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Mid-Atlantic Landscape Indicators Project Plan

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MID-ATLANTIC LANDSCAPE INDICATORS PROJECT PLAN
ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

by

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NOTICE

The United States Environmental Protection Agency (EPA), through its Office of Research and Development (ORD), prescribed the research described here. It has been subjected to the Agency's peer and administrative review, and it has been approved as an EPA publication.

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ABBREVIATIONS AND ACRONYMS

ADQ	Audits of Data Quality
AVHRR	Advanced Very High Resolution Radiometer
BBS	North American Breeding Bird Survey
C-CAP	CoastWatch Change Analysis Program
CCRS	Canada Centre for Remote Sensing
CDF	Cumulative Distribution Function
DQA	Data Quality Assessments
DQO	Data Quality Objectives
ECDMS	Environmental Contaminants Data Management System
EMAP	Environmental Monitoring and Assessment Program
EMAP-L	Environmental Monitoring and Assessment Program - Landscapes
EMAP-LC	Environmental Monitoring and Assessment Program - Landscape Characterization
EPA	Environmental Protection Agency
EROS	Earth Resources Observation System
FIA	Forest Inventory and Analysis Program
GCRP	Global Change Research Program
GIS	Geographic Information System
HUC	Hydrologic Unit Code
IBI	Index of Biotic Integrity
Landsat-MSS	Landsat-Multi-spectral Scanner
Landsat-TM	Landsat-Thematic Mapper
LUCAS	Land-Use Change and Analysis System
MAHA	Mid-Atlantic Highlands Assessment Project
MAIA	Mid-Atlantic Integrated Assessment Project
MAIA GRD	Mid Atlantic Integrated Assessment Geographic Reference Data base
MRLC	Multi-Resolution Land Characteristics Consortium
NALC	North American Landscape Characterization Project
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water Quality Assessment Program
NBS	National Biological Service
NCBP	National Contaminant Biomonitoring Program
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
NRI	Natural Resources Inventory
ORD	Office of Research and Development
QA	Quality Assurance
QAMS	Quality Assurance Management Staff
QAPP	Quality Assurance Project Plan
QMP	Quality Management Plan
RASA	Regional Aquifer-Systems Analysis Program
REMAP	Regional Environmental Monitoring and Assessment Program
SAB	Science Advisory Board
SAMAB	Southern Appalachian Man and the Biosphere Program
STORET	Storage and Retrieval System
TIME	Temporally Integrated Monitoring of Ecosystems Project
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

INTRODUCTION

Landscapes are described by the spatial arrangements of ecological resources. The Environmental Monitoring and Assessment Program Landscapes component (EMAP-L) was initiated in late 1992 and issued its research strategy in 1994 (EPA/620/R-94/009). In the 1994 research plan, EMAP-L selected an approach that examines landscape patterns relative to their affect on the flow of energy, water, nutrients, and biota. The EMAP-L Mid-Atlantic Landscape Indicators Project Plan proposes a set of research initiatives to resolve key technical and operational issues first identified in the 1994 research plan. The issues are especially focused at identifying, testing, and evaluating landscape indicators. Secondly, EMAP-L will test its ability to generate ecological assessments of landscape status and trends of selected societal values at multiple scales, i.e. watershed and region. The selected societal values are biodiversity, watershed integrity, and landscape resilience.

The Mid-Atlantic Landscape Indicators Project Plan has been divided into eight sections which describe: (1) the conceptual basis of the landscape approach including societal values, framework for indicator development, proposed technology using a three-step monitoring process, and relation to other EMAP components and objectives; (2) objectives and approach for the Mid-Atlantic project; (3) study site description, relation to other geographic initiatives and programs, and existing data sources; (4) a series of studies to address research and development issues related to indicator sensitivity, synergism among remote sensing data, and landscape pattern assessment; (5) the conceptual approach for determining landscape status using 1990 Landsat-TM data for the Chesapeake Bay Watershed and landscape status and trends for the entire 8-state Mid-Atlantic region using Landsat-TM and multi-date Landsat-MSS; (6) reporting formats, technology transfer, and data acquisition, analysis, and documentation; (7) application of quality assurance principles to remote sensing and GIS data analysis; and (8) anticipated products and approximate completion dates.

The Mid-Atlantic Region Project provides EMAP-L with its first opportunity to test a number of technical issues and assessment protocols. The Mid-Atlantic is currently the focus of a number of EPA (Mid-Atlantic Highlands Assessment, Mid-Atlantic Integrated Assessment) and other agency regional initiatives (e.g. Southern Appalachian Man and the Biosphere). Collectively, the location contains available spatial data sets and provides both variable landscape characteristics and land use pattern gradients over which to test indicator sensitivity.

The program proposes to implement its research simultaneously along two project lines, i.e. landscape indicator development and landscape status and trend assessment. Landscape indicator development has been further divided into project components that include indicator sensitivity and synergism among remote sensing data.

Indicator sensitivity will examine the influence of data and formula attributes used to calculate indicator metrics, i.e. statistical properties, and the relevance of indicator application to environmental condition over multiple scales, i.e. ecological sensitivity.

Landscape Indicator Development Related to Statistical Properties

Sample number, calculation window-size, land cover class number, statistical independence between metrics, and indicator sensitivity, as a function of land cover misclassification, will be examined under the category of statistical properties. The plan emphasizes an approach which assesses the impact of sample size (number of pixels or pixel aggregations) and the number of attributes, e.g. land cover classes, by varying the number of cover classes and analysis window-size using Landsat-TM data for the Chesapeake Bay Watershed. Secondly, it proposes to evaluate correlations among landscape indicators at varying spatial scales to evaluate the degree to which relationships are scale-dependent. Additionally, landscape pattern metrics will be evaluated for their sensitivity relative to land cover misclassification versus actual changes in land cover using a simulation model to generate an error matrix for the Chesapeake Bay Watershed.

Landscape Indicator Development Related to Ecological Sensitivity

Gradient analysis, association with ecological resource condition, and landscape classification will be examined under the category of ecological sensitivity. The plan proposes using an urban-to-mountain anthropogenic land use gradient that is present along an east-west alignment in the Mid-Atlantic region to test the statistical significance of landscape metric response to environmental change. EMAP-L, under the proposed project plan, will determine the relationship of landscape metric information relative to independent assessments of ecological condition generated by other EMAP components that are performing colocated research within the region, i.e. streams, forests, estuaries. Lastly, the project plan proposes to evaluate spatially-nested relationships of landscape pattern. The project will examine the degree to which certain landscape pattern types and values vary by natural region and by other biophysical attributes, such as climate, soils, and topography, etc.

Synergism Among Remote Sensors

EMAP-L is proposing to evaluate spatial data derived from different remote sensing platforms, i.e. AVHRR, multi-date Landsat-MSS, and Landsat-TM, in terms of advantages and limitations in generating ecologically meaningful landscape pattern metrics. Secondly, EMAP-L will compare landscape pattern estimates derived from classified imagery with those derived from spectral-clustered and reflectance data to determine their utility in evaluating landscape change. Both evaluations will be made on a set of watersheds selected across the Mid-Atlantic region. Landscape pattern metrics will be calculated from different imagery for each watershed and with labeled and spectrally-clustered data sets.

Assessment of Landscape Status and Trends

EMAP-L proposes to implement landscape status and trends assessments within the Mid-Atlantic area. The program is challenged with the goal of assessing and interpreting landscape pattern data with regard to specific societal values and assessment questions. The project plan emphasizes an incremental approach to report protocols by first generating a landscape status assessment of the Chesapeake Bay Watershed and then later expanding the analysis to include status and a twenty-year trend analysis of landscapes for the entire Mid-Atlantic region.

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1.0 INTRODUCTION

1.1 OVERVIEW OF EMAP

Throughout the greater part of this century, most environmental management efforts focused on short-term, local-scale problems such as pollutant abatement. Environmental policy most often reflected a reactive response to past environmental problems rather than a more proactive, anticipatory process (Kaufmann et al. 1994). The 1980s witnessed increased interest in protecting whole ecosystems from chronic environmental problems, but these were often partitioned in relation to specific media, e.g. water, air, or soil pollution (Franklin 1993). Environmental management philosophy of the 1990s has evolved to examine critical environmental problems over larger spatial scales, such as regions or the Nation, and is now assessing the cumulative risk of impairment as the combined result of multiple stressors (Woodley et al. 1993, Noss and Cooperrider 1994). More recently, concern over the condition of larger-scale biogeographic provinces, e.g. landscapes, watersheds, and ecoregions, has received considerable attention and entire science programs have been dedicated to acquiring information which will relate to evaluating the effectiveness of environmental management policies and management actions, and allow for informed adjustments to management practices which favor sustainability of the biosphere, i.e. ecosystem management (Baron and Galvin 1990, Holden 1988, World Commission on Environment and Development 1987, Woodley et al. 1993, Franklin 1993, Kaufmann et al. 1994, Noss and Cooperrider 1994).

In 1989, the U.S. Environmental Protection Agency (EPA), in collaboration with other federal and state agencies and research institutions, initiated the Environmental Monitoring and Assessment Program (EMAP). EMAP is a national monitoring and research program designed to assess the condition of ecological resources in the United States. The program was initiated as a long-term project to periodically evaluate ecological condition, develop innovative methods for anticipating emerging problems before they reach crisis proportions, and contribute meaningful information to decisions on environmental protection and management (Kutz and Linthurst 1990, Messer et al. 1991, Thornton et al. 1993). EMAP efforts are focused on linking existing environmental data and monitoring programs, where possible, and collecting new information as needed to achieve program objectives.

1.2 EMAP INDICATOR DEVELOPMENT STRATEGY

Selection, evaluation, and implementation of indicators are critical in establishing a monitoring program to determine ecosystem health. EMAP describes indicators as measurable characteristics of the environment, both abiotic and biotic, that can provide quantitative information on ecological resources (EPA 1993). Specifically, an indicator is any expression of the environment that quantitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of biological components to stress, or the amount of change in condition (Barber 1994). Indicators may be either a function of a single measurement, a multivariate statistic, or an index based on multiple measurements. Two categories of indicators are defined by EMAP, i.e. condition and stressor (EPA 1993). Condition indicators are characteristics of the environment that provide quantitative estimates of ecological resource condition, whereas stressor indicators represent characteristics of the environment that act as sources of both human-induced and natural stress, e.g. land use and weather. Selection criteria for indicators require that the measurement, or index of measurements, must be responsive to changes in condition of a resource throughout the habitat and region for which it is employed, have clear quantitative signal with minimal variance or noise, can be simply quantified and cost effective, and produce minimal environmental impact during sampling (Hunsaker and Carpenter 1990, Barber 1994).

The EMAP indicator strategy has been evolving since its inception and now includes four basic phases for development, i.e. indicator formulation, evaluation, implementation, and reevaluation (Barber 1994). This framework has been employed by EMAP for monitoring within all major resource classes throughout the United States and has practical application relative to ecological risk assessment (Hunsaker et al. 1990, Suter 1990, Suter 1993). The indicator framework has been applied internationally, including sustainable agriculture in Australia (Hamblin 1992) and other locations.

In general, the indicator development approach involves a series of steps involving definition of the resource population of concern or resource class; identification and selection of societal values with biological relevance; formulation of assessment questions relative to the targeted resource and regional stressors likely impacting those resources; establishment of conceptual models which relate ecological function, structure, and composition; and selection, evaluation, and implementation of indicators and associated sample designs. Indicators are evaluated through simulation and pilot studies. These studies are intended to evaluate the potential of selected indicators to determine status and trends of ecological condition and are the basis for selecting indicators for long-term implementation. This process is continually open for reevaluation as new or improved versions of indicators are developed.

Societal values are generally considered to be those items that serve as goods or services to sustain human development and have ecological importance (Ehrlich and Ehrlich 1991, McNeely et al. 1990, Regier 1993). Societal values are the basis from which assessment questions related to status, extent of resource, change or trend in status and extent, and association to regional stressors are crafted. Conceptual models that describe a resource's ecological components and how they function are developed following the assignment of societal values and assessment questions. Conceptual models are identified either from published accounts or derivations (including combination of models) of published accounts and should consider the temporal and spatial dynamics or pathways of the resource at multiple scales (Wiens 1989). Conceptual models are further utilized to serve as reference points both for the identification and selection of indicators needed to assess the condition of ecological resources and for guiding data analyses or construction of multivariate indices (Barber 1994). Indicators and indices are evaluated for both their sensitivity relative to statistical properties and ecological meaning. Sensitivity relative to statistical properties include indicator variability over a sampling index period, and sensitivity to either the number of samples and configuration of the sample design. Determination of indicators which most accurately define the range of ecological conditions is generally ascertained by evaluating the sensitivity of an indicator or a selected set of indicators to gradients of predefined environmental condition or stress (Ludwig and Reynolds 1988). Predetermined condition is established by convention among consensus groups, usually governmental land management or environmental regulation agencies, and indicator performance is evaluated for correlation against existing data or a consensus opinion of condition (see Section 4.2).

1.3 OVERVIEW OF EMAP-LANDSCAPES

EMAP-Landscapes (EMAP-L) was created in late 1992 as a distinct project within EMAP to assess status and trends in indicators of landscapes, primarily landscape pattern metrics, and to relate its results to ecological goods and services valued by society (i.e., societal values). This program was originally part of the EMAP-Landscape Characterization (EMAP-LC) program. EMAP-LC's primary focus is on the generation of a nationally consistent land cover data base through the Multi-Resolution Land Characteristics Consortium (MRLC, see later discussion). Additionally, EMAP-LC is the primary source of spatial data for other EMAP projects, including EMAP-L. Therefore, EMAP-L has a collaborative arrangement with EMAP-LC on spatial data acquisition, land cover classification, and quality assurance (QA) issues on all of its projects.

EMAP-L proposes to estimate status and trends in landscape composition and pattern. Landscapes are described by the spatial arrangement of ecological resources. EMAP-L intends to evaluate two general types of landscapes, i.e., those that are defined by heterogeneous land areas composed of clusters of interacting ecosystems in repeated pattern (Forman and Godron 1986, Wickham and Norton 1994) and watersheds.

