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LANDSCAPE MONITORING AND ASSESSMENT RESEARCH PLAN

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NOTICE

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EXECUTIVE SUMMARY

INTRODUCTION

Landscape ecology is the study of the structure, function, pattern, and changes in heterogeneous land areas. Landscapes are described by the spatial arrangements of ecological resources. Landscape patterns are an important determinant of the intrinsic sustainability of certain ecological processes that, in turn, provide ecological goods and services (societal values). The Environmental Monitoring and Assessment Program's Landscapes component (EMAP-L) will focus on those landscape patterns that affect flows of energy, water, nutrients, and biota. The primary focus will be on the societal benefits derived from watershed integrity, biotic integrity and diversity, and landscape stability and resilience.

The Landscape Monitoring and Assessment Research Plan is divided into five sections which describe: (1) the theoretical basis (landscape ecology) for monitoring landscapes and how this relates to and complements the objectives of EMAP; (2) the conceptual basis of the approach, including the societal values and assessment questions to be addressed; (3) the indicators of landscape condition; (4) the methods for monitoring and assessing the status and trends of landscape condition; and (5) the research and development activities needed to implement the plan.

RELATIONSHIP OF LANDSCAPE MONITORING TO EMAP OBJECTIVES

The objectives outlined in the Landscape Monitoring and Assessment Research Plan parallel the objectives of EMAP in terms of estimating status and trends in indicators of ecological condition. There is one important distinction: the assessments made by EMAP Resource Groups do not explicitly analyze spatial characteristics among ecological resources because these spatial characteristics are not the primary focus of their assessment questions. EMAP-L, in contrast, has as its key objective the analysis of status and trends in indicators of landscape condition, which includes indicators of the spatial configuration of ecological resources.

Many of the techniques and operational issues relating to EMAP-Landscape Characterization (EMAP-LC) complement those of EMAP-L. EMAP-L and EMAP-LC will continue to collaborate closely to share advances in remote sensing and geographic information system (GIS) technologies, and to achieve economies in implementation of the respective research plans.

PROPOSED METHODS FOR ASSESSING STATUS AND TRENDS IN LANDSCAPE PATTERNS

The plan emphasizes the use of full-coverage, remote sensing and GIS methods rather than ground sample-based methods for use in developing statistical descriptions of landscape status and trends. Synoptic monitoring allows aggregation of landscape data in order to develop statistical descriptions about different landscape configurations (e.g., watersheds as contrasted with landscape pattern types).

An important advantage of the synoptic measures is that they allow EMAP-L to integrate its measurements of landscape patterns with all EMAP Resource Groups that are investigating related ecological values at a finer scale. In so doing, each EMAP Resource Group enhances its interpretive abilities; measurements taken at both the Resource Group scale and the landscape scale are important to understanding the condition of a specific value such as biotic integrity or diversity.

EMAP-L is proposing a three-step approach to monitoring and assessment. The two first steps are conducted to assess status and trends of landscape indicators. EMAP-L's third step is initiated when indicators suggest declining landscape condition.

The first step establishes baseline landscape condition. This is done by calculating landscape indicators from remote sensing imagery, and relating these to societal values. The second step involves satellite-based land cover change detection to update the status of the landscape units established in Step 1. Step 3 involves assessments of association between landscape condition and stressors. This step is invoked in areas undergoing significant landscape change; thresholds of landscape change necessary to trigger a Step 3 analysis have yet to be determined.

RESEARCH AND DEVELOPMENT REQUIRED TO IMPLEMENT THE PLAN

The technical and operational issues that must be resolved in order to implement the proposed landscape monitoring approach include: (1) selecting operational landscape units and scales for conducting assessments; (2) refining the assessment questions that relate the spatial pattern of landscape features to societal values; (3) refining models of landscape patterns and indicators of landscape condition; (4) establishing accuracy objectives for assessment and data quality; (5) selecting and testing indicators of landscape condition; (6) refining criteria to determine when indicators of status, change, and trend warrant evaluation with stressor data (i.e., evaluation of association of observed landscape condition with environmental stressors); and (7) developing a strategy for implementing an EMAP-L program nationwide.

EMAP-L will evaluate the proposed approach by using Landsat Multi-Spectral Scanner (MSS) data to assess 20-year landscape status and change in selected regions. Landsat-MSS data from the early 1970s, mid-1980s and early 1990s are being compiled nationally by the North American Landscape Characterization (NALC) Pathfinder program. Depending on results of evaluations, EMAP-L may conduct retrospective landscape status and trends assessments with a baseline of the early 1970s.

EMAP-L proposes to address these questions through tests of the landscape monitoring approach at pilot areas in the Mid-Atlantic Region-Chesapeake Bay area, and in the western United States (to be determined).

IMPLEMENTATION OF EMAP-L

EMAP-L proposes to implement landscape status and trends assessments within pilot areas for those indicators ready for implementation. Pilot areas will then be expanded to permit reporting by both natural and standard Federal regions within the general area. As landscape indicators pass through sensitivity and uncertainty analyses, they will be added to status and trends assessments. An overall implementation strategy for EMAP-L will be developed within the next three years.

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1.0 INTRODUCTION

1.1 PURPOSE, CONTENT, AND ORGANIZATION OF PLAN

The Landscape Monitoring and Assessment Research Plan presents the theoretical basis for monitoring landscapes and describes a three-step approach for assessing the status, changes, and trends in landscapes nationwide. The plan also highlights research and development needed to implement the program and suggests pilot studies to evaluate, test, and demonstrate the proposed three-step monitoring approach. There are several operational issues, such as data acquisition schedules and data management, that must be resolved in order to implement this approach nationally. However, EMAP-L concluded that the technical approach should be evaluated first, followed by resolution of operational and implementation issues. Therefore, the primary aim of this research plan is to highlight concepts, issues, and approaches related to landscape monitoring and assessments. Operational issues will be treated more fully in an implementation plan for EMAP-L.

The plan is organized into five sections. This section provides background on the objectives and anticipated contributions of EMAP-L. Section 2 discusses issues related to application of EMAP's top-down approach, specifically the relationship between societal values, assessment questions, and conceptual models. Section 2 also provides a brief description of how landscape monitoring might be integrated with monitoring of other EMAP Resource Groups. Section 3 discusses landscape indicators being considered by EMAP-L. Section 4 describes EMAP-L's three-step strategy and proposed methodology for monitoring landscapes. Section 5 describes research and implementation strategies for the program.

1.2 LANDSCAPE ECOLOGY - THE THEORETICAL FOUNDATION FOR MONITORING LANDSCAPES

In the last decade, the field of landscape ecology has been recognized within the U.S. as a key integrating scientific discipline needed to make the concept of ecosystem management viable and operational. For example, many Federal agencies (e.g., U.S. Forest Service, Bureau of Land Management, the U.S. Fish and Wildlife Service) with land management responsibilities have landscape ecologists on their staff, and the discipline's role in agency activities is evident within their organizational structure. Similarly, recent public debate regarding the U.S. Forest Service's management of forest lands in the Pacific Northwest resulted in a landmark application of the principles of landscape ecology and ecosystem management to assess forest ecosystem health and to develop alternative management strategies (Everett et al. 1993).

The phrase "landscape ecology" was coined in 1939 by German geographer Carl Troll, who made widespread use of the new technique of aerial photography. Troll intended that his phrase, landscape ecology, would distinguish his proposed approach for using such imagery to interpret the interaction of water, land surfaces, soil, vegetation, and land use from that of conventional photographic interpretation and cartography (Golley 1993). It has been studied and applied in Europe for many decades and became generally recognized within the U.S. about 1980. Since then, landscape ecology has rapidly evolved as a discipline, spurred by synergistic interactions between remote sensing and GIS techniques and advances in ecological theory and its field applications (Golley 1993).

Landscape ecology can be defined as the study of the structure, function, and changes in heterogeneous land areas composed of interacting organisms (Jensen and Bourgeron 1993). Landscape ecology may be considered as the study of the interaction between landscape patterns and ecological processes, specifically the influence of landscape pattern on the flows of water, energy, nutrients, and biota (Turner 1989). What distinguishes landscape ecology from the many separate disciplines that it embraces (e.g., geography, biology, ecology, hydrology) is that it provides a hierarchical framework for interpreting ecological structure, function, change, and resiliency at multiple scales of inquiry.

Hierarchy theory states that landscapes are organized into patterns within a hierarchy of spatial and temporal scales. Numerous ecological and anthropogenic disturbances (e.g., flooding, fires, clearing of vegetation) maintain landscape patterns or set into motion the creation of new landscape patterns. These disturbance events also occur across a range of spatial and temporal scales (Jensen and Everett 1993).

Traditional measures to protect the environment — such as preventing water pollution or protecting biodiversity — have tended to focus on specific effluent discharges or fine-scale habitat requirements. This method has been described as the "fine-filter" approach. In contrast, the "coarse-filter" approach to resource conservation states that "by managing aggregates (e.g., communities, ecosystems, landscapes), the components of these aggregates will be managed as well" (Bourgeron and Jensen 1993). In other words, the most cost-effective strategy to maintain the resiliency and productivity of ecological systems is to conserve (or restore) the diversity of species, ecosystem processes, and landscape patterns that create the systems (Jensen and Everett 1993, Bourgeron and Jensen 1993). Applying this "coarse-filter" management method requires that landscape patterns be evaluated at multiple spatial and temporal scales, rather than simply at the traditional scales of stream reach or forest stand (Jensen and Everett 1993, Milne 1993, Minshall 1993, Hann et al. 1993, Bailey et al. 1993).

Hierarchy theory allows us to integrate multiple scales of information to determine whether landscape patterns are sufficient to allow ecological processes to operate at the necessary scales. The objective is to investigate changes in the distribution, dominance, and connectivity of ecosystem components and the effect of these changes on ecological and biological resources (Turner and Ruscher 1988, Golley 1989, Forman 1990, Saunders et al. 1991). Ecosystem fragmentation has been implicated in decline of biological diversity and ecosystem sustainability at a number of spatial scales (Forman 1990, Flather et al. 1992, Soule et al. 1992, Van Der Zee et al. 1992, Wilson 1988). Determining status and trends in the pattern of landscapes is critical to understanding the overall condition of ecological resources (Urban et al. 1987, Turner 1989, Forman 1990, Gosselink et al. 1990, Graham et al. 1991, Schlosser 1991, O'Neill et al. 1992a). Landscape patterns thus provide a set of indicators (e.g., pattern shape, dominance, connectivity, configuration) that can be used to assess ecological status and trends at a variety of scales.

A hierarchical framework also permits two important types of comparisons: (1) to compare conditions within and across landscapes and (2) to compare conditions across different types of ecological risks. Such ecological risks include, for example: the risk of erosion, the loss of soil productivity, loss of hydrologic function, and expectations regarding the conservation of biological diversity (Hann et al. 1993).

Applying the principles of landscape ecology requires an understanding of the natural variability of landscape patterns and processes across both space and time. Estimates of this variability are essential to determining whether the current condition of a landscape is sustainable, given its historic patterns and processes (Jensen and Everett 1993). Moreover, descriptions of landscape variability have proven extremely useful in both broad-level assessment of risk to resources, as well as to finer-scale assessments, similar to those ongoing or planned by EMAP Resource Groups (Jensen and Everett 1993, Hann et al. 1993, Shlisky 1993).

Although the objectives of EMAP-L parallel the objectives of the EMAP Resource Groups, EMAP-L seeks specifically to:

1) Estimate, on a regional basis and with known confidence, the current status, trends, and changes in selected indicators of the Nation's landscapes.
2) Estimate with known confidence the geographic coverage and extent of the Nation's landscapes patterns and types.
3) Seek associations between selected indicators of natural and anthropogenic stressors and indicators of landscape condition.
4) Provide statistical summaries and periodic assessments of the condition of the Nation's landscapes.

