e.g., building of structures and management of water flow) on these patterns; and (3) based on a variety of future precipitation scenarios, determine the best strategy for maintaining or improving water flow in regional wetland ecosystems by altering structures or management practices.

The approach will be carried out using a variety of analysis approaches. A series of 10 test sites have been located in the Big Cypress National Preserve and the Everglades National Park. These field data then will be correlated with variations in radar image intensity measurements derived from several different satellite systems, including ERS, Radarsat, and JERS. Approaches will be developed to use the information from the radar imagery to map patterns of water inundation, including the influence of man-made structures and management activities on surface water flow patterns. At the same time, hydrologic models will be obtained and implemented that can be used to estimate the expected patterns of surface water flows for the two test sites. The model will be exercised for the time period during which the radar imagery was collected to determine how well the models can predict actual surface inundation patterns. The models will then be exercised under a variety of scenarios to evaluate how future climate change as well as changes in management practices and restoration activities may influence natural water flows through South Florida wetland ecosystems.

To date, efforts have been focused on establishing field test sites and analysis of available radar imagery. Distinct patterns have been shown to exist on radar imagery (see Figure 1), which correlate closely with seasonal variations in water levels. In addition, it has been demonstrated that the influence of roads on the interruption of the natural surface flow of water can be detected on the radar imagery. Based on these initial results, resource managers from the National Park Service are now considering using radar imagery to restore natural water flow across the Taimiami Trail, which bisects the Big Cypress National Preserve.

Correlation of field data and radar imagery will occur to determine the exact correlation between radar intensity and surface water levels in different vegetation types. In addition, hydrologic models and data sets necessary to exercise these models are being implemented.



13 August 1996 ERS-2 SAR Image - Wet Season

15 April 1997 ERS-2 SAR Image - Dry Season

Figure 1. Two ERS radar images collected over southern Florida. Variations in image intensity are due to changes in water level and soil moisture between the wet seasons and dry seasons.

Development of Environmental Assessment, Mitigation, and Restoration Techniques for Coral Reefs

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The goals and objectives of this project include the following: (1) to improve techniques used for the assessment of coral reef health and sustainability; (2) to develop appropriate coral reef biomonitoring protocols; (3) to develop techniques for coral reef restoration and guidelines for mitigation of anthropogenic disturbance; and (4) to develop a set of criteria for EIA's and EIS' for activities occurring on or adjacent to coral reefs, or within watersheds that may affect coastal coral reef ecosystems.

The approach will involve expanding present studies on the factors affecting reproduction (fertilization) and recruitment of corals, including tests of the effects of water and substratum quality. Survivorship under the conditions of decreased light, increased nutrients, sedimentation, and contamination will be investigated. Comparative bioassays will be performed using EPA-approved species along with the chosen coral and related reef species to determine if the sensitivity is as good or better. In addition, the protocols for coral fertilization and larval settlement bioassays will be standardized, and the ability of transplanted (and cultivated) corals to serve as indicators of stress from sewer outfalls and other human disturbances will be tested.

Preliminary findings indicate that progress has been made on all aspects of the project. During the coral spawning events of July and August, gametes were collected from a variety of species, and a number of fertilization experiments were performed. The techniques for cultivating corals were refined and simplified. Using coral larvae reared from the spawning events, pesticide bioassays were performed using metamorphic induction as the test of effect, with highly significant results. Additional experiments focusing on reef restoration using coral larvae are under way.

The program to study effects of the sewage outfalls and eutrophication on corals is progressing. Cohorts of corals have been raised from larvae for transplantation to the outfall site and two reference sites. Due to the potential hazards involved in diving near the sewage outfalls, specialized dry suits and full face masks were purchased, and divers trained and certified in their use were employed.

The grant also has been used to develop appropriate policies based on scientific data. Regular meetings have been taking place, including the principal investigator and representatives from the regulatory agencies on Guam such as the Guam EPA, the Division of Aquatic and Wildlife Resources, the Coastal Zone Management Program, and the Public Utilities Agency. Also, opportunities for public participation have been made available. During the summer, a community-based coral reef survey was performed with support from this grant.