Hierarchy theory provides the context for integrating multiple scales of information to determine whether landscape patterns are sufficient to allow ecological processes, such as the flow of energy, water, nutrients, and biota, to operate at the necessary scales (O'Neill et al. 1986). In essence, it states that landscapes are organized into patterns within a hierarchy of spatial and temporal scales. Numerous ecological and human-induced disturbances maintain landscape patterns or elicit phase transition into new patterns. These disturbance events occur across a range of spatial and temporal scales (Jensen and Everett 1994). This type of framework then allows the investigation of changes in the distribution, dominance, and connectivity of ecosystem components and the effects that might occur on ecological resources. Secondly, this approach also permits comparisons of condition across mixed landscapes and across different sources of stress to cumulatively assess ecological risk.

EMAP-L has completed a research plan to guide resolution of key technical and operational issues associated with identifying, testing, and evaluating landscape indicators (EPA 1994). In particular, the program is focused on developing indicators of landscape pattern that relate to societal values derived from biodiversity, watershed integrity, and landscape resilience. Workshops and peer reviews have helped identify these societal values related to landscape ecological patterns and processes; however, EMAP-L is still refining landscape values and developing additional assessment questions, e.g. Sharpe et al. 1993, Rapport et al. 1995. Biodiversity is defined as the variety of life and its processes. Watershed integrity is defined as the capability to collect, retain, store, and purify water. Landscape resilience represents a landscape or watersheds ability to sustain its inherent richness of ecological goods and services in the face of natural and anthropogenic stress.

The program is emphasizing the use of remote sensing and geographic information system (GIS) technology rather than ground sample-based methods. This approach allows: (1) simplicity and cost effectiveness of data acquisition via remote observation platforms (including use of existing data), (2) ability to integrate synoptic measurements of landscape pattern across all natural resource classes and provide interpretive enhancement to individual EMAP projects and other research or monitoring projects, and (3) ability to develop assessments at multiple temporal and spatial scales. For example, use of Landsat Multi-spectral Scanner (Landsat-MSS) satellite data would permit trend analysis of landscape pattern metrics over a period of more than 20 years. In contrast, data derived from the Advanced Very High Resolution Radiometer (AVHRR) could provide similar assessments over larger spatial scales and shorter temporal domains.

1.4 EMAP-L MONITORING AND ASSESSMENT APPROACH

EMAP-L has developed a monitoring protocol and proposed a series of landscape pattern metrics that allow for landscape-level assessments of ecological condition (EPA 1994). EMAP-L assumes that Landsat satellite or equivalent imagery for regions of interest will be available on approximately 10-year cycles and hence, these data will form the basis for status and trends assessments.

The approach for assessment has been proposed as a three-step process in which baseline condition is established from selected landscape metrics (Step 1). Condition status for landscapes is regenerated 10 years after baseline from new land cover data (Step 2) and the datasets are combined to determine change in status and extent of resources (Figure 1). Both the type and magnitude of change in Step 2 determine if more detailed assessments are to be carried out in Step 3. Step 3 involves more in-depth analyses of associations between observed landscape

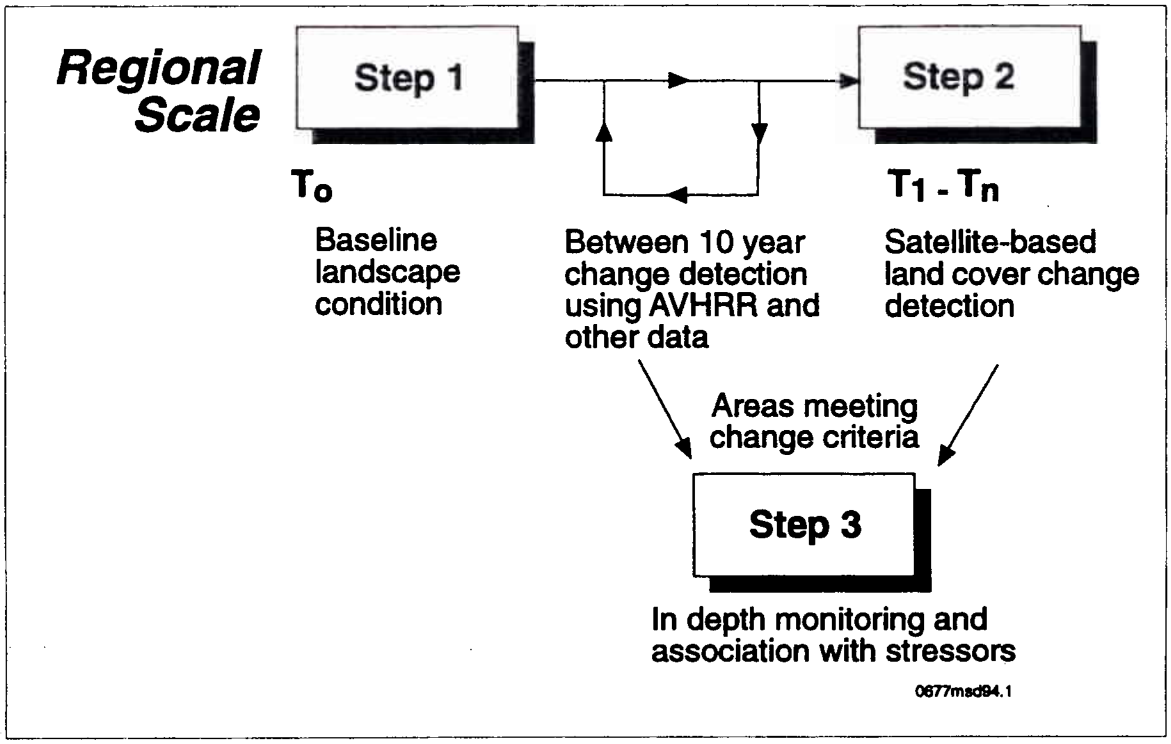

Figure 1. Three-step Landscape Monitoring Approach.

status and trends with environmental stressors and can be focused to address specific subsets of the broader societal values. The program recognizes that significant landscape changes can occur more frequently than on 10-year increments and hence, frequency of image acquisition, processing, and evaluation is a major issue within EMAP-L. Other data sources derived from remote observation platforms, such as AVHRR, are being considered to improve temporal resolution. Although AVHRR spatial resolution is much coarser than Landsat-MSS or Landsat Thematic Mapper (Landsat-TM), its ability to detect major land cover changes resulting from human or natural disturbances may be sufficient to determine if an EMAP-L Step 3 response is warranted. Step 3 will require the use of ancillary data such as stressor information or higher spatial resolution imagery, such as the U.S. Geological Survey (USGS) National Aerial Photography Program 1:40,000 color infrared metric photography. The outcome of a Step 3 analysis is a detailed landscape assessment related to a specific geographic area and selected sources of environmental stress.

1.5 LANDSCAPE APPROACHES TO INTEGRATION

The National Research Council (NRC 1995), EPA Science Advisory Board (EPA 1995a), and EMAP-Landscape Peer Review reports (Sharpe et al. 1993) all state that landscape analyses hold great promise for conducting integrated assessments across EMAP. The following is a discussion of a few of these potential assessments.

It may be possible to relate conditions in individual ecological resources to one another over broad areas through a landscape approach. The procedure involves relating condition of individual resources (e.g., productivity of forests, biotic conditions of streams, breeding bird diversity, to name a few) to landscape composition and pattern at one to several scales (see discussion in Section 4). In a sense, landscape composition and pattern becomes the common denominator by which the condition of one resource type (e.g., streams) can be compared to another (e.g., agricultural lands). Discovery of strong correlation and confidence between landscape indicators and individual ecological resources is critical to this process. If correlations between landscape indicators and individual ecological resources are relatively weak and insignificant then landscape data cannot be used to understand the relationships between conditions in individual ecological resources. Although numerous studies suggest strong relationships between landscape composition and pattern and conditions in individual ecological resources (see discussion in Section 4), these relationships will likely vary by region; therefore, EMAP-L proposes to work with other EMAP projects in the Mid-Atlantic study area to determine these relationships and develop a strategy to test a landscape integration concept.

Where strong relationships exist between landscape composition and pattern and conditions of ecological resources, including streams, forests, agricultural lands, and estuaries, then it should be possible to use landscape assessments as a "coarse filter" of ecological condition over an entire region. This coarse filter is made even more effective when landscape data cover an entire region; this gives complete spatial coverage and allows for condition estimates in areas where point data are not available. Such an approach could be used to prioritize areas for more detailed evaluation.

Landscape pattern metrics, combined with knowledge of how landscape pattern influences ecological resources, can be used to evaluate risk or vulnerability of ecological resources in a given region. For example, an area with decreasing forest patch size and connectivity (increasing fragmentation) is more likely to lose certain interior forest birds than areas with increasing forest patch size and connectivity.

Finally, landscape assessments give environmental managers a bigger, more holistic view of an area's ecology. It allows for conditions derived from analysis of individual samples of ecological resources to be put into a broader context. For example, how uncommon is a particular land cover type within a region? Is forest fragmentation occurring over an entire region, or is it limited to specific areas? What cumulative impacts are discovered at the landscape-level that are not evident at a local or site level? For example, by converting a specific forest patch in an area into a shopping center, are we eliminating a critical "stepping stone" for raptor migration across a human dominated landscape?

1.6 CHALLENGES TO EMAP-L

Although landscape ecology has contributed greatly to our understanding of ecology and ecosystem management (Jensen and Everett 1994), the field is still in its early stages of development. This is especially true of our understanding of how landscape pattern relates to conditions in ecological resources. Therefore, one of EMAP-L's greatest challenges will be to relate empirically-derived landscape patterns to conditions of ecological resources, including individual ecological resources embedded within landscapes (e.g., forests, streams, wetlands), as well as ecological resources that interact with entire landscapes (e.g., breeding birds). One of the primary objectives of this project is to determine the ecological relevance of landscape metrics so that they can be applied as indicators of ecological condition over regional scales. A number of research activities are presented in this plan that deal with this broad issue.

The utility of landscape metrics as indicators of ecological resource condition is also influenced by attributes of data and formula used to calculate metrics. Several research projects have been proposed to deal with these types of issues (see Section 4).

EMAP-L is also challenged with using existing remote sensing data to analyze and assess changes in landscape pattern. A number of potential sources of data exist, each with specific benefits and limitations. EMAP-L will evaluate the range of existing data and determine which provides the best estimates of landscape pattern.

Another important challenge is to identify statistically valid procedures for testing hypotheses of landscape change over time. Parametric statistical procedures require independent and similar experimental units, but these are unlikely to be obtained in regional-scale investigations (Hurlbert 1984, Hargrove and Pickering 1992). Neutral models (Gardner et al. 1987, Gardner and O'Neill 1991, O'Neill et al. 1992) may be used to specify null hypotheses as benchmarks to test observed changes, but there is no *a priori* neutral model which will be appropriate for all tests that could be made.

Finally, EMAP-L is challenged with assessing and interpreting landscape pattern data with regard to specific societal values. EMAP-L proposes to evaluate and develop assessment and interpretation protocols for landscape pattern data within the Mid-Atlantic area and provide interpretive reports relating landscape indicator information to the social concerns identified for the region.

2.0 STUDY OBJECTIVES AND GENERAL APPROACH

2.1 PROJECT OBJECTIVES

EMAP-L proposes a set of research initiatives to address key issues relative to the development and implementation of landscape indicators. Many of these issues were highlighted in the *Landscape Monitoring and Assessment Research Plan* (EPA 1994) which provided a conceptual basis and approach for the program. A primary objective of this project is to evaluate the sensitivity of landscape pattern metrics to statistical properties and ecological condition.

Another key objective is to evaluate the ability of different remote sensing imagery (e.g, AVHRR, Landsat-MSS, and Landsat-TM) to derive landscape pattern metrics and indicators.

Finally, EMAP-L will produce an assessment of the status and change in landscape indicators, including indicators for the entire Mid-Atlantic region.

Indicators are aggregations of metrics which provide information to address assessment questions, which in turn are based on societal values. In the process of developing indicators, EMAP-L is exploring the use of numerous landscape metrics. The objectives of indicator development are to: 1) optimize the number of indicators needed to effectively address assessment questions, and 2) optimize indicators to the fewest number of statistically independent metrics required to fully describe indicator conditions. Table 1 lists indicators presently under development and metrics which are candidates for inclusion in each indicator. Additional indicators and metrics may be developed.

2.2 GENERAL APPROACH

The Mid-Atlantic Region Landscape Indicators Project provides EMAP-L with its first opportunity to test many technical issues. The program will implement its research simultaneously along two project lines: (1) a series of studies to address research and development issues related to landscape indicators, and (2) determination of landscape status and trends assessment within the project area. In FY95, EMAP-L proposes to evaluate the research and development issues within the Chesapeake Bay Watershed and later expand the research and analysis into the entire Mid-Atlantic region (Figure 2). The Chesapeake Bay Watershed covers approximately half of the Mid-Atlantic region, and EMAP-L will utilize a number of existing remote sensing data bases to begin analysis of the monitoring research issues (Dobson et al. 1995).

Multi-date Landsat-MSS (early 1970s, 1980s, and 1990s), Landsat-TM, and AVHRR data coverages will be acquired for the project area. In addition to the spectrally-clustered and classified spatial data, other ancillary datasets, e.g. stressor information or other monitoring data (Table 2), will be utilized to associate landscape condition with environmental disturbance (Jensen 1993, Dobson et al. 1995). Success in resolving key technical issues will determine the ability of EMAP-L to provide meaningful regional and watershed assessments of condition or trend. When landscape indicators pass a series of sensitivity analyses (see Section 4.1), they will be incorporated into assessments (Hunsaker and Carpenter 1990, Hunsaker et al. 1990, Barber 1994).