2.0 SOCIETAL VALUES, ASSESSMENT QUESTIONS, MODELS, AND INTEGRATION WITH OTHER EMAP RESOURCE GROUPS

2.1 GENERAL APPROACH

EMAP's top-down approach is used by EMAP-L as the framework for testing and implementing a landscape monitoring approach. This framework is based on the following steps:

1) identify societal values related to landscape ecological patterns and processes;
2) formulate assessment questions that relate to societal values;
3) develop conceptual models that relate values to ecological function, structure and composition, such that candidate indicators can be identified;
4) identify candidate indicators and sampling designs that relate to assessment questions;
5) test selected indicators by evaluating each against a set of criteria through simulations, field tests, and other analyses;
6) select indicators and sampling design and implement them;
7) continually reassess implemented indicators and sampling designs and bring in (or substitute) new indicators (where and when appropriate).

The key to this process is linking societal values and associated assessment questions to indicators through conceptual models. This increases the probability that data collected on landscape condition are relevant to societal values and key ecological components and processes of landscapes.

2.2 SOCIETAL VALUES TO BE ADDRESSED BY EMAP-L

The motivation for monitoring status and trends in landscapes comes from our desire, as a society, to maintain a wise stewardship of the environment. Our stewardship focuses on specific "values," i.e., properties of the intact landscape that provide services to society and that we wish to maintain. Preserving these values, in turn, requires that we understand the linkage between these services and the spatial pattern of landscapes.

Ecological processes occur within the context of, and are dependent on, the scaled spatial pattern of landscapes (Forman and Godron 1986, O'Neill et al. 1991a,b). If the pattern is disrupted, the underlying biotic processes that depend on the spatial pattern will be disrupted. We develop these concepts by examining three landscape values and showing how preserving these values can be linked to monitoring specific aspects of landscape pattern.

2.2.1 Biotic Integrity and Diversity

Because they provide aesthetics, recreation, and life-support, society values intact biotic communities. Society must also preserve a diversity of genetic material for future biotechnologies, medical applications, and stability.

The link between landscape pattern and intact ecological communities is well established. In fact, community interactions often produce the pattern. Levin (1976, 1978) showed than predator-prey interactions, combined with spatial movement of the populations, can result in patchy spatial distributions. Paine and Levin (1981) demonstrated that disturbance-recovery also produces a patterned landscape.

In turn, spatial pattern impacts the way consumers move on the landscape (Wiens and Milne 1989) and utilize resources (O'Neill et al. 1988b). Species coexistence also depends on spatial pattern (Shmida and Ellner 1984). Dispersal processes interact with pattern to separate competitors in space (Comins and Noble 1985, Geritz et al. 1987) and permit coexistence. This relationship has been shown for both animals (Kareiva 1986) and plants (Pacala 1987).

The most important cause of species loss and subsequent reduction in species diversity is the loss of habitat. As critical habitat is lost, the remaining habitat becomes fragmented and isolated. Fragmentation increases with the loss of corridors between patches of natural habitat (Forman and Godron 1986, Harris and Gallagher 1989).

Connected habitat allows exchange of genetic material among local populations. As corridors are lost and habitat becomes disconnected, local populations can become extinct due to disturbance (Saunders et al. 1991, Lovejoy et al. 1986, Wiens 1985). As a result, the simplest way to monitor potential change in biodiversity is to measure trends in the patch distribution of natural vegetation cover through time.

2.2.2 Watershed Integrity

Another societal value is the landscape's ability to collect, retain, store, and purify water. In addition, intact landscapes control flooding and conserve soil. Decrease in natural vegetation across a landscape, therefore, indicates a potential for future water quality problems (Hunsaker et al. 1992).

Land cover on watersheds and hydrologic processes are linked closely (reviews by Whitmore and Ice 1984, Levine 1992). The physical relationships have been established for more than a decade (Donigian et al 1977, Knisel 1980, McElroy et al 1976, Anonymous 1980).

The theory has been well tested in multivariate empirical studies (see reviews by Berry and Sailor 1987, Regan and Fellows 1980, Levine 1992). The empirical studies often are linked with the Universal Soil Loss Equation (DelRegno and Atkinson 1988, Shanholtz et al. 1988, Hession and Shanholtz 1988, Levine and Jones 1990) to deal with erosion.

Changes in land cover adjacent to streams have an immediate impact on the efficiency of these buffer strips (Phillips 1989a,b, Magette et al. 1989, Naiman and Decamps 1990). The linkage between these intact riparian zones and water quality is well-established at the watershed level (Karr and Schlosser 1978, Schlosser and Karr 1981a,b, Lowrance et al. 1983, 1984, 1985, Peterjohn and Correll 1984).

2.2.3 Landscape Sustainability and Resilience

Because of the many services rendered by intact landscapes, society values an environment that maintains its own integrity (i.e., sustainable) and recovers from disturbances (i.e., resilient). Discovery of the relationship between landscape pattern and sustainability is a relatively new development in landscape ecology (Turner 1987b, 1989). However, percolation theory (Gardner et al. 1989) provides an important link between landscape connectivity and the potential for disturbance spread (White 1979, Runkle 1985). Epidemiology theory can be combined with percolation theory to calculate the probability that a disturbance will spread or become endemic (O'Neill et al. 1992a).

As pattern is disrupted and landscape fragmentation increases, distances increase between disturbed sites and source areas. The source areas provide seeds and reservoirs of animal populations needed for recovery. We know that northern hardwoods take 60-80 years to replace biomass and nutrients lost in harvesting (Likens et al. 1978). This recovery time is significantly increased if distances to seed sources are increased or erosion sets in. Therefore, resilience can be closely related to the frequency distribution of distances between patches.

We know from tragic experience in the American plains and the African Sahel that critical thresholds exist in landscape pattern. Beyond these thresholds, cascading effects or positive feedbacks cause bifurcations that move the system into undesirable modes of operation (Schlesinger et al. 1990).

Empirical studies (Turner et al. 1991, O'Neill et al. 1991a,b) have demonstrated that landscapes show a pattern at multiple scales. Disruption of this scaled structure means that ecological processes dependent on a particular scale have been disrupted. For example, Holling (1992) has established a relationship between scales of pattern and guilds of vertebrates. Monitoring the status and trends in these spatial scales thus has direct implication for the sustainability of vertebrate community structure.

2.3 ASSESSMENT QUESTIONS

Assessment questions bound the scope of the landscape monitoring program and define the components of each value to be assessed. For example, biotic diversity is a broad societal value; formulation of assessment questions refine the components of biotic diversity to be investigated by EMAP-L. The following are examples of broad assessment questions that EMAP-L proposes to address relative to each landscape value:

What are the proportions and geographic distributions of landscapes with acceptable biotic integrity and diversity? How are these changing?

What are the proportions and geographic distributions of watersheds with acceptable ability to collect, retain, store, and purify water? How are these changing?

What are the proportions and geographic distributions of watersheds (or other natural landscape units) with acceptable landscape stability and resilience? How are these changing?

The following are examples of a more specific set of assessment questions that relate to each landscape value. This set of assessment questions helps bound the scope of landscape monitoring as questions are more closely related to indicators of landscape condition.

2.3.1 Biotic Integrity and Diversity

What is the number, area, and distribution of landscape types by region?

What are the relative proportions of forest, grassland, etc., by landscape type and how have they changed between t_1 *and* t_2*? What is the distribution of change?*

What are the relative proportions of natural and man-made landscapes by region and how have these proportions changed? What is the distribution of change?

What proportion of landscapes has significantly changed connectivity and what is the distribution of those landscapes?

What proportion of landscapes has significantly changed shape complexity and what is the distribution of those landscapes?

What proportion of landscapes has lost more than 25 percent of one cover type and what is the distribution of those landscapes?

What proportion of landscapes has altered frequency distribution of habitat patches and what is the distribution of those landscapes?

2.3.2 Watershed Integrity

What is the current status of watersheds, by region, relative to their ability to store and convey water, control floods, and conserve soils?

What percentage of watersheds has increased/decreased their ability to store and convey water supplies from t_1 *to* t_2 *and what is the distribution of those landscapes?*

What percentage of watersheds has increased/decreased their ability to control floods and conserve soil from t_1 *to* t_2 *and what is the distribution of those watersheds?*

What percentage of watersheds has diminished water storage capacity of those watersheds and what is the distribution of those watersheds?

What percentage of watersheds has greater than a critical area of impervious land cover and what is the distribution of those watersheds?

What percentage of watersheds has potential for erosion exceeding tolerable limits and what is the distribution of those watersheds?

2.3.3 Landscape Sustainability and Resilience

What are the proportions of landscapes with significantly reduced sustainability due to loss of natural land cover and what is the distribution of those landscapes.?

Which cover types have undergone the greatest change in connectivity from t_1 *to* t_2 *and what is their distribution?*

What proportion of landscapes is approaching critical thresholds that endanger sustainability and what is the distribution of those landscapes?

What proportion of landscapes has lost critical scales of pattern and what is the distribution of those landscapes?

What proportion of landscapes has altered recovery ability by critically increasing distance to seed sources and what is the distribution of those landscapes?

Finally, EMAP-L will develop a specific set of assessment questions relative to associations between landscape condition and stressors, as well as to associations between landscape condition and other ecological resources (e.g., plant and animal richness). The following are examples of these types of questions:

What is the spatial distribution of changes in cover type and are changes associated with changes in plant and animal species richness?

What is the relationship between landscapes with low connectivity of natural cover types and forest productivity?

What is the relationship between landscapes with low connectivity of natural cover types and stream benthic condition?

What is the relationship between landscapes with low connectivity and the type, distribution, and magnitude of land use?

What proportion of landscapes has significantly increased probability of pest dispersal and what is the distribution of those landscapes?

What proportion of landscapes has significantly increased risk of disturbance (e.g., fire) and what is the distribution of those landscapes?

In order for EMAP-L to address conditions of landscapes relative to each value, EMAP-L must establish a set of thresholds relative to landscape indicators. For example, thresholds for indicators of watershed integrity must be established in order to identify those watersheds that have integrity versus those that do not. EMAP-L recognizes that these thresholds may vary between regions of the United States. Identification of condition thresholds for landscape indicators is a primary research area for EMAP-L.

2.4 LANDSCAPE CONCEPTUAL MODELS

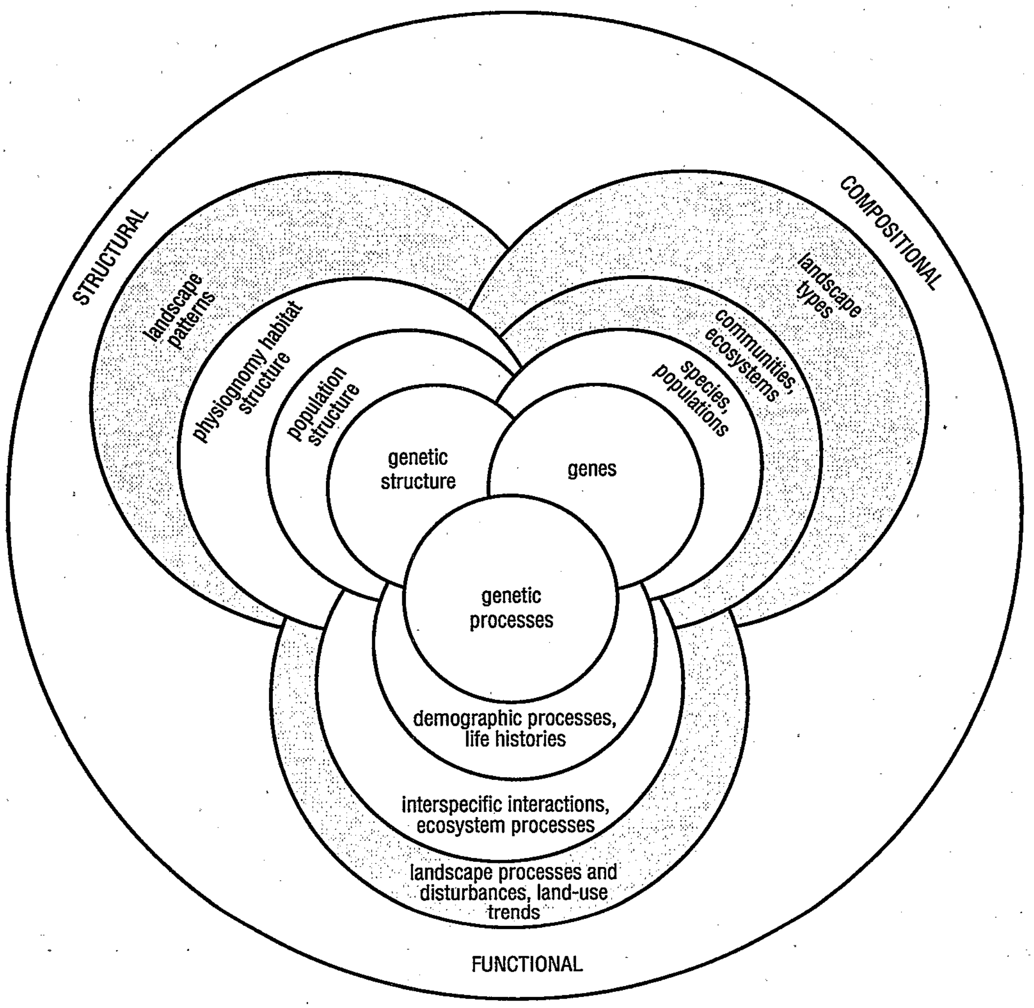
Conceptual models link indicators to societal values. The definitions or descriptions of the societal values (biotic integrity and diversity, watershed integrity, and landscape sustainability and resiliency) provide some insight into measurements that could be used to represent them. For example, defining watershed integrity as the ability to collect, retain, store and purify water suggests that measurements of soil and vegetation will be used to support watershed integrity. The conceptual models provide a framework for identifying the specific indicators to be measured and scales of concern. A general conceptual model is illustrated for each landscape value listed below. We propose to refine these models through a series of workshops, as well as from data gathered in pilots (see Section 5).