The accomplishments and research results include the following: (1) *Coral Cultivation:* A standardized set of protocols has been developed for cultivating coral larvae and coral colonies. (2) *Pesticide Bioassays:* A determination has been made that different life-history stages of corals demonstrate differential sensitivities to pollutants. Water-soluble pollutants are particularly problematic to egg-sperm interactions, while lipophilic substances can interfere with recruitment (settlement and metamorphosis). Studies of the effects of an organophosphate pesticide, Chlorpyrifos, found that this chemical can significantly affect settlement and metamorphosis in coral planula larvae (see Figure 1). This chemical appears to affect both metamorphic inducers found in the preferred settlement substrata and the larval receptors responsible for metamorphosis. (3) *Effects of Sewage on Corals:* Several cohorts of corals have been raised for transplantation at one outfall site and two reference sites. (4) *Criteria for Monitoring Coral Reef Health/EIA's and EIS':* A coral reef "physical exam" has been developed to identify the monitoring options and provide guidance in their application. Also, a draft of EIA and EIS procedures has been prepared as part of a larger effort at developing legislation at both the local and possibly the federal levels.

Procedures for coral cultivation have been standardized to the point where it is practical to develop coral-specific bioassays for environmental monitoring of reefs. Using coral larvae, it was demonstrated that standard LC50 protocols applied to adult corals can miss substantial effects on populations and communities. These data are being used to develop a framework for EIA and EIS requirements for activities proposed adjacent to coral reefs, or within watersheds affecting coastal reef areas.

The coral transplants will be placed out in the field in the near future. Another series of pesticide bioassays is planned for later this year. The cultivated corals are being monitored for growth rates and survivorship. Additional reproductive data are being collected for other species with the potential for use in bioassays. The data being generated by this research, as well as data from other studies, are being compiled and evaluated for application to the assessment of coral reef health.