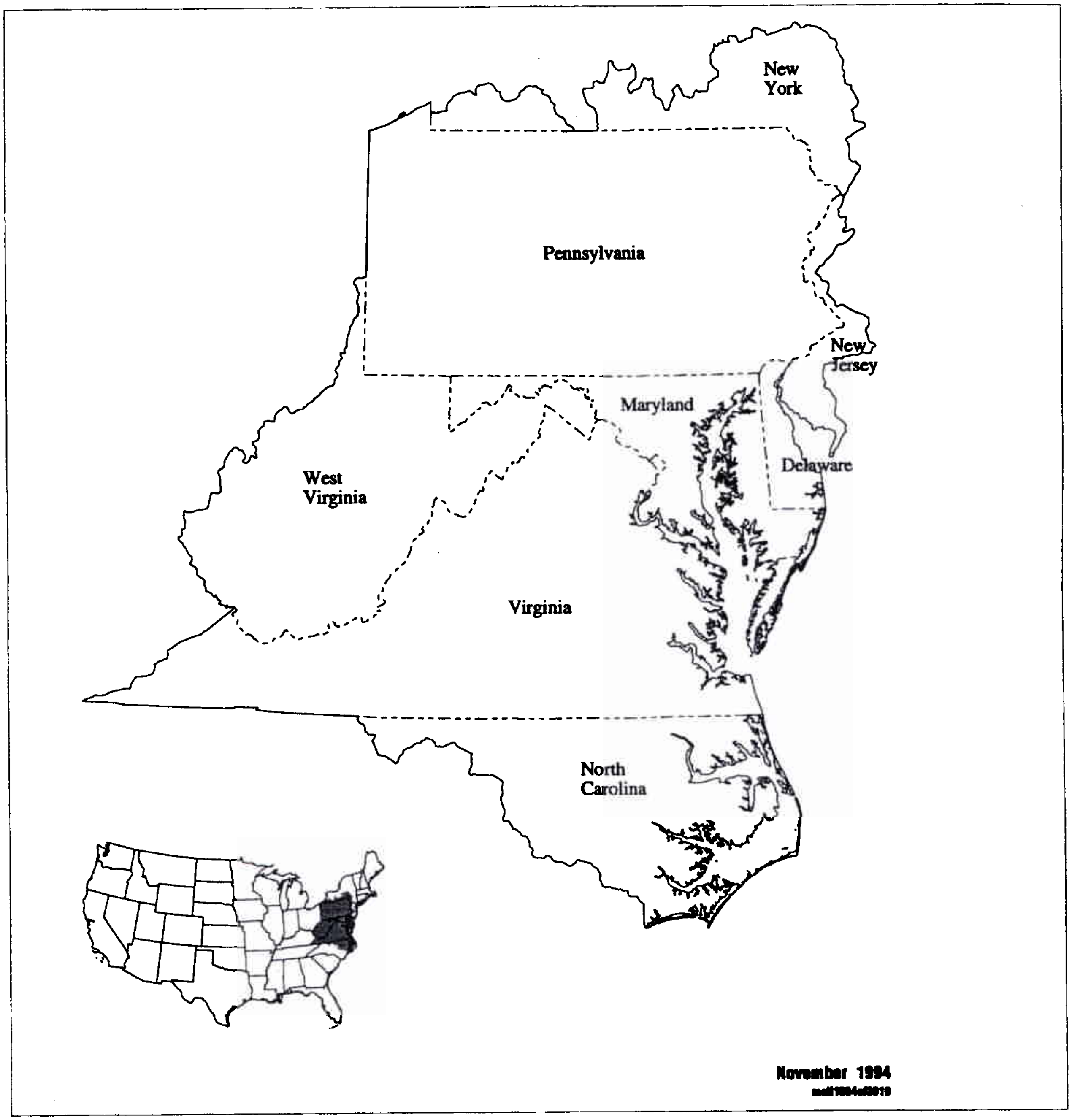

Figure 2. Mid-Atlantic Landscape Indicators Project Area.

Table 1. Societal Values, Example Indicators, and Candidate Metrics

Societal Value	Indicator	Candidate Metrics
Biodiversity	Wildlife Habitat Suitability	patch statistics (number, total area, average size, largest size, distance between, ratio perimeter to area, shape, fractal dimension, square pixel model), fragmentation, contagion, zone fragmentation index, patch per unit area index, dominance, adjacency of land cover types, Shannon diversity, biophysical attribute patterns.
	Stream Biological Condition	diversity, square pixel model, dominance, fragmentation, zone fragmentation index, patch per unit area index, adjacency of land cover types, slope, elevation, diffusion rates, percolation threshold, erosion index, texture, biophysical attribute patterns, geochemical attributes
	Forest Plant Species Richness	diversity, dominance, fragmentation, zone fragmentation index, patch per unit area index, slope, erosion index, texture, patch statistics, square pixel model, biophysical attribute patterns
	Landscape Sustainability	patch statistics, contagion, zone fragmentation index, patch per unit area index, fragmentation, texture, dominance, fractal dimension, square pixel model, biophysical attribute patterns
Watershed Integrity	Water Quality	patch statistics, erosion index, hydrologic modification, adjacency of land cover types, dominance, contagion, zone fragmentation index, patch per unit area index, fractal dimension, square pixel model, elevation, slope, biophysical attribute patterns, geochemical attributes
	Vulnerability to Flooding	patch statistics, adjacency of land cover types, erosion index, dominance, contagion, zone fragmentation index, patch per unit area index, fractal dimension, square pixel model, hydrologic modifications, elevation, slope, texture, biophysical attribute patterns
Landscape Resilience	Landscape Sustainability	patch statistics, contagion, zone fragmentation index, patch per unit area index, fragmentation, texture, dominance, fractal dimension, square pixel model, biophysical attribute patterns

Table 2. Number of EMAP Sampling Points by State in the Mid-Atlantic Region, 1990-1994

EMAP Project	NY	PA	NJ	WV	MD	DE	VA	NC
Agricultural Lands 1992								19
Estuaries								
1990			10		23*	6	30	
1991			8		29*	8	28	
1992			8		29	6	31	
1993			8		34*	6	28	
1994							1	40
Forests								
pre-1994			8		16	2	104	17
1994				21				
Lakes								
pre-1994	6		5					
1994	5		2					
Streams								
1993	2	95		55	7		55	
1994	5	91		43	7	1	55	

* Includes one station identified as DC.

3.0 STUDY SITE DESCRIPTION

3.1 SITE SELECTION/LOCATION

The following criteria resulted in the selection of the Chesapeake Bay Watershed/ Mid-Atlantic Region study location: (1) spatial extent of region sufficient to address multi-state, multi-ecoregion, and multi-scale watershed issues; (2) availability of remote sensing and GIS data bases; (3) availability of variable landscape characteristics and land use to provide ecological gradients to test indicator sensitivity; (4) regional management focus and landscape emphasis with a number of participating state and federal organizations (see Section 3.2); (5) significant potential for collaboration with other EMAP projects and other federal and state monitoring programs; and (6) site of one of EMAP's proposed geographic initiatives (Section 3.2).

The boundaries of the Mid-Atlantic region are provided in Figure 2. The region extends from southern New York state into northeastern North Carolina and includes 17 major drainage basins, i.e. USGS Water Resource Subregions identified by 8-digit Hydrologic Unit Codes (HUC), and 11 ecoregions (Omernik 1995). The proposed study region includes all states within EPA Region III (PA, WV, MD, DE, VA) plus the Susquehanna River and Allegheny River Basins that extend into New York (EPA Region II), Delaware River Basin that extends into New Jersey (EPA Region II), and the Chowan-Roanoke and Neuse-Pamlico River Basins that extend into North Carolina (EPA Region IV). Two prominent geographic features within the Mid-Atlantic region are the Appalachian Mountains, dominated by deciduous forests (oak-hickory and maple-beech), and the Chesapeake Bay.

3.2 STRESSOR CONTEXT/RELATIONSHIP TO OTHER GEOGRAPHIC INITIATIVES

The region has many large urban population centers and extensive agricultural use. As a result, the area is exposed to many stresses which potentially could threaten the environmental and aesthetic values of the region. As an example, this region is estimated to receive the highest rates of atmospheric acid deposition in the United States but has little buffering capacity to counter subsequent impacts of stream acidification. Other environmental threats have been characterized in many forms: urban development (land cover type conversion and fragmentation), industrial and municipal effluent, agriculture (habitat conversion and nonpoint runoff/ infiltration), mining and logging (resource extraction, erosion, siltation, off-site release of mining leachates), and infrastructure development, e.g. roads, pipelines, utility corridors. The consequences of these stressor sources include interruption of the flow and cycling of natural processes related to energy, water, nutrients, and biota. The ultimate outcome is the impairment of desired environmental "goods and services" such as diminished biological diversity, declines in recreational and commercial fisheries, reduction of forest and agricultural products, and loss of recreational opportunities.

Because of the geographic scope of the project and the complexity of stressor effects, EMAP-L will collaborate with numerous geographic projects that are currently in progress. These include several interstate water management programs such as the National Estuary Programs and River Basin Commissions. For example, the Chesapeake Bay Program was initiated in 1983 as a joint project that includes the states of Maryland, Virginia, and Pennsylvania, EPA, the District of Columbia, and the Chesapeake Bay Commission. Estuary Programs and River Basin Commissions are generally interagency organizations responsible for developing and implementing water resource management plans. They routinely monitor water resource conditions and provide important sources of information relative to watershed integrity. EMAP-L intends to forge strong partnerships with federal and state land managers and environmental regulators with existing monitoring programs or proposed regional initiatives. We expect to take advantage of existing data and incorporate the information into assessments at regional, watershed, and landscape scales.

A brief summary of five major geographic monitoring initiatives is described below. These are examples of existing programs or projects where we expect strong interaction and collaboration.

1. National Water Quality Assessment (NAWQA) Program

In 1991, following a series of pilot surface and groundwater projects, the USGS began a 4-year transition into national implementation for NAWQA. The goals of NAWQA are to describe the status and trends in the quality of a large, representative selection of our Nation's surface and groundwater resources and to provide a scientific understanding of the primary natural and human factors that affect the quality of these resources. The program consists of two major components, i.e. study-unit investigations and national assessment activities. The principal building blocks of NAWQA are the study-unit investigations of hydrologic systems that include parts of most major river basins and aquifer systems. The program is accomplished by conducting intensive assessment activities on 60 study areas distributed throughout the Nation and that incorporate about 60 to 70 percent of the Nation's water use served by public water supply. The study-units are first intensively sampled to establish baseline condition and then later sampled on a rotational basis to determine trends in condition. It is anticipated that the first cycle of intensive investigations covering all 60 study-units will be completed by FY 2002. Eight NAWQA study-units are located within the Mid-Atlantic region. They include: Delaware River Basin, Lower Susquehanna River Basin, Delmarva Peninsula, Potomac River Basin, Allegheny and Monongahela River Basins, Kanawha River Basin, Upper Tennessee River Basin, and the Albemarle-Pamlico Drainage (Leahy et al. 1990).

2. Mid-Atlantic Highlands Assessment (MAHA)

MAHA is a project initiated by the Environmental Services Division of EPA Region III and is based on a long history of Region III involvement in comprehensive environmental monitoring projects, e.g. Chesapeake Bay Program. MAHA is designed to improve the effectiveness of local, state, and federal environmental protection efforts by conducting a comprehensive environmental assessment of more than half the land in Region III, approximately 64,000 square miles. The assessment will employ information developed with the assistance of EMAP and is intended to aid strategic environmental planning and decision-making in six Omernik ecoregions (Western Allegheny Plateau, Northern Appalachian Plateau and Uplands, North Central Appalachians, Central Appalachian Plateau, Central Appalachian Ridges and Valleys, and the Blue Ridge Mountains; Omernik 1987, Omernik 1995). Specifically, the objectives of MAHA include the following: (1) assess the current ecological condition of the Mid-Atlantic Highlands, its component ecoregions, and states; (2) locate sensitive areas in need of special protective action, either for remediation or preservation; and (3) prioritize the need for further research into the causes and consequences of pollution in the Mid-Atlantic Highlands. The highlands project area was selected for special study by Region III because of its strategic ecological importance and current exposure to multiple-stressors that threaten areas of high environmental value, e.g. habitats for many unique and critical species.

MAHA is applying two basic features from the EMAP monitoring framework, i.e. measurement of a standard suite of biological attributes to assess ecological quality (indicators) and collection of environmental information using a probability-based sample design to ensure that indicator results can be characterized with known confidence. Concurrent efforts within MAHA will monitor 246 sites for a several-year period. The sampling locations include 65 EMAP-Surface Water sites, 31 Regional Reference Sites, 46 Regional Environmental Monitoring and Assessment Program (REMAP) sites, and

104 Temporally Integrated Monitoring of Ecosystems (TIME) acid deposition sites. Primarily aquatic ecological attributes will be measured annually during a mid-April through June index period.

3. Mid-Atlantic Integrated Assessment (MAIA)

MAIA is one of EMAP's proposed geographic initiatives. It is designed as a collaborative initiative between EPA Office of Research and Development (ORD) and EPA Region III. The MAIA project area is identical to the site proposed for the EMAP Mid-Atlantic Region Landscape Indicators Project (see Figure 2) and completely subsumes the MAHA project area.

The purpose of the MAIA project is to develop information and methods that will be useful to both regulatory and resource management agencies at all levels of decision-making. MAIA will employ the EMAP sample design, indicator, QA, and data collection activities and is particularly focused at developing and integrating assessment methods utilizing EMAP data and other ancillary stressor data to create a large-scale, multi-resource ecological assessment. MAIA defines integrated ecological assessment as a process by which information is brought together within a management context to discern patterns, relationships, and associations that provide a scientific basis for making decisions related to ecological resource problems and to the protection of critical ecological resources. Figure 3 shows the distribution of EMAP sampling points within the MAIA project area for surface waters, forests, and estuaries by USGS Water Resource Subregions. Table 2 shows the number of EMAP sampling points by state and date of collection that will be used for the MAIA integrated assessment; ancillary stressor data sets will be obtained from other sources, e.g. weather data.

4. Southern Appalachian Man and the Biosphere (SAMAB)

SAMAB is a partnership of ten federal agencies (EPA, National Biological Service [NBS], National Park Service, Tennessee Valley Authority [TVA], U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, U.S. Forest Service, USGS, Economic Development Administration, and Department of Energy) and three states (Georgia, North Carolina, and Tennessee). The SAMAB Program includes the west-central portion of the Mid-Atlantic region. It is designed to promote and conduct ecosystem management in pursuit of sustainable development in the Southern Appalachian region. SAMAB partners, along with several private organizations, began a regional assessment of ecological status and trends and their relationships to environmental stressors in 1994. EMAP-L is participating in SAMAB and will benefit from the protocols developed within the project. Objectives of the SAMAB assessment are similar to the MAHA and MAIA projects and include: (1) develop an integrated, spatially explicit data base reflecting current ecological quality or condition, thereby setting up issue-specific assessments; (2) locate sensitive areas or communities at risk, suggesting priorities or recommendations for remediation or preservation; (3) examine associations between resource impairment to environmental stressors such as land development, air pollution, non-point source pollution, and exotic species, and; (4) develop and analyze policy options for implementation within SAMAB.