2.4.1 Biotic Integrity and Diversity

Biodiversity is defined by the Office of Technology Assessment (1987) as "the variety and variability among living organisms and the ecological complexes in which they occur." This is a commonly cited definition of biodiversity (Noss 1990, see also Stoms and Estes 1993). It is insightful because it acknowledges the value of ecological complexes in their own right not necessarily linked to living organisms. Examining the diversity of ecological complexes is the appropriate level of organization for EMAP-L.

Our conceptual model of biodiversity (Figure 2.1) is from Noss (1990). It presents biodiversity as four levels of organization (genes, species, communities, and landscapes) divided into compositional, structural, and functional components, which are the primary components of an ecosystem (Franklin et al. 1981).

The conceptual model helps to identify the specific indicators to measure landscape biodiversity. Landscape composition and configuration influence the number and types of plants and animals that can inhabit an area (Saunders et al., 1991). Indicators of landscape composition include number and proportion of cover types, including the number and proportion of natural cover types in a watershed. The presence of riparian habitat is likely "keystone" in



Indicators

	Composition	***Structure***	***Function***	***Inventory and monitoring tools***
Regional Landscape	Indentity, distribution, richness, and proportions of patch (habitat) types and multipatch landscape types; collective patterns of species distributions (richness, endemism)	Heterogeneity; connectivity; spatial linkage; patchiness; porosity; contrast; grain size; fragmentation; configuration; juxtaposition; patch size frequency distribution; perimeter-area ratio; pattern of habitat layer distribution	Disturbance processes (areal extent, frequency or return interval, rotation period, predictability, intensity, severity, seasonality); nutrient cycling rates; energy flow rates; path persistence and turnover rates; rates of erosion and geomorphic and hydrologic processes; human land-use trends	Aerial photographs (satellite and conventional aircraft) and other remote sensing data; Geographic Information System (GIS) technology; time series analysis; spatial statistics; mathematical indices (of pattern, heterogeneity, connectivity, layering, diversity, edge, morphology, auto-correlation, fractal dimension)

Figure 2.1 Conceptual model of biodiversity hierarchy

affording high biodiversity of flora and fauna. Riparian corridors are structurally complex ecosystems that support high biodiversity (Odum 1978, Gregory et al. 1990, Naiman et al. 1993), especially in the arid, western United States (Thomas et al. 1979). Indicators of structure include heterogeneity (e.g., the number of different natural cover types surrounding a point), edge-to-area ratios, and interpatch distance (by cover type).

Measures of landscape function are admittedly less straightforward, primarily because they involve measurement over time or some predictive ability. Measures of percolation, e.g., the measure of connectivity of a cover type, (Gardner et al. 1992) permit hypothesis testing of variability in disturbance regimes. Measures of patch persistence will also be useful. Loucks (1970) pointed out that the niche of a species has a temporal domain. Land cover transition matrices can be created to determine patch persistence. An example land cover transition matrix is provided by Hall et al. (1991a) (Table 2.1).

2.4.2 Watershed Integrity

EMAP-L has defined watershed integrity as the ability to collect, retain, store, and purify water. The conceptual model (Figure 2.2, from B. Richter, The Nature Conservancy, personal communications) shows the important categories of indicators to measure on watersheds. As indicated by Figure 2.2, land cover is the primary driving force behind a watershed or other area of land to maintain its ability to process water.

Slope, vegetation, and land cover provide data to measure the ability to collect, retain, and store water. Aspects of collection, retention, and storage of water can be measured by combinations of slope and land use (e.g., agriculture on excessive slopes). Agriculture on slopes greater than three percent increases risk of erosion (USDA 1951). Erosion estimates are available through the U.S. Soil Conservation Service National Resources Inventory (NRI) program.

Measurements of riparian habitat may be the most useful gauge of natural water purification. Riparian habitat has been shown to function as a “sponge,” and prevents excess runoff of nutrients and chemicals into streams (Peterjohn and Correll 1984, Lowrance et al. 1984, Schlosser and Karr 1981a,b). Peterjohn and Correll (1984) note that the ability of riparian forests to retard and store excess runoff is likely a universal effect. Simple presence of vegetation adjacent to water is a potential indicator of all four aspects of watershed integrity (collection, retention, storage, and purification).

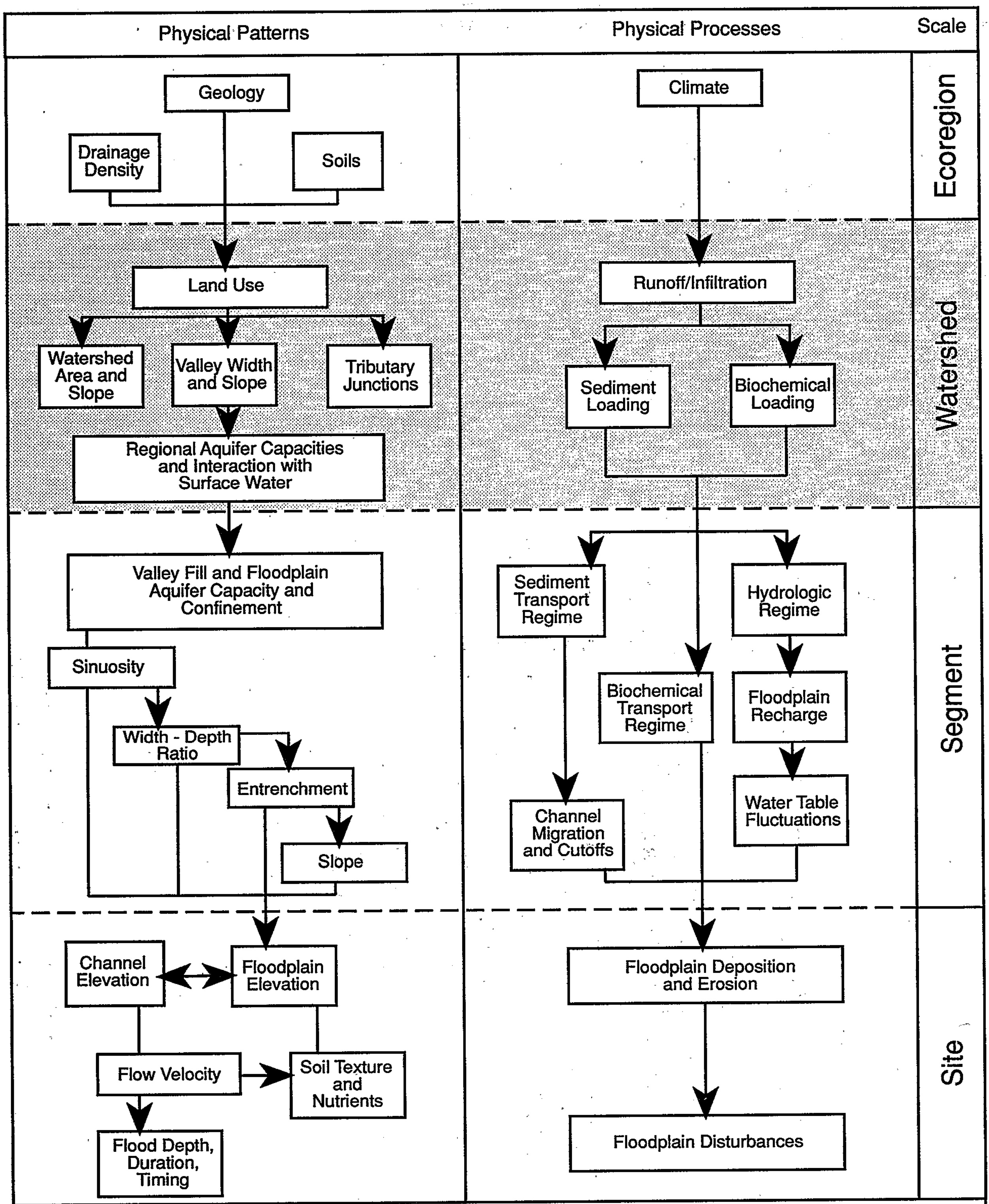
2.4.3 Landscape Sustainability and Resilience

The conceptual model for landscape sustainability and resilience is based on combining the three primary ecosystem attributes of Franklin et al. (1981) with the concepts of state and transition and resilience from Holling (1973). The model is illustrated in Figure 2.3. The composition, structure, and function add up to define the ecosystem state. Under natural conditions, the ecosystem can be conceived as occupying N possible states, within which it varies over time (these are considered normal or typical states). These N possible states comprise a dynamic

Table 2.1 Example of a Land-Use Change Matrix

	1983 State					
1973 state	Clrng	Rgnrt	Brdlf	Mixed	Cnfr	Other
Clearings	*17.09*	45.54	16.72	15.20	5.22	0.12
Regenerating	4.55	*30.83*	16.93	37.27	10.03	0.36
Broadleaf	1.12	19.72	*47.06*	27.61	4.16	0.28
Mixed	0.52	6.81	11.28	*58.11*	22.55	0.72
Conifer	1.04	4.37	1.81	31.02	*57.80*	3.93
Other	0.53	3.14	3.19	8.60	13.38	*71.06*

Note: The italicized numbers are retention frequencies.



Source: Modified from B. Richter, Western Regional Office, The Nature Conservancy.