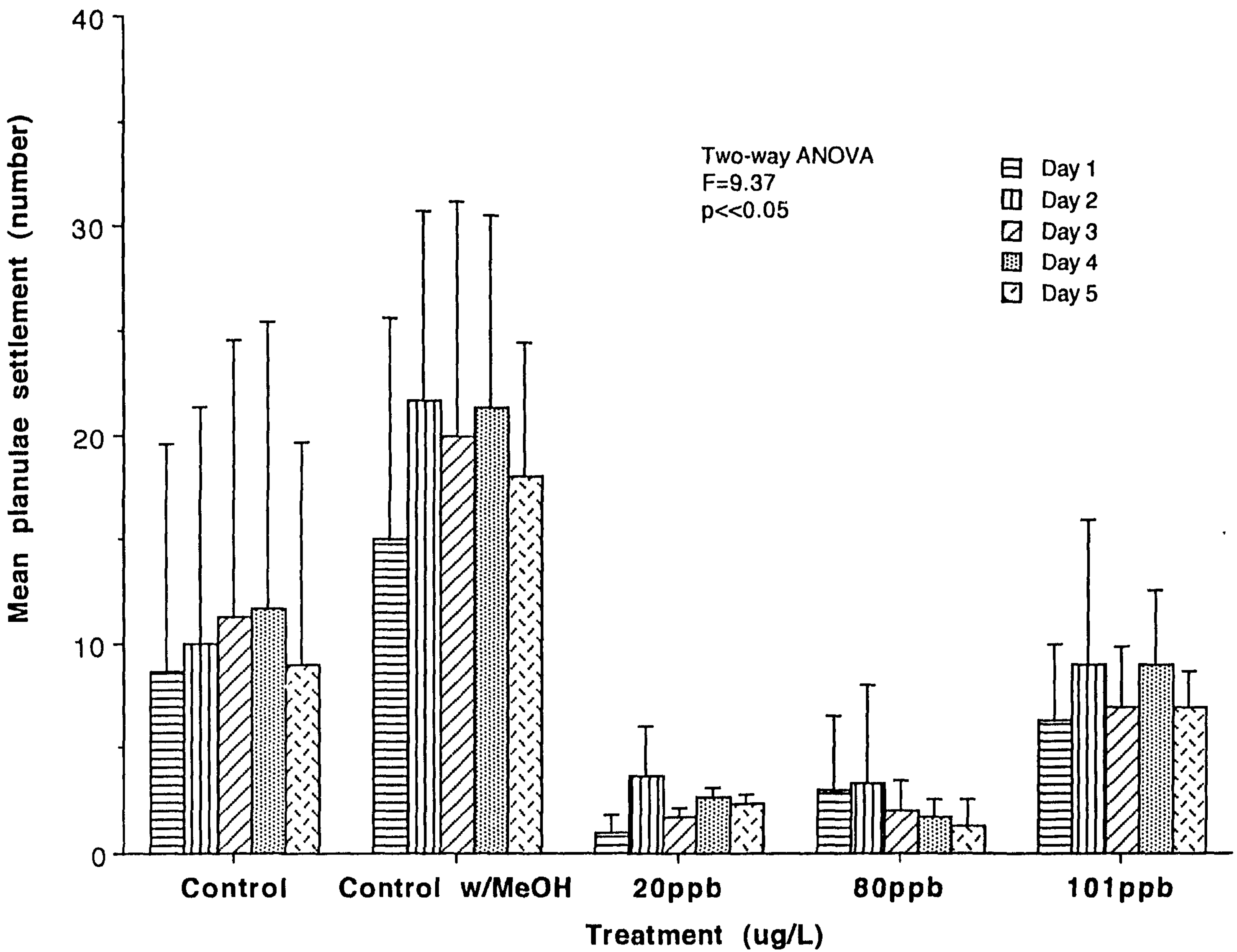

Figure 1. Effects of potential hydrophobic/lipophilic substance, Chlorpyrifos (organophosphorus pesticide), on planulae settlement (substrate was exposed to pollutant for 24 hours).

Assessment and Analysis of Ecosystem Stressors Across Scales Using Remotely Sensed Imagery: Reducing Uncertainty in Managing the Colorado Plateau Ecosystem

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This project investigates scale issues in reducing uncertainty in ecosystem management for the Colorado Plateau Ecosystem (CPE), by examining potential characteristic scales at which environmental stressors and their effects may be manifested on ecosystem landscapes, using remotely sensed imagery. The project objective is the development of a standardized analytical algorithm for using multiscale, remotely sensed data in the characterization and analysis of landscapes at the ecosystem level.

Earth system processes and the effects of human/land interactions can be detected and monitored over specific space and time intervals, known as *characteristic scales*. Remotely sensed data are resampled across a range of pixel resolutions over the spatial extent of the CPE. Scale analysis techniques are used to examine the landscape at different pixel resolutions, indicating characteristic scales of ecosystem processes, patterns, and disturbances. The Landsat MSS imagery used is available through the North American Landscape Characterization (NALC) program and has been initially resampled to a 60 meter pixel resolution. NALC data sets contain imagery from the 1970s, 1980s, and 1990s as well as a Digital Elevation Model (DEM). Subsequent resampling creates a sequence of lower resolution versions of the images (see Figure 1), corresponding in part to the 250 meter, 500 meter, and 1,000 meter pixel resolutions of the proposed NASA MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. Scale effects methodologies are used to analyze each image at each time point and resolution level as well as to analyze difference images (e.g., 1970s/1980s). The scale effects methodologies being used include the following: fractal analysis, local variance analysis, variogram analysis, and multiscale variance analysis.

Based on suggestions of the proposal reviewers, preliminary work was added to the project involving the choice of resampling methodology for use in the project. Eight subsets (864 x 864 pixels) representing different landscape types across the CPE were used to examine the responses to four different resampling methodologies: (1) averaging; (2) systematic sampling; (3) filter weighting; and (4) filtering, using an algorithm designed to simulate results from a lower resolution sensor (MODIS). Results indicate that using a straight averaging algorithm methodology presents some difficulties with the way in which landscapes are represented (i.e., linear ground objects are weighted and represented more heavily than their polygon counterparts in the original image). Preliminary work with the filter weighting algorithm indicates that it is the most appropriate approach to effectively represent the ecosystem landscape at lower resolutions.

The resampling algorithm used to change the pixel resolution of imagery for scale analyses does make a difference on the results of subsequent analyses performed. Choosing an appropriate resampling algorithm that allows for a more realistic simulation of a lower resolution sensor will result in more meaningful and useful results of subsequent analyses.