A landscape status report, or atlas, based on remotely-sensed imagery (primarily Landsat-TM) will be produced in 1995, and associated maps and summary statistics will be available as part of the integrated data base.

5. CoastWatch Change Analysis Program (C-CAP)

C-CAP is a program initiated by the National Oceanic and Atmospheric Administration (NOAA) to develop a comprehensive, nationally standardized information system for monitoring land cover and habitat change in the coastal regions of the United States. Its purpose is to improve understanding of coastal uplands, wetlands, and sea grass beds and their linkages with the distribution, abundance, and health of living marine resources. C-CAP utilizes both satellite and aircraft-based sensors to map emergent wetlands and surrounding uplands as well as submerged aquatic vegetation (Dobson et al. 1995, Klemas et al. 1993). The goal of the program is to monitor coastal areas every 1 to 5 years depending on the rate and magnitude of change in each region. The prototype project for C-CAP is the Chesapeake Bay

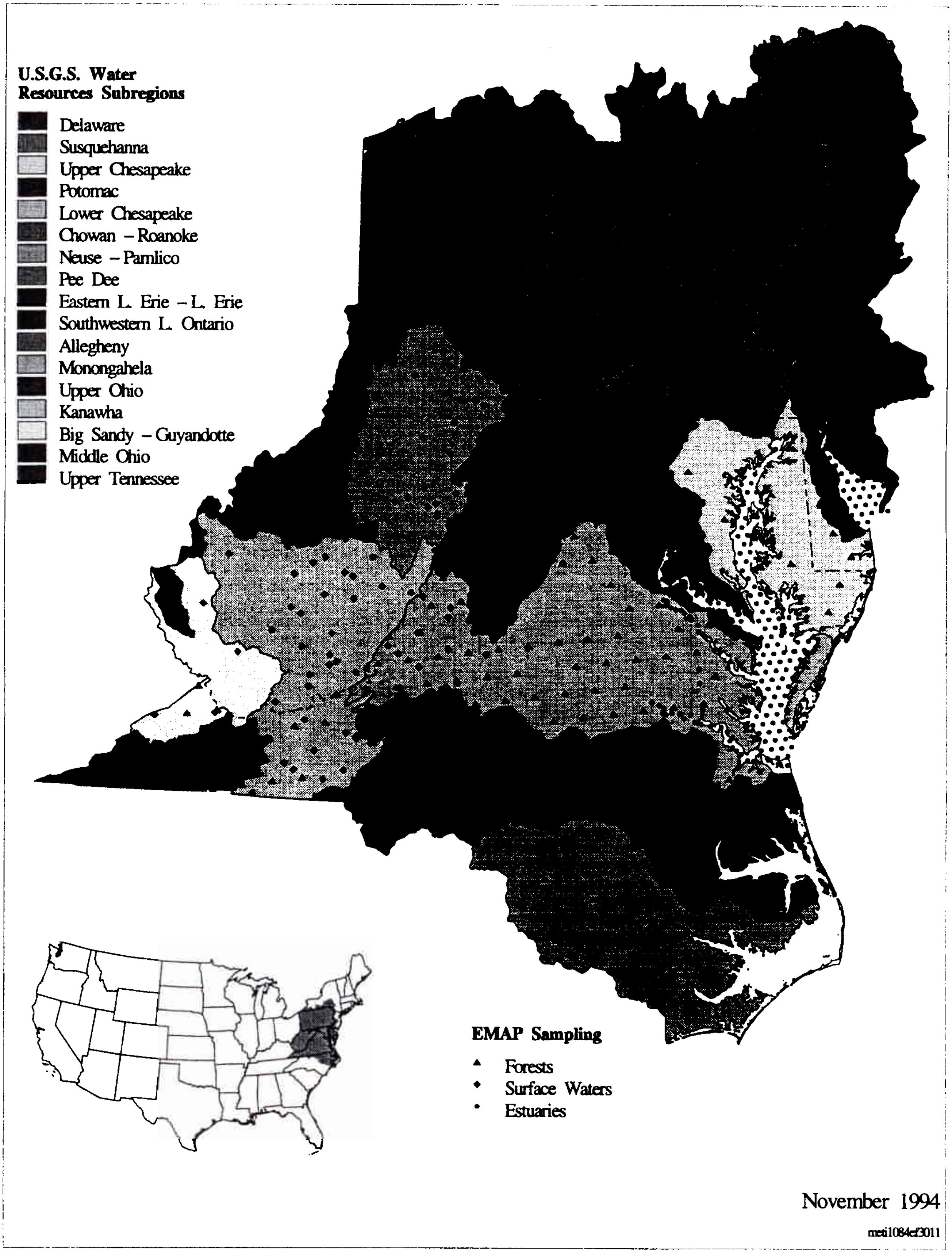

Figure 3. EMAP Sampling within Major Drainage Basins in the Mid-Atlantic Region.

Land Cover Classification Data Set which documents changes in land cover over the 5-year interval from 1984 to 1989. This data set constitutes one of the largest change detection efforts ever attempted, covering an area of approximately 30,000 square miles with a source data resolution of 30 meters by 30 meters, i.e. Landsat-TM.

3.3 EXISTING DATA SOURCES

As previously mentioned, EMAP-L will be drawing data from a number of sources to develop analyses of landscape indicator sensitivity relative to ecological significance. Data from four EMAP projects, i.e. Forests, Agricultural Lands, Estuaries, and Surface Waters (Streams and Lakes), in addition to REMAP data have been identified for this purpose (Table 2). Other national monitoring networks will be accessed for their information. Some examples of existing monitoring and data base networks are included in Table 3.

The spatial data used for calculation of landscape metrics will be derived primarily from two sources, i.e. North American Landscape Characterization Project (NALC) and the MRLC. A brief summary of each data source is described below.

1. North American Landscape Characterization (NALC) Project

The NALC project has been developed in support of the U.S. Global Change Research Program (GCRP) and is designed to take advantage of historical and current Landsat satellite remote sensor measurements. NALC is focused at characterizing land cover types and evaluating their change over time using satellite sensors. The goal of the project is to produce standardized data sets for the majority of the North American continent. The data sets are three-date (July 1972 through September 1992), georeferenced Landsat-MSS land cover characterizations which allow retrospective evaluations of change detection. The project is being conducted in collaboration with the National Aeronautics and Space Administration, USGS Earth Resources Observation System (EROS) Data Center, and the Canada Centre for Remote Sensing (CCRS). These data have been archived in digital form and represent the only existing remote sensor system that has a digital archive with a long-term record of acquisitions over a major portion of the Earth. The Chesapeake Bay Watershed was selected by NALC as the first pilot study in which to test standard land cover characterization and change detection procedures. The Chesapeake Bay pilot was conducted over the 64,000-square mile watershed using six land cover/land use classes. NALC is also interested in developing a prospective evaluation methodology based on the use of Landsat-TM data to facilitate more detailed spectral and spatial analysis of ecosystems and detection of changes in land cover.

2. Multi-Resolution Land Characteristics Consortium (MRLC)

MRLC is being developed to provide the capability for broad-based research on current and future conditions of physical and biological resources of the United States. MRLC began in April 1993 and is sponsored by five federal environmental monitoring programs having similar remote sensing and research needs, i.e. NAWQA/USGS, EMAP/EPA, NALC/EPA, C-CAP/NOAA, and GAP Analysis Program/NBS, in partnership with the EROS Data Center/USGS. The goal of the MRLC is to generate a land cover dataset for the United States based on Landsat-TM data. Collectively, advantages under the consortium arrangement include substantial savings of time, effort, and money related to scene acquisition, processing, QA, and application and management of the land cover data.

A six-class, land cover map has been produced over the entire Chesapeake Bay Watershed; these data are available through EMAP-LC. A ten-to-twelve class land cover data base is being developed by the MRLC; these classifications are being done from 1992 to 1993 Landsat-TM digital data.

A three-date (early 1970s, mid-1980s, early 1990s) Landsat-MSS data base for the entire MAIA area is under development; these data should be available by July 1995. AVHRR data are available from EMAP-LC via the USGS EROS Data Center.

Table 3. Example National Monitoring and Information Systems Containing Ancillary Data Available to EMAP-Landscapes

U.S. Geological Survey
- National Stream Quality Accounting Network (NASQAN)
- National Water Quality Assessment Program (NAWQA)
- National Digital Cartographic Data Base
- National Water Information System
- National Water-Use Information Program
- Federal National Trends Network
- Toxic Substances Hydrology Program
- Regional Aquifer-Systems Analysis Program (RASA)

U.S. Environmental Protection Agency
- Storage and Retrieval System (STORET)
- Industrial Facility Discharge File
- River-Reach File
- Environmental Monitoring and Assessment Program (EMAP)
- North American Landscape Characterization Project (NALC)

U.S. Fish and Wildlife Service
- Environmental Contaminants Data Management System (ECDMS)
- National Wetland Inventory (NWI)

U.S. Forest Service
- Forest Inventory and Analysis Program (FIA)

U.S. National Biological Service
- North American Breeding Bird Survey (BBS)
- National Contaminant Biomonitoring Program (NCBP)
- GAP Analysis Program

U.S. Soil Conservation Service
- National Resources Inventory (NRI)

U.S. National Agricultural Statistics Service
- U.S. Census of Agriculture

U.S. Census Bureau
- U.S. Census of Population

U.S. State Department
- Land Use Change and Analysis System (LUCAS), Man and the Biosphere Program

4.0 PROJECT COMPONENTS

The EMAP-L program consists of multiple projects related to indicator sensitivity, comparability among remote sensing data, and landscape pattern assessment in the Mid-Atlantic region.

EMAP-L will evaluate several aspects of landscape metric sensitivity. For the purpose of discussion, EMAP-L has divided landscape sensitivity into two general categories: those issues related to statistical properties and those related to ecological condition.

4.1 SENSITIVITY RELATED TO STATISTICAL PROPERTIES

EMAP-L will evaluate a number of metrics with regard to their utility as indicators of change relevant to societal values. Particular metrics selected for use in the Mid-Atlantic region are listed in Table 1. Additional candidate metrics are discussed in EPA (1994) and equations can be found in Riitters et al. (1995).

4.1.1 Number of Samples, Calculation of Window Size, and Number of Land Cover Classes

Landscape metrics with a reasonable ecological basis may still be unusable because they are overly sensitive to measurement errors in land cover or are insensitive to landscape change. For example, diversity indices are overly sensitive to the number of attributes, i.e. too many attributes result in values that are insensitive to actual change. Fractal dimension requires a relatively large number of patches, because dimension is estimated from a regression of patch perimeter on patch area. Furthermore, each patch must contain at least four pixels; the shape of patches smaller than four pixels is constrained, thus including them would yield biased estimates. These and other estimation issues are discussed by Milne (1988, 1991).

EMAP-L will combine some additional studies with existing studies to determine the extent of landscape indicator sensitivity to sample size and to the number of attributes. The impact of sample size (number of pixels or pixel aggregations) and the number of attributes (e.g., land cover classes) on landscape pattern metrics will be determined by varying the number of land cover classes and calculation window size. EMAP-L will change the number of land cover classes using the Chesapeake Bay Watershed Landsat-TM data base to simulate the influence of the number of land cover classes on landscape metric sensitivity to actual landscape change. EMAP-L will vary the size of calculation windows for each metric to evaluate the influence of scale on indicator sensitivity.

4.1.2 Statistical Independence of Landscape Metrics

Some 50 existing landscape metrics have been proposed for use in development of EMAP-L indicators. It is the intent of EMAP-L to optimize metrics and indicators, i.e., to employ only those metrics which are sensitive to landscape change in a predictable and defined manner. As a first step in the optimization process, the statistical independence of the metrics is being investigated. Groups of statistically related metrics can be represented by one or two critical metrics which are most responsive to change or which reflect change with a defined response. EMAP-L will evaluate correlations among landscape indicators and determine the number and nature of orthogonal axes that explain variation in landscape pattern.

Window-based analyses (e.g., Potnick et al. 1993) have been used to study effects of changing scale on indicator values. EMAP-L is also interested in evaluating the degree to which relationships are scale-dependent. To accomplish this, EMAP-L will use a form of spatial filtering. Spatial filtering is an approach that has traditionally been used in remote sensing. It involves passing a window that is typically an odd multiple of the pixel size itself through an image and changing the pixel classification according to one of several possible rules. When applied to a land cover map, the result is often an aggregation of pixels into identical classes that has the effect of changing the scale of the image. The change in scale is an important property of the landscape (and landscape change) that EMAP-L will investigate. EMAP-L will vary the calculation window size to determine the influence of the number of pixels on indicator correlations.

This evaluation will be conducted over the Chesapeake Bay Watershed using the existing Landsat-TM data base, and subsequently, over the entire Mid-Atlantic region as remote sensing data become available.

4.1.3 Indicator Sensitivity to Land Cover Misclassification

Landscape pattern metrics are generated from remote sensing data classified into land cover maps or digital data bases. These data are converted to ASCII files and interfaced with landscape metric statistical software to produce landscape statistics. It is important to know the relative accuracy of assigning land cover types and it is necessary to test the sensitivity of the metrics to classification error. If landscape pattern metrics are more sensitive to random errors in land cover classification than to actual land cover change, their use in long-term monitoring would be compromised.

EMAP-L proposes two activities: (1) an extensive review of existing studies and literature, and (2) a simulation study. The objective of the literature review is to evaluate different sources of error that contribute to land cover misclassification (e.g., from the satellite to the generation of landscape pattern statistics). This error progration study will build upon work conducted by Lunetta et al. (1991) and Jensen (1993).

A Monte Carlo simulation model, written in ARC/INFO GRID language, will be used to test the sensitivity of landscape metrics to misclassification. The simulation will be based on: (1) the misclassification rates that are calculated from an error matrix, and (2) spatial autocorrelation in land cover classification error (Congalton 1988). The error matrix (Story and Congalton 1986) is the standard medium for reporting land cover classification accuracy (Congalton and Green 1993). An error matrix is constructed as a square contingency table where the columns represent reference data and the rows represent classified data. The main diagonal of the error matrix contains the number of correctly classified pixels and the off-diagonal elements are incorrect classifications. Either aerial photography, site visits, or both are typically used to compile reference data. Congalton (1988) showed that much of the error in land cover classifications is at the edge between two land cover classes. That is, land cover misclassification is spatially autocorrelated. Error is likely to be higher at the edge separating two classes than in the interior of a patch. Spatial autocorrelation in land cover classification error is at least partly due to mixed pixel (edge effect) phenomenon (Lillesand and Kiefer 1987). Mixed pixels occur when two of more distinct earth surface features (e.g., soil and water) contribute to the signal recorded for that pixel.