Figure 2.2 Conceptual model of hydrologic functions

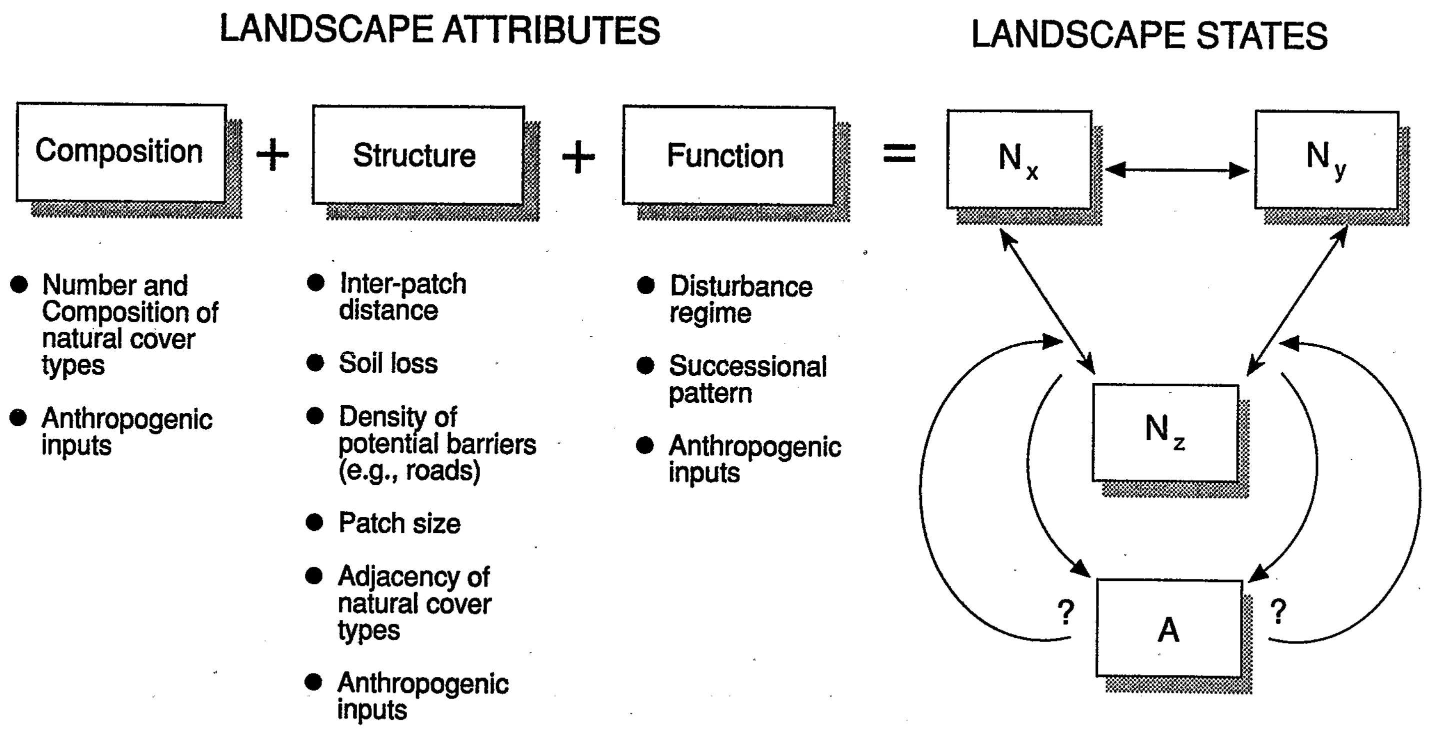


Figure 2.3 Conceptual model of landscape sustainability and resilience

stability (Sprugel and Bormann 1981), which, in effect, defines sustainability. Disturbances pass through the ecosystem over time causing the transition to a new ecological state. Resilience is the ability of the ecosystem to take on a new state within the range of normal or typical states following disturbance.

The dashed line to an altered ecological state highlights the possibility that disturbances (presumably anthropogenic ones) have caused a transition to an "altered" ecological state, and that transition back to one of the normal or typical ecological states is perhaps either not probable or possible.

Several indicator categories are listed under the compositional, structural, and functional ecosystem components, which measure aspects of landscape sustainability and resilience as described herein. The number and distribution of natural cover types within the landscape measures an aspect of landscape stability and resilience because imposition of barriers between these patches hinders dispersal between the patches. This measure of composition could be combined with measures of structure such as inter-patch distance edge to area ratio, and patch size distribution. The land cover transition matrix introduced above under the discussion of biodiversity would serve as an indicator of landscape sustainability and resilience for the functional component of the ecosystem. Indicators derived from percolation theory (Gardner et al. 1989) would also fall under the functional ecosystem component.

Several examples illustrate how these indicators could be used to address landscape stability and resilience. Prior to settlement, the eastern United States was largely forested (Whittaker 1975). Fragmentation of forests into smaller, more isolated patches creates a source/sink gradient for dispersal of propagules needed to maintain succession. An abundance of small forest patches at high inter-patch distances would indicate that forest successional patterns could not be maintained.

Grover and Musick (1990) have shown how grazing practices and climate have interacted to create excessive soil erosion. As a result of the grazing intensity and climate scenario, shrub encroached on natural grasslands in the Southwest. Shrubland encroachment, in turn, caused accelerated eolian erosion, which has prevented the return of grasslands (and artificially maintained shrublands) even in the absence of grazing pressure.

The study by Grover and Musick highlights the introduction of an "altered" state shown in the conceptual model. Grazing pressure, soil loss, and vegetation were the inputs into indicators that were used for this study. Each of these can be measured by EMAP-L. Grazing pressure can be estimated from the Department of Commerce, Census of Agriculture, and livestock inventories (by county); soil loss can be estimated from NRI data; and vegetation can be measured from land cover and remote sensor data.

2.5 INTEGRATION WITH EMAP RESOURCE GROUPS

Biotic integrity and diversity, watershed integrity, and landscape sustainability and resiliency are umbrella values that are relevant to both a landscape monitoring program and the individual EMAP Resource Groups. For example, EMAP-Forests is interested in status and trends of indicators of forest habitat structure relating to breeding birds. EMAP-Surface Waters is interested in the biotic condition of streams. EMAP-Landscapes is interested in landscape condition (e.g., pattern indicators) relating to biotic integrity. Individual resource group values of biotic integrity are nested within a landscape. Indeed, streams, wetlands, forests, agroecosystems, and arid ecosystems are all nested within a landscape (although not all of them always in one place). Because of this spatial nesting, landscape condition indicators are often viewed as stressor indicators at the individual ecological resource level. For example, EMAP-L considers the degree of connectivity as a landscape condition relevant to biotic diversity, whereas EMAP-Forests might view this as a stressor (e.g., fragmentation) associated with condition of forests at the plot level. However, EMAP-Forests also is interested in landscape conditions within and around forest patches to gain greater insight into forest sustainability.

Despite some of these differences, status and trends in indicators at both scales (e.g, resource groups and landscapes) are necessary to address biotic diversity at a regional scale. Figure 2.4 provides an example of this relationship. In this example, the basic value is biotic diversity, but the assessment questions specifically relate to a component of biotic diversity, breeding bird habitat. One assessment question deals with horizontal and vertical structure

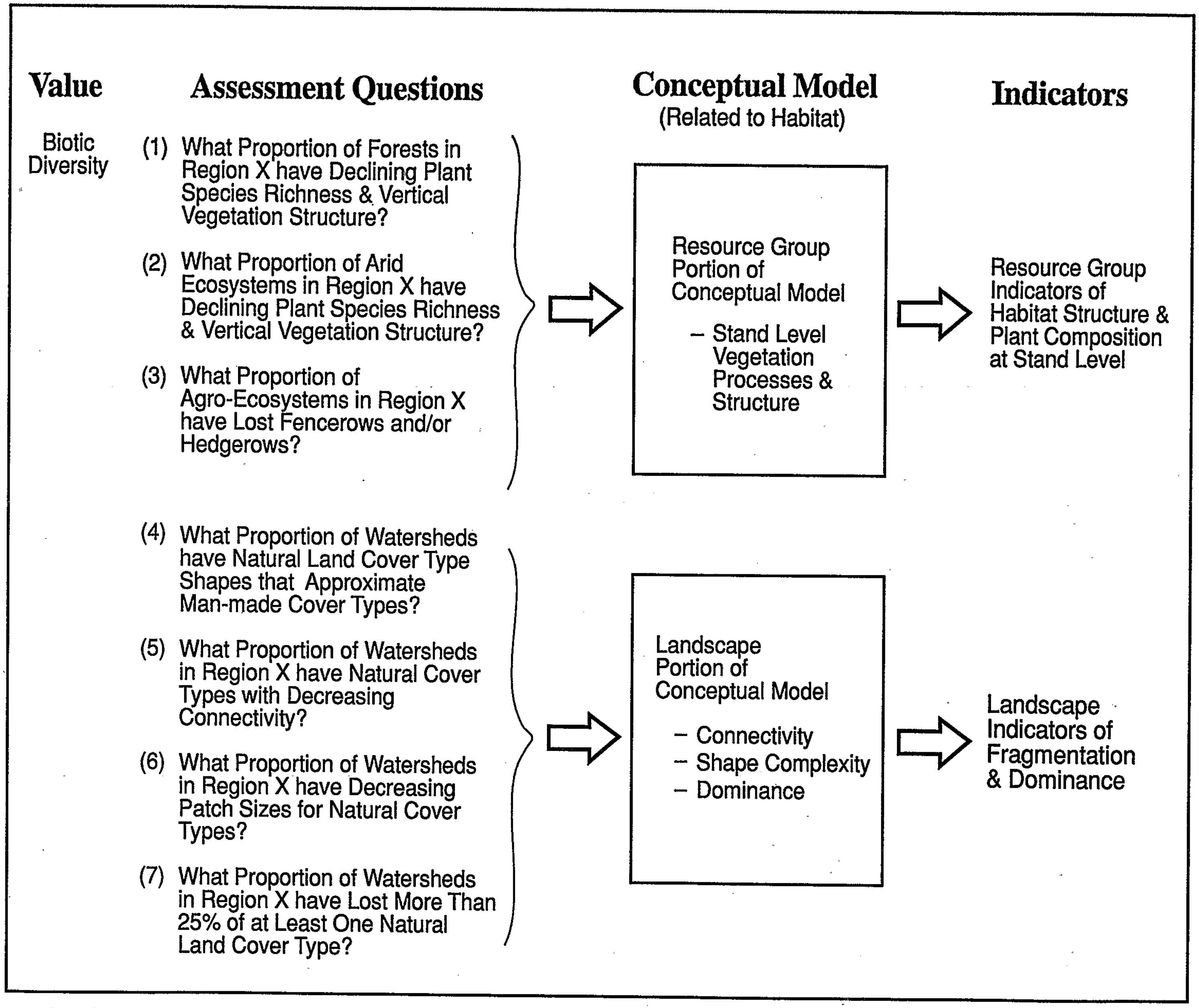


Figure 2.4 Conceptual Framework Relating EMAP-L to EMAP Resource Groups

at the "stand" or "patch" level and the other with spatial configuration of ecological resources at a landscape level. The conceptual model suggests (although not illustrated in this case) that both scales are important in determining the quality of breeding bird habitat. Therefore, habitat measurements are necessary at both scales to determine status and trends in breeding bird habitats. In this example, a series of common habitat measurements (or at least those that could be normalized) could be implemented among EMAP Resource Groups in order to address the stand-level assessment questions, whereas certain landscape metrics must be calculated in order to address the landscape-level assessment questions. Figure 2.4 thus expands the general top-down approach of EMAP (see earlier discussion) into a framework for integrating monitoring approaches among EMAP Resource Groups and EMAP-L. Such an approach could be used to address other common societal values.

3.0 INDICATORS OF LANDSCAPE STATUS AND TRENDS

Some indicators will be used to quantify landscape status and trends or identify areas undergoing significant change. Others will be used for in-depth assessments.

Candidate indicators represent a spectrum from fully field-tested to preliminary concepts. We have organized the presentation into three sections. The criteria by which the indicators will be evaluated is discussed in Section 5.

3.1 INDICATORS OF BIOTIC INTEGRITY AND DIVERSITY

Landscape monitoring can contribute to our understanding of status and trends in biodiversity by addressing changes in the configuration of habitats. The simplest indicator considers the number of pixels that show changes in land cover. Changes in natural vegetation cover reflect loss or gain of wildlife habitat. Attention will be focused on specific transitions, such as the loss of rare land cover types (e.g., sky island forests of the Southwest).

O'Neill et al. (1992b) present a list of rare and endangered species in southeastern United States that are uniquely dependent on a habitat type. A portion of the list is reproduced in Table 3.1. In specific regions, such as central Florida, the loss of sandy scrub habitat permits an immediate indicator of habitat status and trends relative to endangered species.