Following the implementation of the filter weighting algorithm to all of the images, the next steps involve the creation of the difference images for the time steps (e.g., 1970s/1980s; 1980s/1990s) and multiscale analysis (i.e., implementation of the four scale effects methodologies on all of the images).

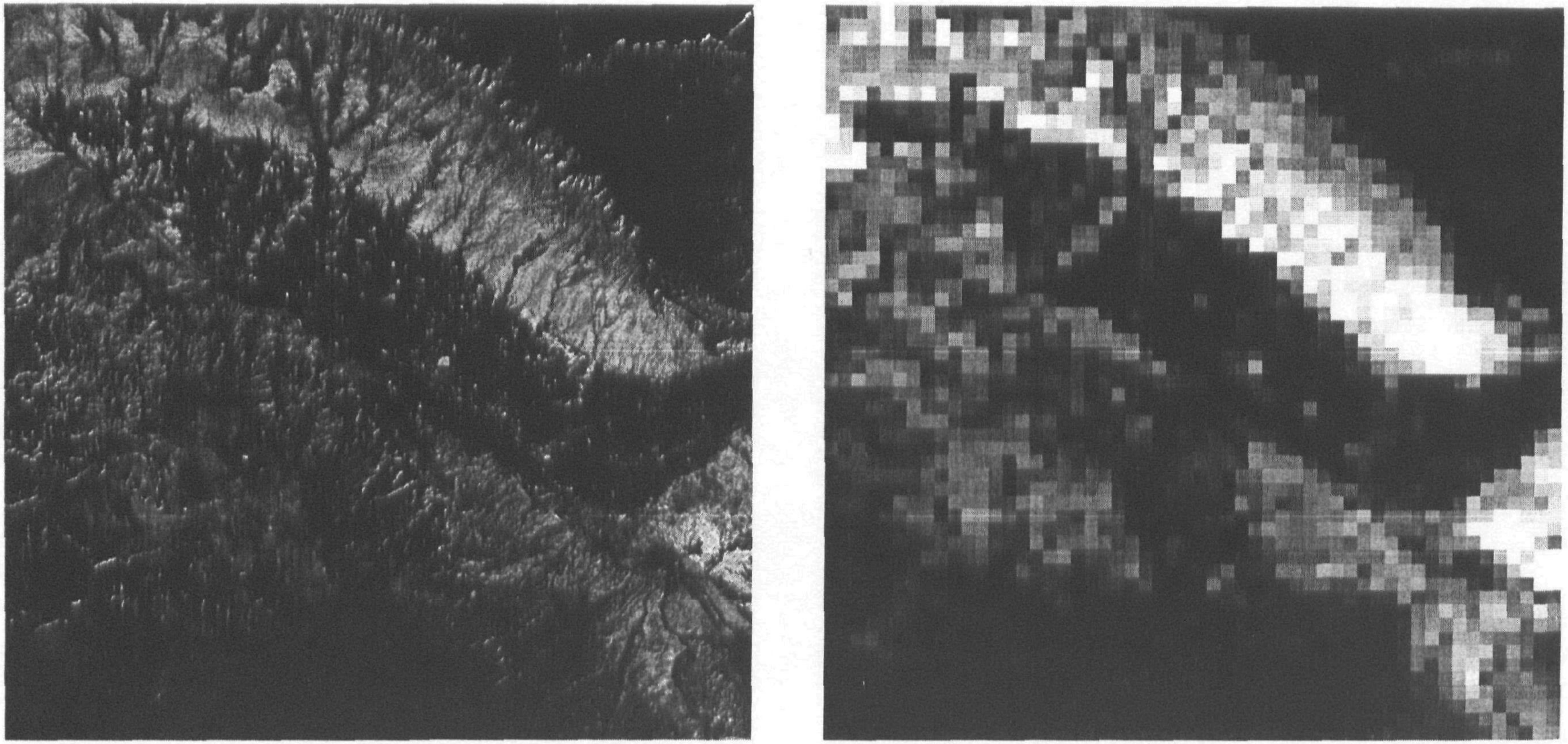

Figure 1. A 60 meter vs. 960 meter pixel resolution. Agricultural region along Gunnison River, CO.