4.2 SENSITIVITY RELATED TO ECOLOGICAL CONDITION

If landscape metrics are to be used as indicators, they must be sensitive to change. Sufficient evidence exists to support the general hypothesis that changes in landscape pattern alter ecological processes which in turn affect the condition of ecological resources (Turner 1989). For example, habitat fragmentation is known to increase extinction probabilities of certain fauna and flora (Whitcomb et al. 1981). Similarly, water quality is influenced by landscape composition and pattern (Hunsaker et al. 1992, Walker et al. 1993).

The primary objective of this activity is to determine the sensitivity of landscape metrics to ecological status and change. This activity has been separated into three components: (1) gradient analysis, (2) association with ecological resource condition, and (3) landscape classification.

4.2.1 Gradient Analysis

Considerable variation in the degree of human influence exists within the Mid-Atlantic region. Urban areas have modified landscapes along the eastern coast, whereas landscapes in the western mountainous areas have undergone little modification. Landscapes with anthropogenic influences (e.g., agriculture and urban development) will have different landscape patterns, i.e., landscapes with high anthropogenic influence are likely to have: (1) smaller average patch sizes of natural land cover (e.g., forests), (2) higher degrees of fragmentation, and (3) more simplified shapes than landscapes with relatively low anthropogenic influence. Biophysical attributes of areas within the Mid-Atlantic region will likely influence the response of landscapes to anthropogenic and natural stress. We will take advantage of this existing east-west gradient to test landscape metric sensitivity, i.e., how far along this gradient must one move to detect a statistically significant change in the metric. Once the statistical sensitivity of metrics to actual change is known, it will then be possible to identify those hypotheses which can be tested in practice. In other words, statistical significance is different than practical relevance. Knowledge of statistical properties is a prerequisite for knowing which questions of practical significance can be asked of the data.

EMAP-L will establish an urban-to-mountain gradient by ranking the watersheds depicted in Figure 4 (USGS 8-digit HUCs) by U-index values. This index (Krummel et al. 1987) is the ratio of the area devoted to anthropogenic land use to total area. Low U-values reflect a forest-dominated watershed, and high values indicate dominance by urban, suburban, or agricultural land uses. Use of the U-index between 8-digit HUCs represents a space-for-time approach to determining the feasibility of metrics for detecting changes through time. Space-for-time is an accepted methodological approach in ecological studies (Pickett 1989).

In addition to determining landscape pattern variation along this gradient, EMAP-L will evaluate the influence of biophysical attributes, including topography, landform, geology, and soils on observed responses of watersheds.

4.2.2 Association with Ecological Resource Condition

First, this activity will determine the degree to which landscape metrics can be used to supplement assessments of status and trends in individual ecological resources at regional scales. Second, individual EMAP projects will benefit from an understanding of relationships between landscape pattern and conditions of their ecological resources of focus. EMAP-L proposes to work collaboratively with other EMAP projects in conducting this research. Finally, these analyses will emphasize assessments for the Mid-Atlantic region. EMAP-L will emphasize ecological risk assessment and ecosystem management. For example, findings on relationships between landscape condition and stream water quality can be used to formulate risk models relating landscape change to the risk of impact on stream biota.

It is EMAP-L's central hypothesis that changes in landscape pattern influence and constrain the condition of all ecological resources within the landscape (EPA 1994). Hierarchy theory points out that larger-scaled systems, such as landscapes and watersheds, constrain the dynamic behavior of subsystems, such as patches of forests or wetlands. Thus, monitoring land cover patterns is necessary to assess the present and changing conditions of ecological resources.

An outcome of this hierarchical relationship is that landscape change may signal resource change in advance of its onset. In other words, there may be a time-lag and landscape pattern may indicate a poor or declining condition before such a condition is apparent from analysis of field-collected data. The Pacific Northwest region provides an example of such a relationship. Increasing fragmentation of the forest in this region suggests reduced forest connectivity, increased distances between patches, and increased simplification of forest patch edges (Kaufmann et al. 1994). Many have argued that such changes signal a decline in forest condition that is not yet evident at the plot or stand levels. An analysis of landscape pattern data could have indicated the increased risk to spotted owl populations from fragmentation of forest patches before local population extirpation was observed and before

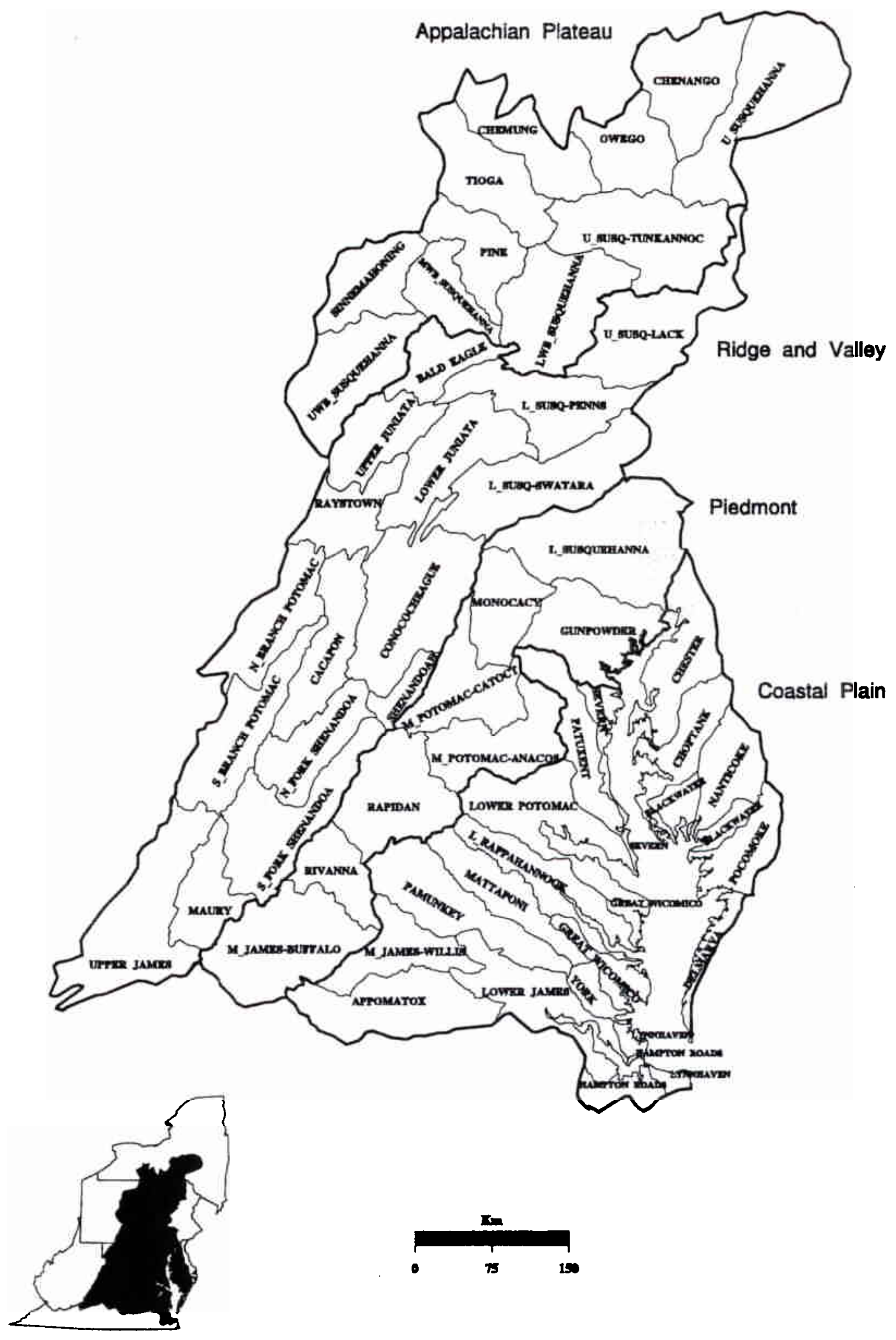

Figure 4. USGS 8-digit Mid-Appalachian Watersheds.

landscape-level disturbance processes were widespread enough to cause population decline in the entire metapopulation of spotted owls. Therefore, monitoring landscape condition, in close coordination with individual resource monitoring, is critical in assessing risks to ecological resources within a region.

The sections which follow describe proposed activities to be undertaken by EMAP-L in collaboration with particular ecological resource monitoring programs. In this initial phase of activities in the Mid-Atlantic region, most efforts will be conducted in conjunction with other EMAP projects participating in the MAIA program.

(A) STREAMS

Stream biotic (e.g., fish and benthos) and abiotic (e.g., water quality and physical habitat) conditions will be compared to landscape pattern metrics at several scales. This research will be collaborative with the EMAP-Surface Waters project. EMAP-L and EMAP-Surface Waters propose to evaluate a number of associations in the Mid-Atlantic region, including the following:

(1) Different stream organisms integrate conditions over different scales of watersheds. Fish can migrate considerable distances during a life span and should show poorer correlation to land cover in the immediate watershed where they are sampled. Relatively immobile benthic invertebrates should show strong correlation with the immediate watershed.

(2) Condition in low-order streams show highest correlation with small, immediately adjacent land cover. As stream order increases, the correlation decreases as more of the adjacent watershed is included in the analysis; individual additions of stream order never explain as much variation as low-order streams.

(3) Watershed land cover influences stream biota through the physical and chemical characteristics of the water. Therefore, there should be stronger correlations between landscape characteristics and water physicochemical data than with stream biota.

(4) Fragmentation affects diversity of stream biota, i.e., isolation of streams from other streams reduces the probability of recolonization. This condition increases the probability of local extinction (given natural and anthropogenic disturbance) and therefore constitutes a risk to stream biotic diversity.

(5) Undisturbed low-order streams that are in different ecoregions or biophysical settings should have higher variation in species composition. Streams that are closer together with similar land cover hould be more uniform in species composition.

EMAP-L and EMAP-Surface Waters propose to calculate landscape pattern metrics on various sized watersheds that contain stream sampling sites. Landscape metrics will be calculated for: (1) the riparian zone, as defined by proximity of vegetation to water drainage, (2) the entire drainage area, and (3) land cover patches weighted by distance from the stream. In selected areas, a combined area model will be used. These analyses will clarify which areas of the watershed have significant influence on stream biota.

EMAP-L will select a gradient of watersheds based on biotic and abiotic stream conditions, and calculate landscape pattern metrics to determine an initial sensitivity of stream condition to landscape metrics. EMAP-L will rank watersheds based on landscape metric values known to correlate with stream condition for the entire area.

In addition to stream biotic condition, EMAP-L will evaluate the relationship between landscape pattern and water quality and discharge. EMAP-L will use USGS and EPA data on water quality and discharge and correlate these data to landscape metrics and other biophysical attributes.

(B) BREEDING BIRDS

EMAP-L will evaluate the association of landscape pattern with presence and abundance of breeding birds. The objective of this project is to determine concordance between status and changes in landscape attern and bird species richness and abundance. Additionally, results of this work should allow EMAP-L to produce an assessment of status and changes in bird habitat suitability for the Mid-Atlantic region.

Breeding bird data collected from the North American Breeding Bird Survey (BBS), cover a 28-year period within the Mid-Atlantic region starting in 1966. EMAP-L will calculate landscape metrics by using variable-scale windows around breeding bird sites. Birds will be lumped into habitat quanta using Holling's (1992) allometric analysis of bird home range sizes. Various bird home range requirements will be used to select window size for landscape metric comparisons. In addition to conducting a space-for-time analysis by comparing early 1990 bird and land cover data, EMAP-L will analyze correlations between changes in landscape pattern (via three-date Landsat-MSS data) with changes in breeding bird presence/absence, abundance, and species richness. Data from the BBS will be provided by the NBS. EMAP-Center (Research Triangle Park, NC) will provide additional data obtained from a song-bird census method development study being conducted within the MAIA area.

(C) FORESTS

EMAP-L proposes to evaluate associations between landscape pattern and indicators of forest condition, including plant species diversity, presence/absence of exotic species, and vertical vegetation. EMAP-L will collaborate with EMAP-Forests in determining the sensitivity of landscape metrics to forest condition. Forest indicator data will be derived from the Forest Health Monitoring program plots within the Mid-Atlantic region. Landscape metrics will be calculated on variable-scale windows surrounding each forest sample. We will evaluate window sizes ranging from a few hectares up to several hundred hectares to determine scaling relationships between landscape pattern metrics and forest indicators.

(D) ESTUARIES

A proposed EMAP-L collaboration with the EMAP-Estuaries program to develop research relating landscape metrics to condition of estuarine environments will commence in 1995. Estuarine conditions may be a function of their spatial distribution, connectivity, and shape. Therefore, we will evaluate relationships between spatial patterns of estuaries and estuarine condition. EMAP-L will evaluate the correlation between landscape pattern on watersheds and conditions of estuaries. A similar sample design to that proposed for surface waters will be used to evaluate which landscape metrics and which scales are correlated to estuarine biotic and abiotic condition. EMAP-L will evaluate the number of paired watersheds and estuaries necessary to correlate landscape pattern and estuarine condition.

4.2.3 Landscape Classification

EMAP-L will evaluate the degree to which values of landscape pattern and their association to conditions in ecological resources (e.g., forests and streams) are nested within or constrained by coarser-scale biophysical attributes and processes (this is often termed pattern recognition). For example, EMAP-L will evaluate the degree to which landscape pattern varies by ecoregion (e.g., Omernik 1995), and by other biophysical attributes, including climate, geology, soils, and topography. Additionally, EMAP-L will evaluate the degree to which finer-scale patterns of landscapes are constrained or determined by coarser-scale landscape pattern. The landscape pattern type analysis of Wickham and Norton (1994) is one method for evaluating nested relationships of landscape pattern.

This analysis will be performed in an ARC/INFO GIS environment by evaluating the degree to which certain landscape pattern types and values are spatially-nested within digital coverages of biophysical attributes and natural region boundaries. Nested hierarchies would suggest that landscape patterns are constrained by higher-level ecological processes, including climate, geology, and topography. Initial analyses of these relationships will use data for the Chesapeake Bay Watershed; this study will be expanded to the entire Mid-Atlantic region as data become available.