Table 3.1 Endangered Species of the Southeastern U.S.A. by Habitat

Sandy Pine/Oak Scrub (Central Florida)
Florida Scrub Jay (Aphelocoma c. coerulescens)
Eastern Indigo Snake (Drymarchon corais couperi)
Blue-tailed Mole Skink (Eumeces egregius lividus)
Sand Skink (Neoseps reynoldsi)
Wide-leaf Warea (Warea amplexifolia)
Four-petalled Pawpaw (Asimina tetramera)
Florida Bonamia (Bonamia grandiflora)
Pygmy Fringe Tree (Chionanthus pygmaeus)
Florida Golden Aster (Chrysopsis floridana)
Scrub Lupine (Lupinus aridorum)
Scrub Plum (Prunus geniculata)
Scrub Mint (Dicenandra fruteaceus)
Snakeroot (Erygium cuneifolum)
Lakelas Mint (Dicerandra immaculata)
Highland Scrub Hypernicum (Hypernicum cumulicola)
Papery Whitlow-wort (Paronychia charactacea)
Wireweed (Polygonella basiramia)
Carter's Mustard (Warea carteri)

Mature Oak-Hickory Hardwoods
Large-flowered skullcap (Scutellaria montana)

Prairie/Savannah Arkansas
Geocarpon minimum

Salt Marsh
Atlantic Salt Marsh Snake (Nerodia f. taeniata)

Pine-Grass Ecotone
Gopher Tortoise (Gopherus polyphemus)
Rough-leaved Loosestrife (Lysimachia asperulaefolia)

Conifer-Hardwood Ecotone
Carolina Northern Flying Squirrel (Glaucomys s. coloratus)

Scrub-Agriculture Ecotone
Florida Grasshopper Sparrow (Ammodramus s. floridanus)

Riparian-Hardwood Ecotone
Indiana Bat (Myotis sodalis)

Granite Outcrops
Granite Snapdragon (Amphianthus pusillus)
Quillwort (Isoetes melanospora)
Quillwort (Isoetes tegetiformans)

We would also be concerned with the status and trends in indicators of landscape pattern. We will focus on aspects of pattern that are known to influence biodiversity. For example, we will follow changes in landscape connectivity as reflected in loss of corridors between patches of natural habitat (Forman and Godron 1986, Harris and Gallagher 1989). A number of field studies have shown that wildlife utilize these corridors to move between resource patches (e.g., Mwalyosi 1991).

The length of edges adjacent to natural patches can also be related to status of the landscape relative to wildlife (Correll 1991, Gardner et al. 1991, Turner et al. 1991). In general, loss of edge results in decreased biodiversity (Wilson 1988). Edges often form unique habitats that may be associated with rare and endangered species (O'Neill et al. 1992b).

It is also relevant to examine the relationship of edges to patch size. For example, cowbirds on forest edges are nest predators on warblers (Harris 1988, Terborgh 1992). Forest patches have to be sufficiently large so that nest sites are far away from edges and cowbirds cannot find them. If patches get too small, warbler populations start to decline. Therefore, it will be important to quantify status and trends in patch size distributions.

Much of what we understand about the influence of landscape pattern on ecological processes is based on patch configuration (Kareiva 1986, Franklin and Forman 1987). For example, the frequency distribution of patch sizes can be important because some species require a minimal patch size. As the distribution of patch sizes changes, the landscape becomes more hospitable to some species and less hospitable to others.

The largest habitat patch may also serve as a reservoir that maintains a population on the landscape. Fragmentation of a landscape into many isolated patches has been shown to reduce biodiversity (Bierregaard 1990, Gardner et al. in press, Saunders et al. 1991, Lovejoy et al. 1986, Wiens 1985). Therefore, we will follow changes in the largest patch size.

It would also be useful to monitor the frequency distribution of distances between patches. These nearest-neighbor distances are related to the difficulty experienced by wildlife moving across the landscape.

Some spatial arrangements of patches may be particularly vulnerable to fragmentation. Isolated habitat may be configured in a longitudinal pattern, like a string of pearls. Examples include alpine tundra along ridgetops of the Rockies, dune vegetation along beaches, and granite outcrops. Disruption of linear patch configurations, by removal of a single patch, may split in two the entire habitat if the gap exceeds the dispersal ability of the populations. We will develop an indicator that will quantify the status and trends of these spatial configurations.

One method to assess a land cover would be to ask: "What is the current status of land cover, compared to its potential?" This suggests an index that compares each pixel with overlying maps of potential vegetation cover (e.g., Küchler 1964) and calculates trends in the difference.

It is also possible to quantify status and trends in landscape potential for specific wildlife (see Danielson 1992). Consider a square "window," the size of an organism's home range. Within the window we could consider a variety of habitat requirements, such as vegetation mixture, edge, and available water. We could then place the window over a corner of the landscape map and determine if the land covers within the window met all habitat requirements. The window could then be moved systematically over the map to obtain an overall indicator of the status of the landscape for this organism. We could design a suite of windows for insects, birds, mammals, etc. This approach provides a simple indicator of status and trends that could be interpreted in terms of the impact on animals of a change in landscape pattern.

Another indicator of the impact of land cover changes on wildlife would be miles of new roads. In addition to fragmenting the landscape, roads have an immediate impact on wildlife mortality.

Percolation theory (Stauffer 1985) provides a framework for relating landscape pattern to the ability of an organism to move across the landscape (Gardner et al. 1987). Diffusion rates can be calculated and interpreted in terms of wildlife utilization or disturbance spread. The percolation backbone defines the fewest steps needed to traverse the landscape.

Percolation theory also defines percolation thresholds of habitat coverage (Gardner et al. 1992). On a random square lattice, the critical value is 59.28 percent. If percent cover for habitat is less than this value, the landscape becomes dissected into isolated patches. Resource utilization scale measures the scale at which an organism must operate to utilize the resources on a landscape (O'Neill et al. 1988b). Percolation theory thus suggests several indicators of landscape status and trends.

Empirical studies (O'Neill et al. 1991a,b) have confirmed the prediction from Hierarchy Theory

(O'Neill et al. 1986, O'Neill 1988, 1989, O'Neill et al. 1989) that landscapes should show pattern at distinct scales. This approach uses statistical analysis of transect data to identify multiple scales of pattern (S. Turner et al. 1991). Disruption of this scaled structure means that ecological processes determining a particular scale have been disrupted. We will monitor the status and trends of landscapes by quantifying the number of scales extracted from the remote imagery.

Recently, Holling (1992) has established a relationship between landscape scales and vertebrates. Because of the close relationship between vertebrate body size and home range, Holling was able to establish that clusters of body sizes can be directly related to landscape scales. Holling's work makes it possible to relate the loss of a landscape scale to the risk of losing a guild of vertebrates that are dependent on that specific scale of resource distribution.

One of the most recent, and most sophisticated, indicators of wildlife use utilizes the concept of cellular automata. This involves an imaginary organism, or automaton, that moves across the landscape, one pixel at a time. The automaton moves randomly, but never moves backward. The organism steps freely (probability = 1.0) onto natural vegetation, and moves less freely (probability << 1.0) across clearing, agriculture, or other land uses. By releasing 1,000 automata, allowing each to take 1,000 steps and recording the number of times a pixel is visited, it is possible to evaluate how organisms will utilize a landscape configuration. This approach is particularly valuable for identifying gaps or clearings that are likely to be heavily used.

Another indicator of landscape status and trends can be developed by weighting individual pixel transitions. One might, for example, apply a greater weight to a transition that fragments a large patch. Similarly, a transition could be weighted by the probability of forming a barrier to animal movement or breaking up a corridor. It would be important to distinguish between 100 pixels scattered randomly and 100 pixels in a line, forming a new barrier to animal movement.

Individual transitions can also be weighted by characteristics of the entire landscape. Loss of a rare cover type may be more important than loss of an abundant cover type.

3.2 INDICATORS OF WATERSHED INTEGRITY

It is also possible to develop indicators of status and trends in landscapes that relate to changes in water quality due to changes in terrestrial landscapes (Hunsaker et al. in press). Across a region, increases in agriculture and urban land use or decreases in natural vegetation indicate a potential for future water quality problems. The basic cover changes could be weighted by distance to water, soil type, and slope calculated from digital elevation models. Essentially, the same data set can be used with the Revised Universal Soil Loss Equation to follow status and trends in erosion potential.

A second type of indicator might focus on the potential for undesirable hydrologic events. For example, a flood indicator could include vegetation cover and surficial geology.

Riparian zones (e.g., vegetation adjacent to water) are important buffers for maintaining the water quality of streams (Naiman and Decamps 1990). Changes in width of buffers, weighted by slope, would be an important indicator. The actual index might be average width, or miles of riparian zone that are narrower than desirable. This standard could be applied by counting pixels that encroach into the recommended buffers.

Similar indicators might be the formation of contiguous agriculture adjacent to a stream or lake, both of which may contribute to reduced water quality. We would weight more heavily a pixel change that increases contiguous agricultural cover. Contiguous agricultural fields along flow paths increase hydrologic length and lead to channelization. Specifically, we would calculate hydrologic distance which includes vegetation characteristics along the overland flow path calculated from digital elevation data.

Hydrologic pathways are altered by road surfaces, and water quality can be affected when the roads intersect streams. Therefore, miles of new roads weighted by distance to water might form another useful indicator.

Some research indicates that more precise predictions of water quality can be made on the basis of land cover on the watershed. The approach is empirical, relying on correlations between land use and water quality on monitored streams. The correlations will undoubtedly be different in different regions of the country, and considerable additional research is needed. Nevertheless, such a watershed indicator would have enormous potential for monitoring status and trends in landscapes at the watershed level.

3.3 INDICATORS OF LANDSCAPE STABILITY AND RESILIENCE

As previously discussed, percolation theory (Gardner et al. 1989) provides a framework for relating landscape pattern to wildlife habitat. Because it deals with landscape connectedness, the same theory is useful for monitoring the potential for disturbances to spread across the landscape (White 1979, Runkle 1985). Specifically, if percent cover for disturbance-prone land cover is higher than a threshold value, the potential for disturbance spread becomes significantly higher (Gardner et al. 1991, 1992). Particularly noteworthy is the combination of epidemiology theory with percolation theory to calculate the probability that a disturbance or pest will spread or become endemic (O'Neill et al., 1992).

In addition to predicting economic activity, miles of roads also indicate potentially accelerated dispersal pathways for pests and exotic biota. This has been particularly noteworthy in the spread of the gypsy moth. New infestations often begin around trailer parks where recreational vehicles have transported the larvae from one forested area to a distant point in the region.

Unlike wildlife habitat and water quality, the relationship between landscape pattern and disturbance spread is a relatively new development in landscape ecology (Turner 1987b, 1989). It can be expected, therefore, that a number of new indicators will be developed as research continues.

For example, we have little insight into how spatial pattern affects the ability of systems to recover from disturbance. We know that northern hardwoods may take 60-80 years to replace biomass and nutrients lost in harvesting (Likens et al. 1978). How would this recovery time change if distances to seed sources were increased or if erosion set in?

We need to identify ecological systems that are particularly sensitive to spatial disturbances. We are aware of the proverbial erosion effects of tire tracks in the Arctic Tundra, but arid lands may be equally sensitive. Even the casual observer can see how small alterations in natural landform result in major changes in arid land vegetation.

The potential sensitivity of arid lands also alerts us to the need to identify critical thresholds in landscape pattern. We know from percolation theory that small changes in land cover can critically alter landscape connectivity.

4.0 GENERAL APPROACH, DESIGN ISSUES, AND ASSESSMENTS

This section will describe the general approach to monitoring and assessing landscape condition over time. Some implementation issues and researchable questions will then be described, followed by an example of the general approach.

4.1 SUMMARY OF THE THREE-STEP APPROACH

EMAP-L will use a phased, three-step approach of monitoring and assessment (Figure 4.1). A "baseline" landscape condition is first established in Step 1, then Step 2 is designed to quantify change in landscapes over time. Satellite images are used for both steps. Together, the first two steps are the basis for statistical reports of landscape status and trends. Step 2 also serves to identify those landscapes which have changed the most and are therefore of particular interest for assessments. Depending upon the results of Steps 1 and 2, Step 3 entails in-depth analyses of particular situations of interest.

Status and trends reports will be prepared, at fixed time intervals, for all landscapes with respect to broadly-defined societal values as measured by condition indicators. The primary objective is to summarize the overall condition of landscape units on a regional basis with known confidence. To help decide whether a more in-depth analysis is warranted, the amount and types of landscape pattern change will be reported. EMAP-L will take advantage of GIS technology in analyzing and displaying landscape status and change.

In-depth assessments will address the relationships among specific subsets of societal values and environmental stresses. They will be prepared only when warranted by evidence of changing landscape conditions for specific geographic areas, and the objectives will depend upon the particular types of change which have been observed as well as the societal values and environmental concerns that are perceived to be important in those areas. By improving the understanding of the relationships between stressors and landscape condition, these analyses should enable projections of relative risks to societal values given different landscape condition and stressor scenarios.