4.3 COMPARABILITY OF AND SYNERGISM AMONG DIFFERENT REMOTE SENSING IMAGERY

If change could be determined accurately from unlabeled data (spectral reflectance and spectrally-clustered data), then costs of certain landscape assessments might be significantly reduced, and EMAP-L could use this approach in Step 2 of its proposed three-step monitoring and assessment process (Section 1.4). EMAP-L will evaluate different remote sensing data (e.g., spatial data derived from AVHRR, Landsat-MSS, and Landsat-TM imagery) in terms of advantages and limitations in derivation of ecologically meaningful landscape pattern metrics. This study has been limited to the three remote sensing data platforms listed above because of their continuous coverage, spatial scale, and easy accessibility. Landsat data have been shown to be useful at the scales selected by EMAP-L in all of the major ecosystem regions, including coastal areas (Browder et al. 1989). Additionally, EMAP-L will evaluate the potential of using spectral reflectance and spectrally-clustered data to determine landscape change. Labeling of remote sensing imagery into digital land cover data bases is an expensive process.

EMAP-L will evaluate concordance in landscape pattern metrics derived from different imagery (AVHRR, Landsat-MSS, Landsat-TM) by selecting a subset of watersheds (USGS 8-digit HUCs) across the Mid-Atlantic region. On each watershed, landscape pattern metrics will be calculated from the different imagery. Some landscape metrics have been shown to remain nearly constant over a range of 4 to 80 meters (Wickham and Riitters, in press). However, the values of particular landscape metrics do not remain constant at a threshold of 1 ha and larger pixel sizes (Wickham and Riitters, in press; Turner et al. 1989). Therefore, we hypothesize that AVHRR-derived landscape metrics will depart significantly from Landsat-MSS and Landsat-TM because of its relatively large pixel sizes (1.1 km on a side versus 30m and 80m for Landsat-TM and Landsat-MSS, respectively). This will be especially true for those landscape metrics requiring several thousand pixels (e.g., diversity metrics). We hypothesize that Landsat-TM and Landsat-MSS will generate relatively similar landscape pattern results over 8-digit HUC watersheds because pixels are closer in size and because at least some spectral bands of the two sensors collect data in similar portions of the electromagnetic spectrum (e.g., Landsat-MSS band 4 matches Landsat-TM band 2, and Landsat-MSS bands 6 and 7 match Landsat-TM bands 3 and 4).

Relating landscape pattern derived from Landsat-MSS and Landsat-TM has some important ramifications for the EMAP-L program. Landsat-MSS data will be available over a large portion of the Nation and cover time periods dating back to the earlier 1970s. EMAP-L would like to use Landsat-MSS data to produce its first assessments of landscape status and change. However, the Landsat-MSS program has been phased out, leaving only the Landsat-TM sensor to produce data at a similar scale. Therefore, the later assessments of landscape change would involve comparison of landscape patterns derived from Landsat-MSS and Landsat-TM. Dottavio and Dottavio (1984) provide a framework for matching Landsat-MSS and Landsat-TM.

EMAP-L will compare landscape pattern estimates derived from land cover data with those derived from spectrally-clustered and reflectance data to determine their utility in evaluating landscape change. The comparisons will also be made on the same set of 8-digit HUC watersheds; a space-for-time concept will be used to evaluate their potential use in landscape change detection.

Interest in detection of land cover change using remotely sensed data pre-dates the advent of Landsat, the oldest satellite sensor system (Shepard 1964). Since the advent of Landsat and other satellite systems, their use in detection of land cover change has been a principal research focus. Several change detection methods have been developed and evaluated, including differencing, ratioing, and regressing multi-date imagery, principal components and comparison of independent land cover classifications (post-classification comparison). Reviews of these methods can be found in Jensen (1981, 1983), Singh (1989) and Mouat et al. (1993). These methods can be grouped into two broad categories: image enhancement and multi-date classification (Pilon et al. 1988).

Detection of land cover change using multi-date satellite data must control for the confounding effects of different atmospheric conditions, different sensors, and accurate registration of the temporal image sets. Image enhancement methods are designed to control for different atmospheric conditions and different sensor characteristics. The image enhancement techniques have been found to accurately identify "change" versus "no change" (see Stauffer and McKinney 1978, Nelson 1983, Fung and LeDrew 1988, Fung 1990). Once "change" versus "no change" has been determined for a multi-date data set, additional image processing techniques are required to determine the "from" and "to" categories of change (e.g., "from" forest "to" urban").

The logic of post-classification comparison is better suited for categorical determination of land cover change (Jensen 1986, Jensen 1993). However, the method is often hindered by its inability to distinguish changes in land cover from differences in the environment (e.g., atmospheric difference). Post-classification comparison can lead to improbable "from" and "to" categories (e.g., "from" urban "to" forest). These improbable changes can be the result of the multiplicative effect of error in each of the classifications. For example, land cover maps that each have an 80 percent overall classification accuracy could result in a "from"/"to" change map that has an overall accuracy of 64 percent (0.80 x 0.80 = 0.64). The potentially poor accuracy of post-classification comparison can apparently be overcome if the individual classifications and geometric registrations are sufficiently accurate (Jensen 1986, Jensen 1993).

The NALC Landsat-MSS triplicate data set for path/row 15/33 (Washington, DC) is currently being analyzed by EMAP-L. Independent classifications for the 1973, 1987, and 1990 imagery were created, requiring the implementation of the post-classification comparison change detection method. Several processing techniques will be used to compare these independent classifications. The techniques are a compilation of those found in Pilon et al. (1988), Schott et al. (1988), and Jensen (1993).

4.4 FUTURE PRACTICAL APPLICATIONS

The three-step approach proposed by EMAP-L has a number of important potential practical applications, particularly in the area of environmental management. A recent report by the Science Advisory Board (SAB; EPA 1995b) stresses the need for future planning and recommends formation of an Environmental Futures Committee to forecast future environmental problems and develop resolutions. Specific recommendations relevant to the work being conducted in EMAP-L include providing as much attention to avoiding future environmental problems as is given to controlling current ones, establishing an early-warning system, paying particular attention to the sustainability of terrestrial ecosystems and development and use of non-traditional environmental stressors, improving and integrating environment-related futures studies, focusing attention on broad causes of environmental change, and establishing a broad-based data system for anticipating future environmental risks (EPA 1995b). The applications being developed by EMAP-L, if successful, will provide some of the tools critical to achieving the objectives of the SAB's recommendations. The combined use of existing historical data and new data in establishing trends can potentially be used in an early-warning system and provide critical information on the sustainability of terrestrial and riparian ecosystems. The metrics and indicators being developed in EMAP-L are direct or surrogate measures of ecosystem-level stressors. Finally, the EMAP-L assessments integrate a wide variety of data sets, i.e., integration of ground-based ecological studies with remote sensing data collected by other agencies for non-environmental uses.

While the development phase of the EMAP-L three-step approach is being conducted at the landscape scale, it should be possible to adapt applications to a variety of scales. The use of multiple scales has applications in delineating status and trends of the habitats of small to large animal species, investigating the effects of pollution point sources, and detecting changes in particular land cover types from low-order streams to large forests and rangelands. Scale applications was one of the points raised in a review of EMAP by the National Research Council (NRC 1995). Another issue raised by the NRC was EMAP's reliance upon statistical-based sampling designs; the EMAP-L approach permits full-scale coverage. The EMAP-L approach makes extensive use of existing data, another issue raised by the NRC review. Finally, the EMAP-L approach provides integration of multiple data layers in a GIS-based work environment.

5.0 ASSESSMENT OF STATUS AND TRENDS

EMAP-L has selected the Mid-Atlantic region as a research and assessment location based on a number of criteria. The EMAP-L assessment strategy is to conduct assessments in areas where extensive spatial data exist and preferably are of known confidence. Secondly, EMAP-L has targeted indicator and assessment research in locations where other EMAP projects are active. Hence, EMAP-L interpretations of status and trends will add value to other EMAP research and assessment activities. Further, EMAP-L will collaborate with other research or monitoring programs currently under development, e.g. NAWQA, SAMAB.

EMAP-L will produce three types of status and trends products in the Mid-Atlantic study area by late FY96: (1) a landscape statistical summary, (2) an interpretive assessment, and (3) a series of journal articles. Estimates of landscape indicators for 8-digit HUC watersheds will be determined within the Chesapeake Bay Watershed in FY95; landscape status and trends and their relevance to societal values will be highlighted in an interpretive report for the entire Mid-Atlantic region by late 1996.

5.1 CHESAPEAKE BAY, FY95

A statistical summary will be developed for the Chesapeake Bay Watershed using 1990 Landsat-TM data. The status of landscapes in the Chesapeake Bay Watershed will be reported in two formats, i.e. cumulative distribution functions (CDFs) and raster maps. The CDF format will utilize USGS 8-digit HUCs as landscape units, that is, the indicators will be calculated separately for each HUC and aggregated to a regional status report by aggregating the values for each HUC. The raster map format will utilize the same map extent, grain size, and resolution as the input land cover maps, and indicators will be calculated by using sliding windows of various sizes. Thus, the output maps will be "surface maps" of indicator values. These surface maps are primarily useful for visualizing broad-scale patterns of indicator values. It will be possible to stratify these maps (by watershed, ecoregion, etc.) for further status and trend assessments and for drawing correlations with finer-scale information from other EMAP projects.

We will use the Chesapeake Bay Watershed study to explore different ways to communicate results to data users. Viable alternatives include paper reports, CD-ROM, and Internet (via an existing EMAP Mosaic server). The best distribution channel will depend upon the capabilities of the primary data users. Maps will be made available in formats suitable for access via ARC/INFO GIS software.

The following are examples of assessment questions that EMAP-L will address in the Chesapeake Bay:

1) What is the status of wildlife habitat suitability across the Chesapeake Bay Watershed based on landscape composition and pattern at multiple scales?

2) Which 8-digit watersheds have the highest amount of suitable habitat for interior forest species? For forest-edge species?

3) Which patches of forests have the biggest potential influence on habitat suitability? Which patches, if lost, would have the greatest negative influence on forest connectivity?

4) What is the distribution of roads and other human influences across the Chesapeake Bay and what is their spatial relationship to wildlife habitat suitability?

5) What is the spatial distribution of landscape pattern types over the Chesapeake Bay? To what degree do biophysical attributes and man influence these patterns?

5.2 MID-ATLANTIC PROJECT AREA, FY96

An interpretive assessment will be developed for the entire Mid-Atlantic region by late FY96. The FY96 Mid-Atlantic Region project area will be handled as an expansion of the FY95 Chesapeake Bay Watershed study. New elements will include trend analysis and optional reporting units in addition to watersheds.

Twenty-year trends in landscape ecological condition will be the focus of this report, but a current status report will also be prepared. The Mid-Atlantic regional land cover maps from the MRLC Landsat-TM data and the NALC Landsat-MSS data will be used. The MRLC maps have an advantage of finer scale, while the NALC maps offer the unique opportunity to quantify past trends in land cover over the entire region.

Landscape condition changes will be related to societal values, i.e. biodiversity, watershed integrity, and landscape resilience, established for the region and can be compared to other assessments derived independently from other EMAP projects or other multi-agency assessment programs. The interpretive assessment will also use ancillary data sets to help establish associations between ecological condition and stressor types and intensities.

Landscape units, metrics, indicators, calculation windows, software, reporting formats, and other details will be similar to those used in the Chesapeake Bay Watershed study, but modified according to what has been learned in that exercise. It is expected that additional biogeographic and political boundaries (that is, not just watershed boundaries as in the Chesapeake Bay example) will be employed.

The following are examples of assessment questions that EMAP-L will address over the entire Mid-Atlantic region:

1) What are the status and trends in wildlife habitat suitability across the Mid-Atlantic region based on landscape composition and pattern at multiple scales?

2) Which 8-digit watersheds are gaining or losing habitat for interior forest, forest-edge, and edge species? How do these gains and losses vary with spatial scale?

3) What are the relationships between type, magnitude, and distribution of anthropogenic stress and status and changes in wildlife habitat suitability? What is the influence of biophysical attributes, including geology, landform, topography, soils, on these relationships?

4) What are the associations between landscape composition and pattern and water quality over the Mid-Atlantic region? What is the influence of biophysical attributes on these relationships? Based on these associations, and landscape composition and pattern change over the Mid-Atlantic region from 1972-1992, which watersheds are vulnerable to declines in water quality?

5) What are the associations between landscape composition and pattern and biotic condition of streams in the Mid-Atlantic region? What is the influence of biophysical attributes on these relationships? Based on these associations, and landscape composition and pattern change over the Mid-Atlantic region from 1972-1992, which watersheds are vulnerable to declines in stream biota?

6) What are the associations between landscape composition and pattern and forest condition in the Mid-Atlantic region? What is the influence of biophysical attributes on these relationships? Based on these associations, and landscape composition and pattern change over the Mid-Atlantic region from 1972-1992, which watersheds are vulnerable to declines in forest condition?

7) What are the associations between landscape composition and pattern and estuarine condition in the Mid-Atlantic region? What is the influence of biophysical attributes on these relationships? Based on these associations, and landscape composition

and pattern change over the Mid-Atlantic region from 1972-1992, which estuaries are vulnerable to declines in overall condition?

8) To what degree does breeding bird richness vary with landscape composition and pattern across the Mid-Atlantic region at multiple scales? What is the influence of biophysical attributes on this relationship? To what degree do breeding bird guilds vary with landscape composition and pattern?

9) What are the relationships between changes in landscape composition and pattern from 1972 to 1992 and changes in breeding bird richness and guilds over the entire Mid-Atlantic region? Do these relationships vary among different spatial scales? What is the influence of biophysical attributes on these relationships? Based on these assessments, which areas are vulnerable to declines in breeding bird richness?

10) How have flooding events varied by watershed across the Mid-Atlantic region? What are the characteristics of watersheds that have exhibited little or no flooding, moderate flooding, severe flooding? What percentage of this variation is explained by status and changes in landscape composition and pattern? by biophysical attributes? by hydrologic modification?

11) To what degree does the condition of ecological resources in watersheds vary by landscape pattern type across the Mid-Atlantic region?

12) What is the spatial distribution of landscape composition and pattern change between 1972 and 1992 over the entire Mid-Atlantic region? To what degree did the distribution and magnitude of change vary with anthropogenic stress? with natural stress? What proportion of the variation in landscape change was explained by biophysical attributes? Which watersheds appear to be most resilient to anthropogenic stress? natural stress? combinations of anthropogenic and natural stress?

13) Is watershed resiliency related to the condition of ecological resources? to biophysical attributes? to sustainability of specific ecological resources?

EMAP-L anticipates that part of the results of landscape assessments will be included in a larger report for the MAIA region. A separate research plan highlighting the overall MAIA assessment is under development by EMAP-Center.

5.3 DATA BASES OF LANDSCAPE STATISTICAL SUMMARIES

EMAP-L will provide a data base of landscape statistics derived for both the statistical summary and interpretive assessment reports. GIS data layer coverages will be provided in addition to the tabulated descriptive statistics. Data layers will include the spatial convolution maps for the selected indicators and may include ancillary datasets used to determine the spatial correlation relative to stressor sources. Data bases of landscape statistics will be produced on CD-ROM and distributed to other EMAP projects and other agency programs.

6.0 INFORMATION MANAGEMENT

There will be five primary information management activities within the Mid-Atlantic Region Landscape Indicators Project: (1) data acquisition and documentation; (2) data analysis and creation of data bases with results of research and assessments; (3) reports, including journal articles, statistical summaries, and interpretative assessments; (4) technology transfer of EMAP-L computer programs and assessment protocols; and (5) a QA audit of data and data flow used to estimate landscape status and trends.

6.1 DATA ACQUISITION AND DOCUMENTATION

The primary digital imaging processing system used is ERDAS Imagine Version 8.2. Spectral and land cover data bases will be acquired via EMAP-LC and NALC. They include a 6-class Landsat-TM data base of the Chesapeake Bay Watershed, a 10-class Landsat-TM data base of the entire Mid-Atlantic region, and an 8 to 11-class Landsat-MSS data base covering three dates (the early 1970s, the mid-1980s, and the early 1990s). EMAP-L anticipates receiving partial coverages of the 10-class Landsat-TM and 8 to 11-class Landsat-MSS data bases until the entire area is covered in FY95 (Table 4). The 6-class Chesapeake Bay Watershed data base has already been received by EMAP-L. All classifications will be simplified (i.e., aggregated) to the Anderson Level I classification system (Anderson et al. 1976).

EMAP-L will acquire other spatial data bases from EMAP-LC that will be used to evaluate landscape indicator sensitivity, including multiple-scale spatial patterns of landscapes (see Section 4). EMAP-LC has developed an on-line geographic reference data base for the MAIA area (the MAIA GRD). This data base can be accessed via Internet.

Figure 5 summarizes sources and flow of data to be used by EMAP in the Mid-Atlantic Region Landscape Indicators Project. Each spatial data set is accompanied by a metadata file containing the "genealogy" or lineage of the data. This metadata file includes all ancillary information relevant to the digital data, land cover maps produced using the data, and results of any data verification activities. Specifically, this documentation must include the following, at a minimum: source of digital data, date obtained, results of initial data checks and scans, summary of land cover classification system used and definitions of each land cover category, notation of all "missing" data categories (e.g., cloud and shadows), minimum map unit, methods of data aggregation, methods of data "smoothing", and land cover error matrices.

Table 4. Approximate Schedule of Land Cover Data Base Availability in the Mid-Atlantic Region

Chesapeake Bay Watershed Landsat TM Data Base	Aug. 1994
Mid-Atlantic AVHRR Data Base	Dec. 1994
Mid-Atlantic Landsat-MSS Data Base (three date)	Jul. 1995
Mid-Atlantic Landsat TM Data Base	Dec. 1995

6.2 DATA ANALYSIS

EMAP-L will use the LandStat/Spatial Convolution programs (developed by K. H. Riitters at TVA) to analyze landscape pattern and commercial statistical software to conduct multivariate analysis of the data sets. Spatial coverages will be exported in GRID ASCII format so that they can be imported into statistical programs that calculate landscape metrics. Similarly, results of landscape analyses will be imported back into ARC/INFO in the GRID ASCII format.

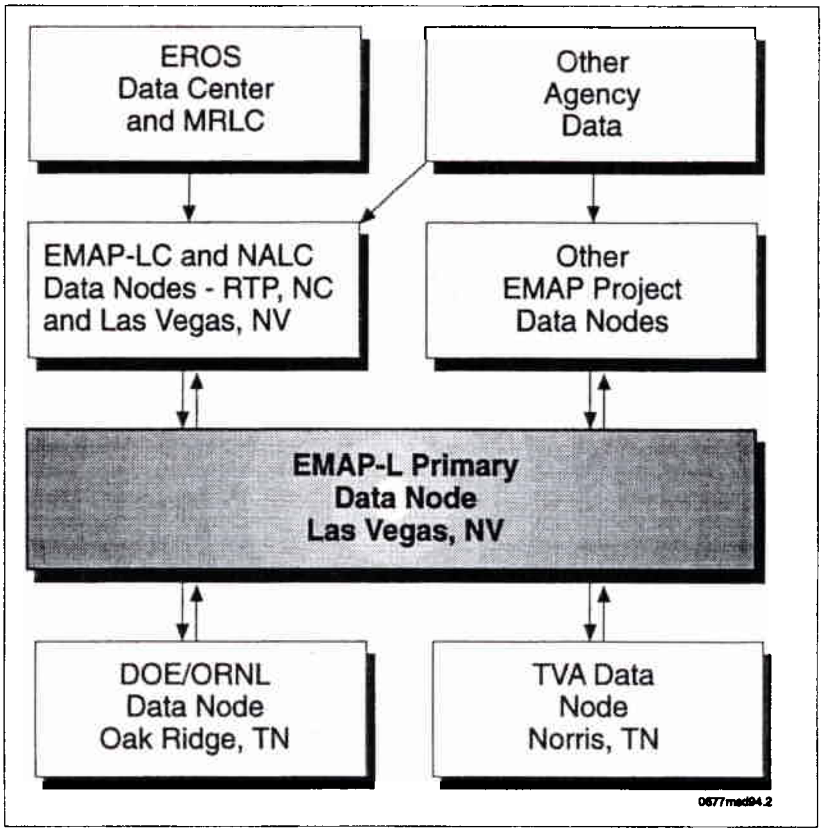

Figure 5. **Sources and Flow of Data to be Used by EMAP-L in Conducting Research and Assessments in the Mid-Atlantic Region.**

Spatial comparisons and analyses in ARC/INFO require that spatial data have similar projections (e.g., represent the same areas), are in similar format (e.g., vector or raster), and are of similar scale or resolution. EMAP-L will ensure that each of these criteria are met prior to conducting an analysis.

6.3 REPORTS

EMAP-L will produce a series of journal articles, statistical summaries, and interpretative reports of its results for the Mid-Atlantic Region Landscape Indicators Project area. Statistical summaries will be distributed as hard copy reports, as well as data bases. Data bases will include metadata, tables of results, and spatial displays (e.g., spatial convolution applications). These data bases will be made available on tapes, via Internet, and through the use of EMAP-wide information system.

6.4 TECHNOLOGY TRANSFER

EMAP-L has and will continue to develop a series of statistical tools related to calculation of landscape pattern metrics, including spatial displays of statistical results. It is EMAP-L's intent to make these tools available to EPA Regions, EPA Program Offices, other agencies, and the scientific community as specific applications are completed and tested.

7.0 QUALITY ASSURANCE

Quality assurance is an integral component of all EMAP-L activities (Kirkland 1994). Application of QA principles to remote sensing and GIS is a relatively new endeavor, therefore, much research and development is still being undertaken. The EMAP-L QA program is designed to take advantage of ongoing QA research, much of which is being conducted at EPA's Characterization Research Division in Las Vegas (CRD-LV). In addition, the EMAP-L QA program contains a large research component to investigate issues directly related to the EMAP-L design and indicators. The primary areas of QA research and development within EMAP-L include: (1) data quality objectives (DQO), (2) audits of data quality (ADQ), and (3) data quality assessments (DQA). The QA program for EMAP-L is documented in the Quality Assurance Project Plan (QAPP; Chaloud, in prep.) which is updated as needed to reflect changes and advances in development of the QA program.

7.1 DATA QUALITY OBJECTIVES (DQO)

For many of the EMAP-L indicators, existing data are not available on the sources and extent of variability. The primary thrust of research in this area is identification and quantification of sources of variability and investigation of the impacts of variability on particular metrics or indicators. The indicator development projects, e.g., indicator sensitivity, error propagation and ecological significance investigations (see Section 4), are the major contributors to this research. Once the major sources of variability are identified, QA procedures can be developed to control, minimize, and measure the contributed uncertainty.

A program-level DQO for EMAP has been established as the ability to detect 20 percent change over 10 years with an alpha of 0.2 and beta of 0.3 (power of 0.7) (Kirkland 1994). EMAP-L, through its research on landscape indicator sensitivity (e.g., space-for-time and 3-date Landsat-MSS evaluations), will evaluate each indicator's ability to meet this DQO. Because the two primary sources of data used by EMAP-L are NALC and MRLC, these three groups will work closely together in evaluating DQOs.

7.2 AUDITS OF DATA QUALITY (ADQ)

EMAP-L makes extensive use of data bases generated by other programs. The primary data sources for EMAP-L are the NALC and MRLC programs. In addition, EMAP-L will use expanded synoptic data sources, i.e. AVHRR, Landsat-TM, Landsat-MSS, and ground sample probability-based data (see Tables 2 and 3). In using data generated by other sources, it is critical to ascertain the quality of the data and associated metadata, establish the traceability and integrity of the data, and define the potential uses and limitations of the data set. The ADQ is the assessment tool used for this purpose. Development of processes for conducting ADQs has been given high priority in the EMAP-L QA research program because EMAP-L plans to utilize data sets dating back to the 1970s. Initially, the EMAP-L will develop the ADQ procedures in conjunction with MRLC and NALC programs. Once procedures have been fully developed and tested, they will be used to conduct ADQs of historical data sets.

7.3 DATA QUALITY ASSESSMENTS (DQA)

Data quality assessments are necessary to evaluate achieved data quality against the DQOs established for the program. The DQAs include calculation of achieved precision, accuracy, completeness, and detection limits or other acceptance limits as appropriate for specific analyses and indicators. These calculations will be summarized in statistical tables for inclusion in statistical summary reports and status reports. In addition, the DQA data are available for inclusion in journal articles.

8.0 PROJECT OUTPUTS AND TIMELINE

A number of products will result from the Mid-Atlantic Region Landscape Indicators Project, including: (1) journal articles on findings of research, (2) assessments of landscape status and trends, and (3) digital data bases with spatial coverages of statistical analyses. Assessment reports will include both statistical summaries and interpretive assessments; these will be in the form of EPA reports and journal articles. Table 5 provides a list of anticipated products, relative priority ranking, and approximate completion dates. Completion of Mid-Atlantic Region Landscape Indicators Project reports will depend on the completion of land cover data bases over the entire area. Table 4 lists key land cover data bases and delivery dates (to EMAP-L).

Table 5. List of EMAP-L Products Anticipated From the Mid-Atlantic Region Landscape Indicators Project.
Each is Listed by Major Activity Type (see Sections 4 and 5). Priority: 1 = high; 2 = medium; and 3 = low.

Product	Priority	Anticipated Completion Date
Sensitivity - Statistical Properties		
Cumulative Error Propagation in Estimating Landscape Status and Trends - Journal article	2	September 1995
Impact of Land Cover Misclassification on Landscape Pattern Metrics - Journal article	1	January 1995
Orthogonality of Landscape Metrics at Multiple-scales - Journal article	2	June 1995
Ecological Sensitivity of Landscape Pattern Metrics		
Landscape Metric Sensitivity Along an Urban to Rural Environmental Gradient in the Chesapeake Bay Watershed - Journal article	1	March 1995
Relationships between Landscape Pattern and Stream Condition in the Mid-Atlantic Region - Journal article	1	May 1996
Relationships between Landscape Pattern and Forest Condition in the Mid-Atlantic Region - Journal article	2	May 1996
Relationship between Landscape Pattern and Water Quality in the Chesapeake Bay Watershed - Journal article	1	October 1995
Watershed Vulnerability to Severe Flooding - a Landscape-Level Approach - Journal article	3	September 1996
Status and Trends in Breeding Bird Habitats - a Landscape-level Assessment - Journal article	1	June 1996
A Landscape-level Analysis of Wildlife Habitat - an Example from the Chesapeake Bay Watershed - Journal article	1	June 1995
Influence of Multiple-scale Biophysical Attributes on Landscape Pattern - Journal article	2	July 1996
Sensor Synergism		
Comparison of Satellite Sensors and Their Ability to Detect Landscape Pattern Status and Change - Journal article	1	July 1996
Detecting Landscape Pattern Change from Reflectance and Spectral Cluster Data - Journal article	3	July 1996
Assessments		
Landscape Status in the Chesapeake Bay Watershed - Statistical Summary	1	August 1995
Landscape Status and Change in the Mid-Atlantic Region - Interpretive Report Relative to Landscape Values - Journal article	1	September 1996
Other		
Findings of Landscape Indicator Research in Eastern U.S. Landscapes - Journal article	2	October 1996
EMAP-L Quality Assurance Project Plan - EPA Report	1	August 1995

9.0 REFERENCES

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. *A land use and land cover classification system for use with remote sensor data.* U.S. Geological Survey, Professional Paper 964, Washington, D.C.

Baker, W.L. and Y. Cai. 1992. *The r.le programs for multi-scale analysis of landscape structure using the GRASS geographical information system.* Landscape Ecology, 7(4):291-302.

Barber, M.C. (ed.) 1994. *Environmental Monitoring and Assessment Program: Indicator Development Strategy.* EPA/620/R-94/022, Office of Research and Development, Washington, D.C.

Baron, J. and K. A. Galvin. 1990. *Future directions of ecosystem science.* Bioscience, 40(9):640-642.

Browder, J. A., L. N. May, A. Rosenthal, J. G. Gosselink, and R. H. Bauman. 1989. *Modeling future trends in wetland loss and brown shrimp production in Louisiana using Thematic Mapper imagery.* Remote Sensing of Environment, 28:45-59.

Chaloud, D. J. 1995. *Quality Assurance Project Plan for EMAP-Landscapes.* U.S. Environmental Protection Agency, Las Vegas, Nevada (in preparation).