4.2 DESIGN ISSUES FOR IMPLEMENTATION

This section will mention some design issues that are relevant to implementing the three-step approach. These include the definition of landscape scales and units, the uses of different types of indicators, and the choices of databases.

4.2.1 Definition of Landscape Scales

Scales can be defined for the spatial, temporal, and attribute dimensions of a landscape (more generally, for any ecosystem). Selecting a spatial scale for monitoring means defining a grain size (i.e., the minimum resolvable size of a unit) and extent (i.e., the number of units) for a particular calculation or assessment. The temporal scale is the frequency at which landscapes will be analyzed. The attribute scale is a function of the types and numbers of different attributes which are recognized in an analysis.

It is a design issue to optimize the scale for each value, assessment question, and indicator. These choices must consider the available data and the sensitivity of indicators at different scales. Furthermore, the same indicator may be analyzed at several different scales (for example, over different total extent) depending upon the assessment question, since some

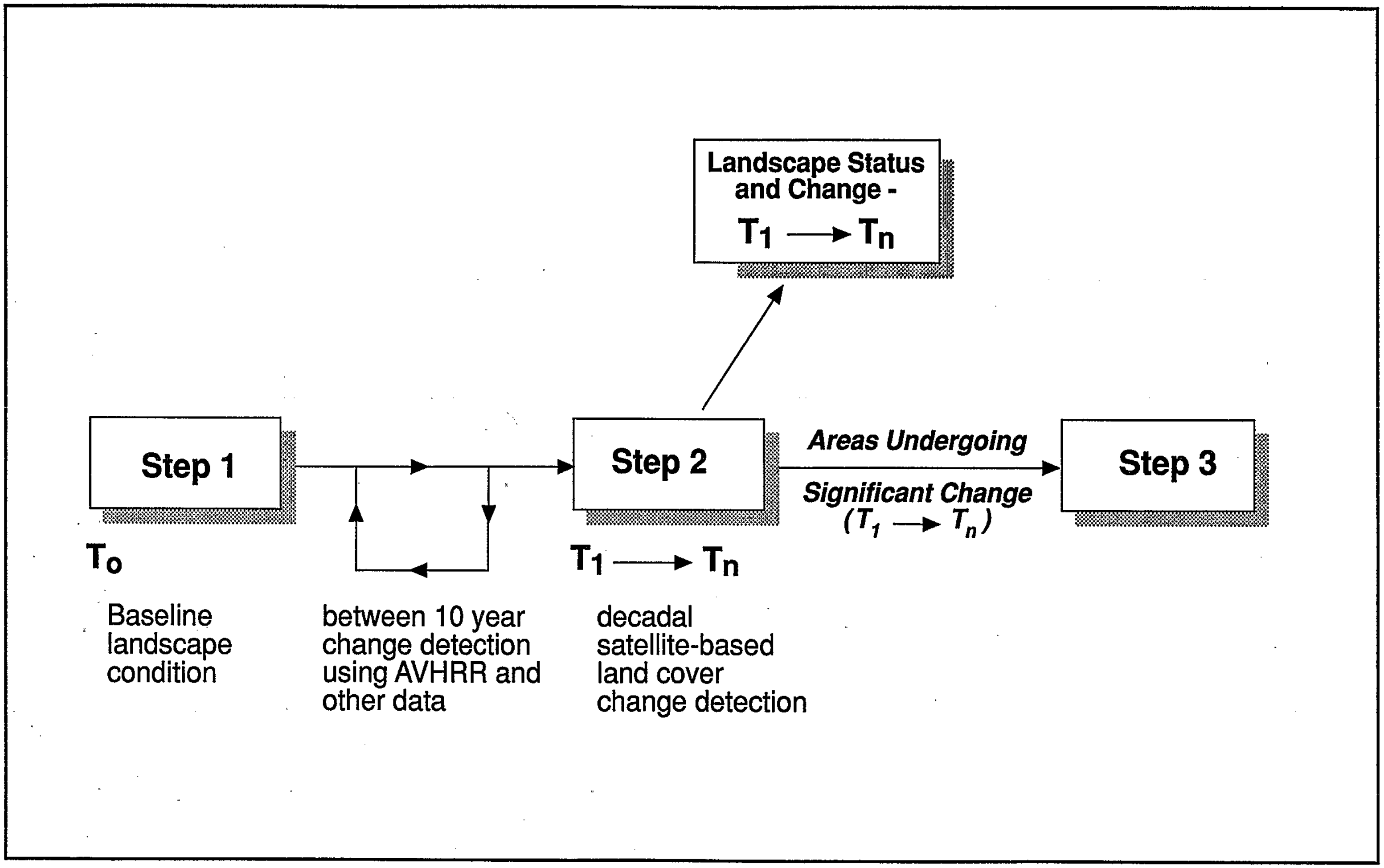


Figure 4.1 Proposed landscape monitoring approach

ecological processes operate at multiple scales (Saunders et al. 1991, Ledig 1992, Terborgh 1992, Ulfstrand 1992). This rationale assumes that if different ecological processes operate at distinct scales, then the scale must be matched to that process (Meentemeyer 1989). Turning this rationale around, it is also possible to detect the scales (and changes in scales) at which ecological processes are operational (S. Turner et al. 1991, O'Neill et al. 1991b).

4.2.2 Definition of Landscape Units

As for ecosystems in general, there is not a unique definition of what constitutes a landscape. But all numerical procedures require that a specific area be defined, and all assessments must be made for specific geographic areas. Thus, landscape units will be operationally defined as appropriate for specific assessment questions and for the conceptual models and indicators which are used to answer those questions. It is a design issue to optimize the landscape units for monitoring.

The measurement unit is the smallest resolvable area on the landscape image; it is completely specified by the data collection procedures (Figure 4.2). An example is a pixel in a raster landscape map. Flexibility is necessary when aggregating measurement units into landscape units because the aggregation strategy for one analysis will probably not be optimal for any other analysis, even though the total reporting region may be the same. To provide for both multi-scale analyses and consistent reporting, it is useful to distinguish "fixed" landscape units from "scalable" units.

There are two types of fixed units: "reporting units" and "natural regions." A reporting unit is a geographic area for which statistical reports will be prepared, for example, a standard Federal region. A natural region is made up of one or more geographic areas classified on the basis of similar large-scale and long-term biogeophysical attributes, e.g. ecoregions (Omernik 1986, Bailey 1991). The variety of potentially useful classification rules means that a variety of natural regions could be used depending upon the assessment question.

Scalable units are needed to address landscape ecology issues at multiple scales within a hierarchical framework. Examples of scalable units include patches, patterns, and landscapes. A patch unit is a set of contiguous measurement units (e.g., pixels) which have the same numerical value. A pattern unit is a collection of measurement units and/or patch units which have the property of being the minimum unit descriptor of a larger spatial area. A landscape unit may be a collection of pattern units in the spirit of Forman and Godron's (1986) definition of a landscape. More generally, a landscape unit is simply a collection of measurement, patch, and/or pattern units which comprise a logical grouping. Patches, patterns, and landscapes are considered to be scalable because their precise definitions depend upon the choices of scales and indicators as described above.

The scales of assessment questions and indicators suggest two types of landscape units, watersheds and landscape pattern types (LPTs) (Wickham and Norton 1994). Both watersheds and LPTs appear to capture (or bound) four important flow processes operating within and among landscapes: flows of energy, water, nutrients, and biota. These processes, in turn, are the main factors influencing the landscape values of biotic integrity and diversity and landscape stability and resilience. Watersheds are an obvious choice for addressing landscape condition in terms of watershed integrity. Furthermore, both watersheds and LPTs are scalable and hence suitable as landscape units. Several scales of watershed and LPTs will range from approximately 10^3 to 10^6 units in extent, and from approximately 1 to 100 hectares in grain size.

4.2.3 Indicators

A number of indicators were introduced in Section 3. It was mentioned that some would be used for assessing status and trends and others for in-depth analyses. The exact roles that each indicator will play remain to be worked out for most indicators. Of particular interest is the set of indicators that will be used in Steps 1 and 2 of the three-step process. These are important because they are the basis for statistical reports of status and trends. The issue is complicated by the planned use of satellite images for both steps because not all indicators can be estimated strictly from satellite images.

Landscape status is established by positioning the landscape units somewhere along a continuum defined by an indicator. The condition of a landscape is judged on the basis of the indicator value — nominal, subnominal, etc. The threshold values are not

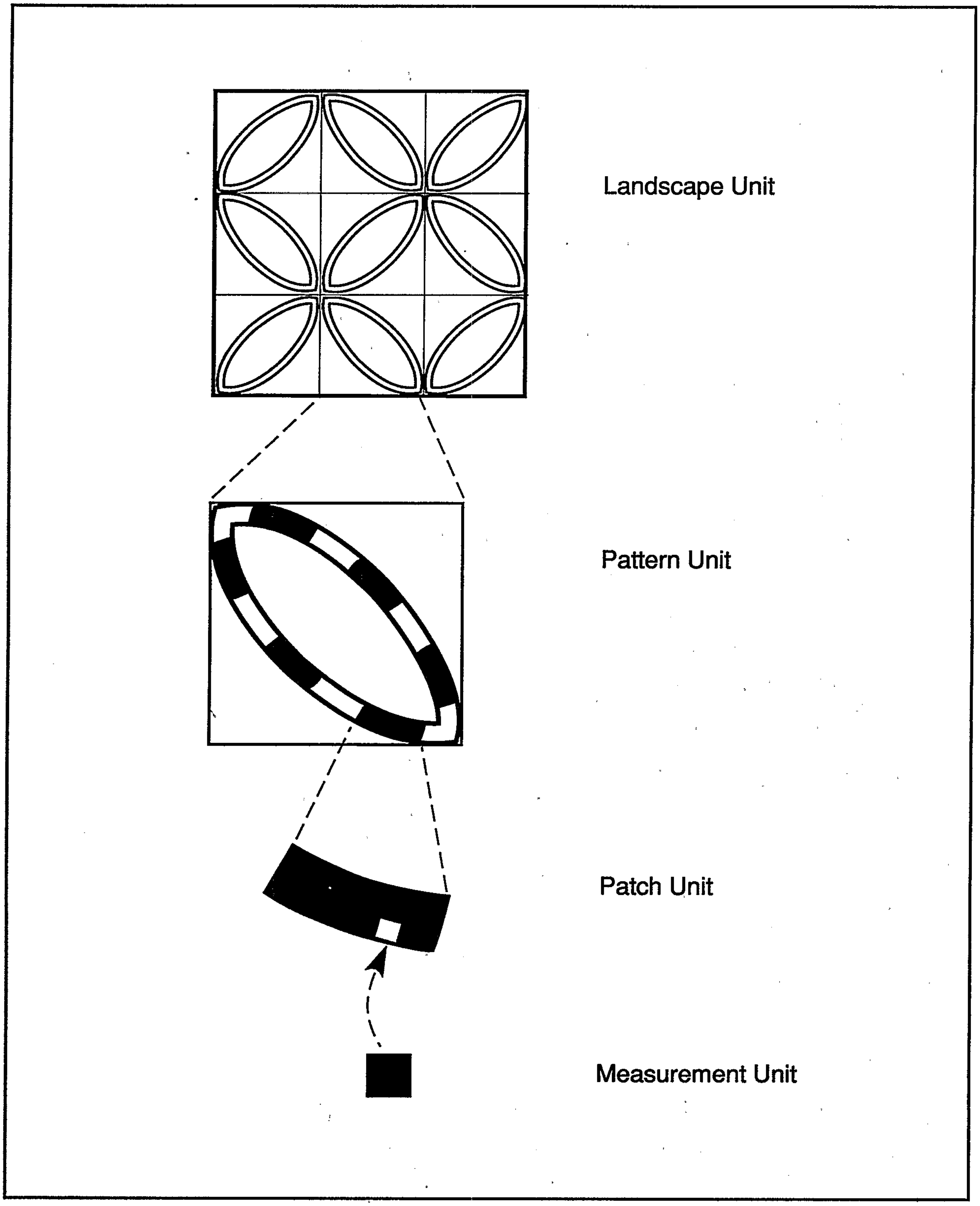


Figure 4.2 Scalable landscape units

known for most indicators, but Section 3 described generally how such thresholds could be determined. This is an important research question.