Congalton, R. S. 1988. *Using spatial autocorrelation analysis to explore the errors in maps generated from remotely sensed data.* Photogrammetric Engineering and Remote Sensing, 54(5):587-592.

Congalton, R. S. and Green, K. 1993. *A practical look at the sources of confusion in error matrix generation.* Photogrammetric Engineering and Remote Sensing, 59(5):641-644.

Dobson, J., R. L. Ferguson, D. W. Field, L. L. Wood, K. D. Haddad, H. Airedale, J. R. Jensen, V. V. Klemas, R. J. Orth, and J. P. Thomas. 1995. *NOAA CoastWatch Change Analysis Project: Guidance for Regional Implementation.* National Oceanic and Atmospheric Administration, Washington, D.C. (In press). 128 pp.

Dottavio, C. L. and F. D. Dottavio. 1984. *Potential benefits of new satellite sensor for wetland mapping.* Photogrammetric Engineering and Remote Sensing, 50(5):599-606.

Ehrlich, P. R. and A. H. Ehrlich. 1991. *Healing Planet: Strategies for Resolving the Environmental Crisis.* Addison-Wesley Publishing Company, Inc., Reading, Massachusetts. 366 pp.

Environmental Protection Agency (EPA). 1993. *Environmental Monitoring and Assessment Program: Master Glossary.* EPA/620/R-93/013, Office of Research and Development, Washington, D.C.

Environmental Protection Agency (EPA). 1994. *Landscape Monitoring and Assessment Research Plan.* EPA 620/R-94/009, Office of Research and Development, Washington, D.C.

Environmental Protection Agency (EPA). 1995a. *Review of the Environmental Monitoring and Assessment Program Landscape Component.* U.S. Environmental Protection Agency, Science Advisory Board (EPA-SAB-EPEC-LTR-95-002). Washington, D.C.

Environmental Protection Agency (EPA). 1995b. *Beyond the Horizon: Using Foresight to Protect the Environmental Future.* U.S. Environmental Protection Agency, Science Advisory Board, Environmental Futures Committee, Washington, D.C. 34 pp.

Forman, R. T. T., and M. Godron. 1986. *Landscape Ecology.* John Wiley and Sons, New York.

Franklin, J. F. 1993. *Preserving biodiversity: species, ecosystems, or landscapes.* Ecol. Appl., 3:202-205.

Fung, T. and E. LeDrew. 1988. *The determination of optimal threshold levels for change detection using various accuracy indices.* Photogrammetric Engineering and Remote Sensing, 54(10):1449-1454.

Fung, T. 1990. *An assessment of TM imagery for land-cover change detection.* IEEE Transactions on GeoScience and Remote Sensing, 28(4):681-684.

Gardner, R. H. and R. V. O'Neill. 1991. *Pattern, process and predictability: The use of neutral models for landscape analysis.* pp 289-307. In: Turner, M. G. and R. H. Gardner (eds.), Quantitative Methods in Landscape Ecology. The Analysis and Interpretation of Landscape Heterogeneity. Ecological Studies Series, Springer-Verlag, New York.

Gardner R. H., B. T. Milne, M. G. Turner, and R. V. O'Neill 1987. *Neutral models for the analysis of broad-scale landscape pattern.* Landscape Ecology, 1: 19-28.

Hamblin, A. 1992. *Environmental Indicators for Sustainable Agriculture.* Department of Primary Industries and Energy, Bureau of Rural Resources. Canberra, Australia. 96 pp.

Hargrove, W. W., and J. Pickering. 1992. *Pseudoreplication: a sine qua non for regional ecology.* Landscape Ecology, 6: 251-258.

Holden, C. 1988. *The ecosystem and human behavior.* Science, 242: 663.

Holling, C. S. 1992. *Cross-scale morphology, geometry, and dynamics of ecosystems.* Ecological Monographs, 62(4):447-502.

Hunsaker, C. T., R. L. Graham, G. W. Suter II, R. V. O'Neill, L. W. Barnthouse and R. H. Gardner. 1990. *Assessing ecological risk on a regional scale.* Environmental Management, 14:325-332.

Hunsaker, C. T., and D. E. Carpenter, eds. 1990. *Environmental Monitoring and Assessment Program: Ecological Indicators.* EPA/600/3-90/060. U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Hunsaker, C. T., D. A. Levine, S. P. Timmins, B. L. Jackson, and R. V. O'Neill. 1992. *Landscape characterization for assessing regional water quality.* Pp. 997-1008, In: D.H. McKenzie, D.E. Hyatt, and V.J. McDonald (eds.), Ecological Indicators. Elsevier Appl. Sci., New York.

Hurlbert, S. H. 1984. *Pseudoreplication and the design of ecological field experiments.* Ecological Monographs, 54: 187-211.

Jensen, J. R. 1981. *Urban change detection mapping using Landsat digital data.* The American Cartographer, 8(2):127-147.

Jensen, J. R. (ed.) 1983. *Urban/suburban Land Use Analysis.* Manual of Remote Sensing, Volume II, 2nd. Ed. pp. 1571-1666. American Society of Remote Sensing, Bethesda, Maryland.

Jensen, J. R. 1986. *Introductory Digital Image Processing: A Remote Sensing Perspective.* Prentice-Hall, Englewood Cliffs, New Jersey.

Jensen, J. R., D. J. Cowen, J. D. Althausen, S. Narumalani, and O. Weatherbee. 1993. *An evaluation of the CoastWatch change detection protocol in South Carolina.* Photogrammetric Engineering and Remote Sensing, 59(6):1039-1046.

Jensen, M. E., and R. Everett. 1994. *An Overview of Ecosystem Management Principles.* Pp. 7-16, In: Jensen, M. E., and P. S. Bourgeron (eds.), Eastside Forest Ecosystem Health Assessment, Vol II, Ecosystem Management: Principles and Applications. USDA Forest Service. PNW-GTR-318.

Kaufmann, M. R., R. T. Graham, D. A. Boyce Jr., W. H. Moir, L. Perry, R. T. Reynolds, R. L. Bassett, P. Mehlhop, C. B. Edminster, W. M. Block, and P. S. Corn. 1994. *An Ecological Basis for Ecosystem Management.* USDA Forest Service. General Technical Report RM-246.

Kirkland, L. L. 1994. *Environmental Monitoring and Assessment Program Quality Management Plan.* U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Klemas, V. V., J. E. Dobson, R. L. Ferguson, and K. D. Haddad. 1993. *A coastal land cover classification system for the NOAA CoastWatch Change Analysis Program.* Journal of Coastal Research, 9(3):862-872.

Krummel, J. R., R. H. Gardner, G. Sugihara, R.V. O'Neill, and P. R. Coleman. 1987. *Landscape patterns in a disturbed environment.* Oikos, 48: 321-324.

Kutz, F. W., and R. A. Linthurst. 1990. *A systems-level approach to environmental assessment.* Toxicological and Environmental Chemistry, 28 (2-3):105-114.

Leahy, P. P., J. S. Rosenshein, and D. S. Knopman. 1990. *Implementation Plan for the National Water-Quality Assessment Program.* Open-File Report 90-174. U.S. Geological Survey, Reston, Virginia. 10 pp.

Lillesand, T. M. and R. W. Kiefer. 1987. *Remote Sensing and Image Interpretation.* 2nd. Ed. John Wiley and Sons, New York.

Ludwig, J. A., and J. F. Reynolds. 1988. *Statistical Ecology.* John Wiley and Sons, New York.

Lunetta, R. S., R. G. Congalton, L. K. Fenstermaker, J. R. Jensen, K. C. McGwire, and L. R. Tinney. 1991. *Remote sensing and geographic information system data integration: error sources and research issues.* Photogrammetric Engineering & Remote Sensing, 57(6):677-687.

McNeely, J. A., K. R. Miller, W. Reid, R. Mittermeier, and T. Werner. 1990. *Conserving the World's Biological Diversity.* IUCN, World Resources Institute, World Bank. WWF-US and Conservation International, Washington, D.C.

Messer, J. J., R. A. Linthurst, and W.S. Overton. 1991. *An EPA program for monitoring ecological status and trends.* Environmental Management, 17:67-78.

Milne, B. T. 1988. *Measuring the fractal geometry of landscapes.* Applications in Mathematics and Computation, 27:67-79.

Milne, B. T. 1991. *Heterogeneity as a multi-scale characteristic of landscapes.* Pp. 69-84, In: J. Kolasa and W. E. Waters (eds.), Ecological Heterogeneity. Springer-Verlag, New York.

Mouat, D. A., G. G. Mahin, and J. M. Lancaster. 1993. *Remote sensing techniques in the analysis of change detection.* Geocarto International, 8(2):39-50.

National Research Council. 1995. *Review of EPA's Environmental Monitoring and Assessment Program: Overall Evaluation.* National Academy Press, Washington, D.C.

Nelson, R. F. 1983. *Detecting forest canopy change due to insect activity using Landsat-MSS.* Photogrammetric Engineering and Remote Sensing, 49(9):1303-1314.

Noss, R. F. and A. Y. Cooperrider. 1994. *Saving Nature's Legacy: Protecting and Restoring Biodiversity.* Island Press, Washington, D.C.

O'Neill, R. V., D. L. DeAngelis, J. B. Waide, and T.F.H. Allen. 1986. *A Hierarchical Concept of Ecosystems.* Princeton University Press, Princeton, New Jersey.

O'Neill, R. V., R. H. Gardner and M. G. Turner. 1992. *A hierarchical neutral model for landscape analysis.* Landscape Ecology, 7: 55-61.

Omernik, James M. 1987. *Ecoregions of the United States. Map at a Scale of 1:7,500,000.* Supplement of the Annals of the Association of American Geographers, 77(1).

Omernik, James M. 1995. *Ecoregions: A spatial framework for environmental management.* In: W.S. Davis and T.P. Simon (eds.), Biological Assessment for Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Chelsea, Michigan. (In press).

Pickett, S.T.A. 1989. *Space-for-time substitutions as an alternative to long-term studies.* Pp. 110-135, In: Likens, G.E. (ed.), Long-Term Studies in Ecology: Approaches and Alternatives. Springer-Verlag, New York.

Pilon, P. G., P. J. Howarth, R. A. Bullock, and P. O. Adeniyi. 1988. *An enhanced classification approach to change detection in semi-arid environments.* Photogrammetric Engineering and Remote Sensing, 54(12):1709-1716.

Plotnick, R. E., R. H. Gardner, and R. V. O'Neill. 1993. *Lacunarity indices as measures of landscape texture*. Landscape Ecology, 8: 201-211.

Rapport, D. J., C. Gaudet, J. Karr, B. Norton, and W. Jackson. 1995. *Guiding principles for evaluating landscape health.* (Bioscience submitted).

Regier, H. A. 1993. *The notion of natural and cultural integrity.* Pp. 3-18, In: S. Woodley, J. Kay, and G. Francis (eds.), Ecological Integrity and the Management of Ecosystems. St. Lucie Press, DelRay Beach, Florida.

Riitters, K. H., R. V. O'Neill, C. T. Hunsaker, J. D. Wickham, D. H. Yankee, S. P. Timmins, K. B. Jones, and B. L. Jackson. 1995. *A factor analysis of landscape pattern and structure metrics.* Landscape Ecology, 10:23-39.

Schott, J. R., C., Salvaggio, and W. J. Volchok. 1988. *Radiometric scene normalization using pseudoinvariant features.* Remote Sensing of Environment, 26:1-16.

Sharpe, D., J. Estes, and K. A. Herman. 1993. *Proceedings of a Workshop: Environmental Monitoring and Assessment Program - Landscape Ecology.* U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, North Carolina.

Shepard, J. R. 1964. *A concept of change detection.* Photogrammetric Engineering, 30(4):648-651.

Singh, A. 1989. *Digital change detection techniques using remotely-sensed data.* International Journal of Remote Sensing, 10(6):989-1003.

Stauffer, M. L. and R. L. McKinney. 1978. *Landsat image differencing as an automated land cover change detection technique (interim report).* Computer Science Corporation, report to National Aeronautics and Space Administration (NASA), CSC/TM-78/6215, Greenbelt, Maryland.

Story, M. and R. S. Congalton. 1986. *Accuracy assessment: a user's perspective.* Photogrammetric Engineering and Remote Sensing, 52(3):397-399.

Suter, G.W., II. 1990. *Endpoints for regional ecological risk assessment.* Environmental Management, 14:9-23.

Suter, G.W., II. 1993. *Ecological Risk Assessment.* Lewis Publishers, Chelsea, Michigan. 538 pp.

Thornton, K.W., D. E. Hyatt, and C. B. Chapman. 1993. *Environmental Monitoring and Assessment Program Guide.* EPA/620/R-93/012, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Turner, M. G. 1989. *Landscape ecology: the effect of pattern on process.* Ann. Rev. Ecol. Syst., 20:171-197.

Turner, M. G., R. V. O'Neill, R. H. Gardner, and B. T. Milne. 1989. *Effects of changing spatial scale on the analysis of landscape pattern.* Landscape Ecology, 3(3/4):13-162.

Walker, J., F. Bullen, and B. G. Williams. 1993. *Ecohydrological changes in the Murray-Darling Basin. Part I. The number of trees cleared over two centuries.* J. Appl. Ecol., 30:265-273.

Whitcomb, R. F., J. F. Lynch, M. K. Klimkiewicz, C.S. Robbins, B. L. Whitcomb, and D. Bystrak. 1981. *Effects of forest fragmentation on avifauna of the eastern deciduous forest.* Pp. 125-205, In: R.L. Burgess, and D.M. Sharpe (eds.), Forest Island Dynamics in Man-dominated Landscapes. Springer-Verlag, New York.

Wickham, J. D. and K. H. Riitters. *Sensitivity of landscape metrics to pixel size.* International Journal of Remote Sensing. (In press).

Wickham, J. D., and D. J. Norton. 1994. *Mapping and analyzing landscape patterns.* Landscape Ecology, 9(1):7-23.

Wiens, J. 1989. *Spatial scaling in ecology.* Functional Ecology, 3:385-387.

Woodley, S., J. Kay, and G. Francis. 1993. *Ecological Integrity and the Management of Ecosystems.* St. Lucie Press, Ottawa, Canada.

World Commission on Environment and Development (WCED). 1987. *Our Common Future.* Oxford University Press, New York.

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