Another important question is how to determine a minimum set of condition indicators to describe overall landscape status. Ideally, the set would address all societal values but would not be redundant. The statistical properties of each would be well-known, and it would be beneficial if they were estimable from satellite images. The set would include integrative measures, so that landscape change would be detectable no matter what the causal agent was. It would be undesirable to include "diagnostic" indicators in this set.

Landscape status can be quantified in terms of the patterns of land cover (type, distribution, dominance, and change) and displayed via a G.I.S. Patterns of land cover play a major role in changing the configuration of landscapes at a regional scale. If land cover patterns change, it is likely that many ecological processes will be affected. Areas of predominantly natural land cover are likely to be in better overall ecological condition than highly-modified landscapes. Areas undergoing dramatic changes in land cover patterns are likely to contain landscapes whose ecological conditions are changing the fastest. Other indicators are also being considered for quantifying landscape status (see Section 3).

4.2.4 Data Design Issues

Ideally, status and trends reports will be based on indicators which are measured on satellite images. Satellites provide frequent, full coverage of all landscapes units. It is a data design issue whether or not to utilize the available full coverage information, as opposed to a probability sample of that information. Flexibility is retained if all landscapes are measured. If landscapes are sampled, costs are lower but information and flexibility are lost. Full-coverage of all landscape units has a crucial and deciding advantage over a sampling approach, and that is the flexibility to reaggregate data in order to assess status and trends for different configurations of landscapes. Because landscapes do not have a fixed definition for all values or indicators, a separate sampling plan would have to be devised for each situation. Another benefit is that landscape information will be easier to combine with the measurements made by all EMAP-Resource Groups, each of which essentially collects measurements in different sets or parts of landscapes.

One alternative for sampling is multi-stage sampling. An example of multi-stage sampling is to first select a sample of arbitrary polygons (e.g., Landsat-TM or Landsat-MSS scenes) and then to select a second-stage sample of landscape units within the first-stage sample units (say, by a point grid or by list sampling).

If landscapes units are defined as continuous or spatially extensive resources, then sampling could associate indicator values with particular points on a map. A calculation window for an indicator would be repeatedly placed within a well-defined geographic area and the indicator value for a given placement would be assigned to the center point of the window. The calculation window functions as a "support region" for the arbitrary point in space.

A calculation window can be randomly placed many times to derive an empirical frequency distribution for the landscape unit, or a systematic grid of window placements can be used to ensure a good spatial distribution of sample points. This procedure can be applied to entire reporting regions, to natural regions within reporting regions, or to samples within very large landscape units. The resulting "surface" of points can then be aggregated by natural region or reporting region as appropriate for different assessment questions. Re-sampling methods can be used to develop variance estimates and confidence intervals.

The frequency of image acquisition and processing is a data design issue. The trade offs involve the degree of image classification, the resolution of different available sensors, and the expected rates of landscape change.

EMAP-L makes the assumption that Landsat imagery for the entire U.S. will be available on approximately 10-year cycles; these data will form the basis for decadal status, change, and trends assessments. It is likely, however, that significant landscape changes will occur more frequently than on 10-year increments.

EMAP-L will evaluate use of annual AVHRR and other GIS compatible data to identify areas potentially undergoing significant landscape changes. The 1.1 km^2 spatial resolution of the AVHRR will not permit detailed land cover analysis (Gervin et al. 1985, Loveland et al. 1991) but may be sufficient to detect major changes resulting from human or natural disturbances. Table 4.1 provides an initial list of

Table 4.1 Federal Databases Potentially Useful in Identifying Landscape Changes

Agency	Database	GIS	Trends	Freq.	Description
DOI, USGS	AVHRR	Yes	?	?	1.1 km data w/ visible & IR channel.
USDA,ERS	MLU	No	Yes	5 yrs	Major Land Uses of the U.S. Provides trends in 11 major land use classes.
USDA,SCS	NRI	Yes	Yes	5 yrs	National Resources Inventory. Provides data on status, trends and condition of soil and water resources, including soil loss estimated using USLE.
USDA,FS	FIDC	?	Yes	1 yrs	Forest Insect and Disease Conditions. Trends in forest insect and disease conditions across all forest ownership classes.
USDA,FS	WFS	?	Yes	1 yrs	Wildland Fire Statistics. Data collected on number and area burned on public and private lands.
DOC,Census	CENDATA	Yes	Yes	10 yrs	CENDATA, decennial census data. An online data source of demographic and socioeconomic information. Also include TIGER line files and TIGER geographic reference products.

GIS compatible data that could be used in combination with AVHRR to conduct Step 2 change detection assessments.

For example, graphical analysis of USDA Major Land Uses (MLU) data (Figure 4.3) shows a substantial decline in Pennsylvania forest cover since the middle 1970s, while the amount of forest cover in Mississippi has remained constant (Both states show a dramatic increase between 1954 and 1964). In this example, comparison of MLU data in Pennsylvania and Mississippi suggests that change detection at shorter than 10-year intervals would be undertaken in Pennsylvania.

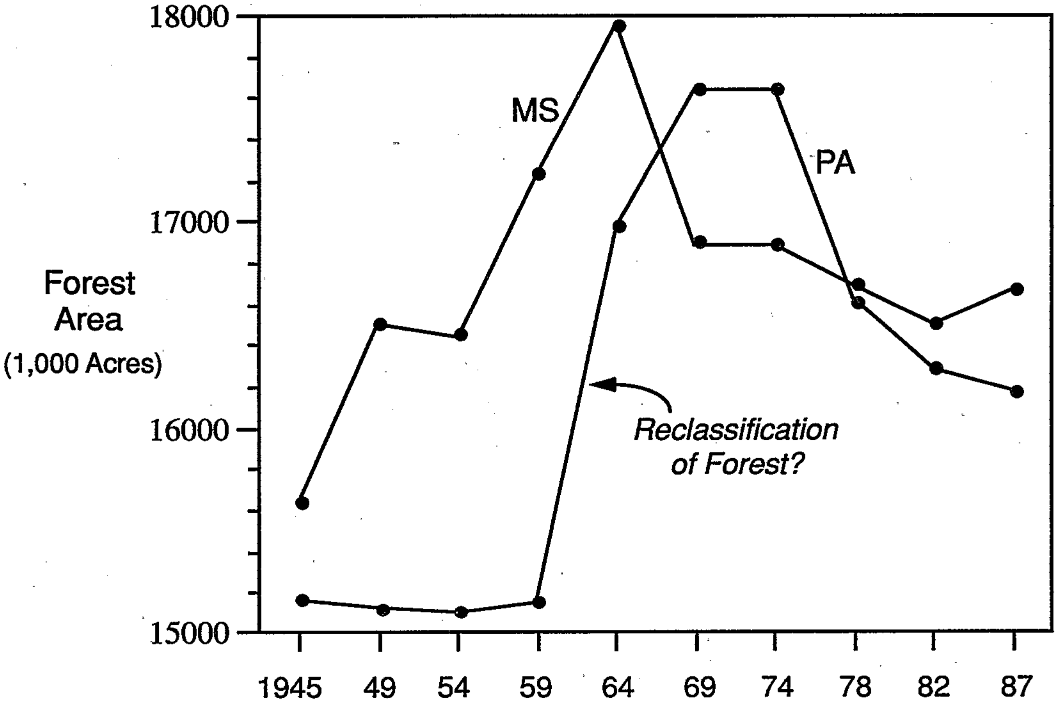
Combining the MLU data with Bureau of Census data would suggest that the forest cover loss is in the southeastern portion of Pennsylvania since the counties in this portion of the state have experienced population increases greater than 10 percent (U.S. Dept. of Commerce 1983). Land cover change data from SCS and NRI could then be examined to "verify" the census data (NRI provides 5-year assessments of land cover proportion that are statistically reliable at USGS, 8-digit (small) watersheds). Finally, examination of temporal AVHRR data could be used to further confirm that significant land cover change is occurring in southeastern Pennsylvania and perhaps more precisely locate the change. This example is illustrative of the "weight of evidence" approach that will be used to monitor land cover dynamics between 10-year Landsat-based land cover detection (Step 2).

The data sources listed in Table 4.1 can be examined quickly across the entire United States. For areas determined to have significant landscape change, EMAP-L would then acquire more detailed imagery (e.g, Landsat-MSS or Landscape-TM). The degree of change would then be evaluated to determine if more detailed evaluation is warranted (see Step 3 discussion).

4.3 ASSESSMENT APPROACH

Briefly, an application of the three-step process (as described in Section 4.1) is as follows. An initial land cover data set is used to determine landscape condition in terms of selected indicators (Step 1). A status report is prepared by using standard statistical methods as applied to those indicators. After a suitable time increment (10 years), new spectral data are combined with the original spectral data to identify changed measurement units (pixels) (Step 2). The changed pixels are then inserted into the original land cover map. Re-calculated values of indicators for this updated land cover type map are then used to update status and trends assessments of landscape condition. Further analysis of the change determines whether or not Step 3 is initiated.

The purpose of this section is to fill in some of the details on how the three-step approach would be implemented and to provide an example.



Combine with Census data at county level would suggest focus on south central and southeastern counties where population increased more than 10 percent from 1970 to 1980

Figure 4.3 Change in forest area in Pennsylvania

4.3.1 Status

Status and trends reports will be prepared based on the initial land cover information and every 10 years after that. Landscape pattern indicators are an appropriate starting point for describing status and trends analyses. Numerous studies have been conducted to develop methods to quantify landscape pattern (Krummel et al. 1987). Information theory measures (O'Neill et al. 1988a; Li and Reynolds in press) and fractal dimension (Milne 1992) summarize basic landscape type and pattern. Studies have shown that individual indices can capture specific aspects of landscape pattern.

As a result, there are candidate pattern indicators available to evaluate in a national landscape monitoring program. For example, dominance (O'Neill et al. 1988a) is an information theoretic index that indicates the extent to which the landscape is dominated by a single land cover type. The indicator, $0 < D < 1$, is given by the following equation.

$$D = 1 - [\Sigma_k (-P_k \ln(P_k))/\ln(n)] \qquad (1)$$

where $0 < P_k < 1$ is the proportion of land cover type k, and n is the total number of cover types on the landscape.

Empirical studies confirm that the fractal dimension (F) of patches indicates the extent of human reshaping of landscape structure (Krummel et al. 1987; O'Neill et al. 1988a). Humans create simple landscape patterns; nature creates complex patterns. The fractal dimension index is calculated by regressing the log of the patch perimeter against the log of the patch area for each patch on the landscape. The index equals twice the slope of the regression line. Patches of four or fewer pixels are excluded because resolution problems distort their true shape.

Contagion expresses the probability that land cover is more "clumped" than the random expectation (O'Neill et al. 1988a; Li and Reynolds In Press). The index, $0 < C < 1$, is given by equation 2.

$$C = 1 - [\Sigma_i \Sigma_j (-P_{ij} \ln(P_{ij}))/(2 \ln(n)] \qquad (2)$$

where P_{ij} is the probability that a pixel of cover type i is adjacent to type j.

Together, this set of indices captures fundamental aspects of pattern that might influence ecological processes. Significant changes in these indices indicate that an observed change in the landscape may result in significant alterations in the quality of the environment. Experience with dominance, contagion, and fractal dimension in a variety of real-world settings will undoubtedly highlight aspects of pattern that are not captured by these indicators.

Cumulative distribution functions (CDFs) are a convenient way to display the indicator values obtained for a population of landscape units (see Figure 4.4). Briefly, a CDF shows the proportion of the population which has indicator values less than some nominal value. A CDF is a useful interpretive device if the nominal value has some meaning, such as a threshold value separating "good" and "bad" landscape condition for that indicator. In many cases, these threshold values can only be arrived at through research or other experience. Constructing a CDF is trivial if all landscape units are measured, and it can be estimated by using standard procedures (Overton et al. 1990) if only a sample of units are measured. A time series of CDFs can be displayed as a way of showing trends.

Indicator values can also be displayed in a map format (via GIS) in order to show the geographic distribution of different landscape conditions (Figure 4.4). Landscape units can be color-coded, for example, according to the calculated value of an indicator for that unit. Such a display makes it easier to discern regional spatial patterns of landscape conditions.

Landscape status will be updated by calculating land cover change using satellite data. Prior to the advent of satellite technology, the potential for land cover change detection using remote sensor data was noted by Shepard (1964); but, at the time, he also acknowledged that change detection had an undeterminable omission error rate because of the lack of objectivity. By eliminating the need for human detection of change (i.e., visual comparison of t1 and t2 air photos), use of satellite or other digital technology adds a degree of objectivity to such studies that can not be achieved from aerial photography.

Land cover change using satellite data has been widely studied (Weismiller et al. 1977, Stauffer and McKinney 1978, Friedman and Angelici 1979, Gordon 1980, Byrne et al. 1980, Robinove et al.

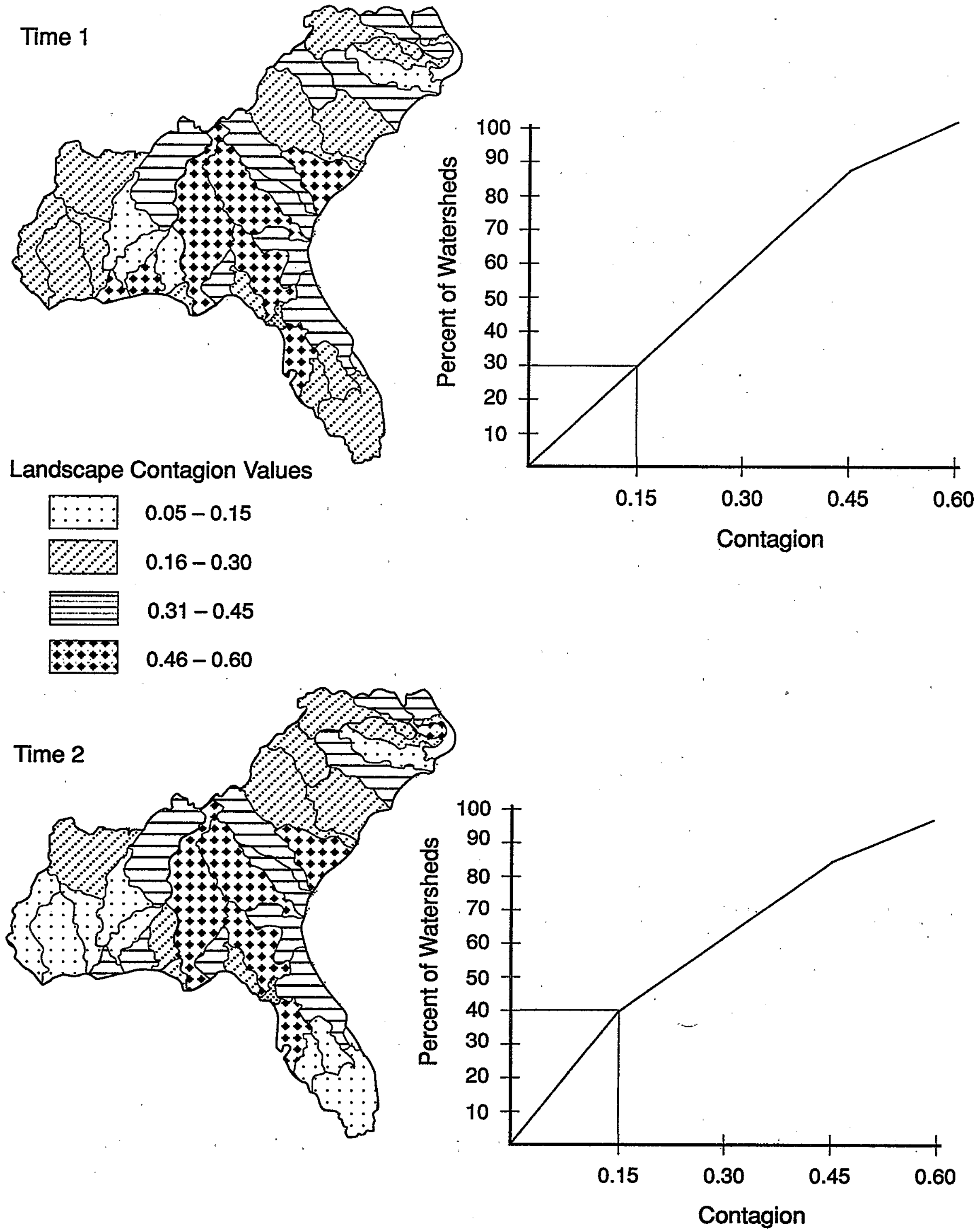
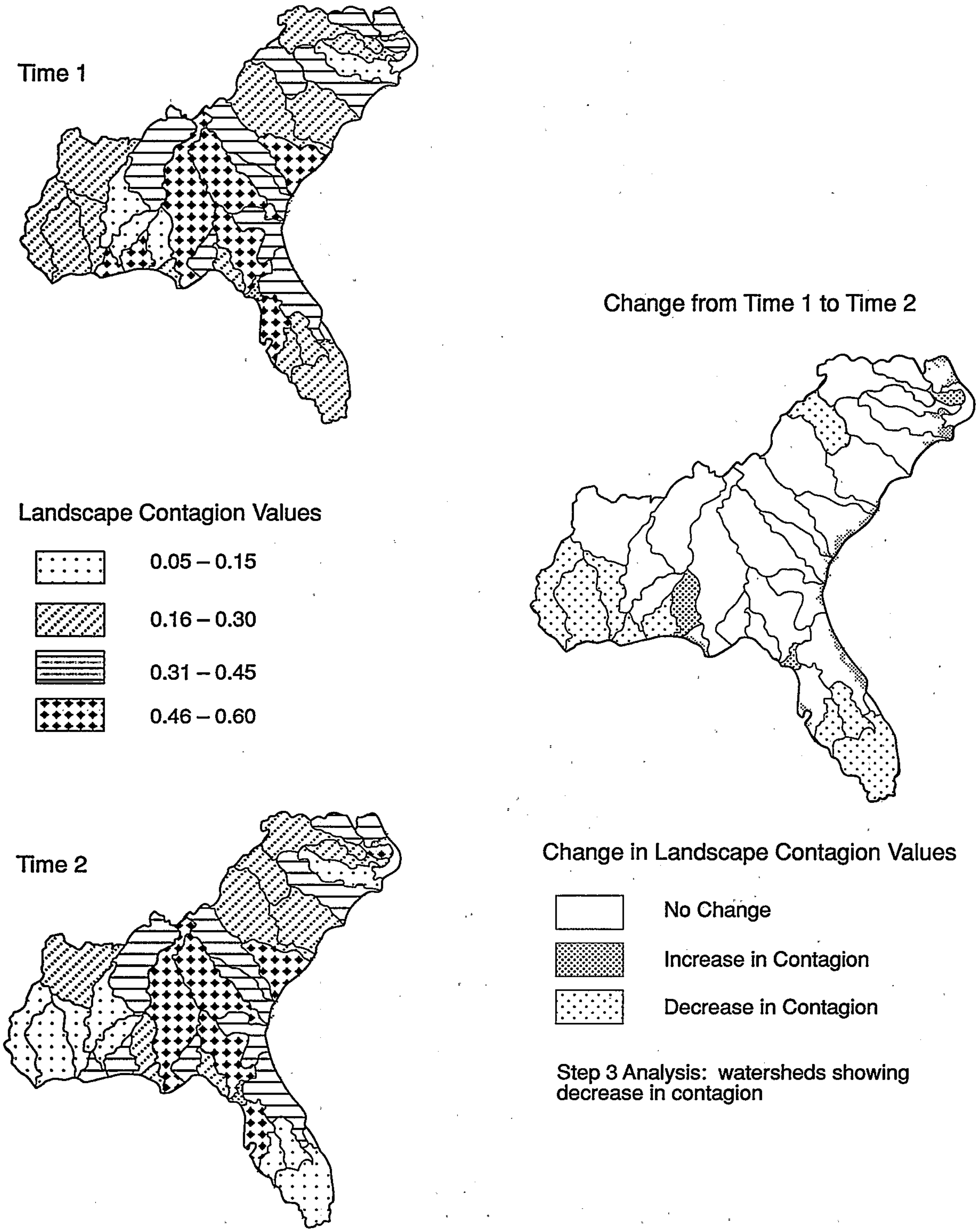


Figure 4.4 Example assessment of landscape status and trends



Step 3 Analysis: watersheds showing decrease in contagion

Figure 4.4 Example assessment of landscape status and trends (cont'd.)

1981, Jensen 1981, 1983, 1986, Howarth and Wickware 1981, Jensen et al. 1987, Fung and LeDrew 1987, 1988, Wickham 1988, A. Milne 1988, Singh 1989, Fung 1990, Hall et al. 1991a, Mouat et al. 1993). Singh (1989) reviewed nine changed detection techniques: image differencing, image regression, image ratioing, vegetation index differencing, principal components analysis, post classification techniques, direct multi-date classification, change vector analysis, and background subtraction (see also Jensen 1981, 1983, A. Milne 1988 for technique reviews). We seek a technique that requires minimal data processing, is sensitive to land cover changes, and has been widely studied.

Image differencing is a straightforward change detection technique that has been widely studied (Weismiller et al. 1977, Stauffer and McKinney 1978, Howarth and Wickware 1981, Jensen 1981, Nelson 1983, Wickham 1988, A. Milne 1988, Fung and LeDrew 1988, Fung 1990) and applied in a variety of geographic settings (Singh 1989). Image differencing has the property that spectral differences between t_1 and t_2 have a near-normal distribution, where land cover change lies at the tails of the distribution (Stauffer and McKinney 1978). The difference values that depart only slightly from the mean are due more to differences in atmospheric conditions, sensor calibration, illumination, soil moisture, and registration error (Singh 1989). The difference procedure uses the equation (Jensen 1981):

$$\Delta x_{ijk} = x(1)_{ijk} - x(2)_{ijk} + c \qquad (3)$$

where Δx is the change in pixel value, x(1) and x(2) are pixel values at t_1 and t_2, respectively, i and j are the pixel row and column position, k is wavelength, and c is a constant (added to keep the distribution of change values between 0 and 255).

Where possible, EMAP-L will use land cover change detection data from the North American Landscape Characterization Program (NALC) to update landscape status. NALC recently completed a review of nine change detection algorithms, and, not surprisingly, found that image differencing was the most effective technique for detecting land cover change (Elvidge et al. 1993).

The most accurate method was image differencing of all four Landsat MSS bands using a radiometric correction technique called *Automatic Controlled* Scattergram Regression (ACSR). ACSR is a technique first developed by Hall et al. (1991b) that has been automated by Elvidge et al. (1993). ACSR uses a set a bright (e.g., beaches) and dark (e.g., clear water bodies) pixels that have not changed between the two dates of satellite acquisition to adjust the radiometry of one scene (the subject) to the radiometry of the other (reference) scene. The radiometric adjustment is accomplished using regression techniques. Image differencing follows radiometric adjustment.

A second technique that was nearly equal to image differencing using ACSR radiometric adjustment was image differencing of Normalized Vegetation Index (NDVI) ratios. NDVI ratios (Tucker 1979) are created by dividing the difference of the near-infrared (NIR) from the red wavelength by their sum. Detecting land cover change by image differencing of vegetation indices (e.g., NDVI, NIR/red ratio) carries two advantages. First, vegetation indices have been shown to distinguish vegetation cover from other earth surface features (e.g., water, soil) (Knipling 1970, Tucker 1979). Second, differencing just vegetation indices eliminates the cost analyzing four Landsat MSS or six TM bands of change data. Also, change from t_1 to t_2 can be categorized into two components of coarse estimates of fragmentation using difference data derived from vegetation indices. A decrease in the ratio of NDVI value over time for a given landscape unit provides a coarse estimate of fragmentation. An increase in the ratio of NDVI values over time provides a coarse estimate of connectivity.

A third technique proposed by NALC is post-classification subtraction. This technique relies on complete land cover classification of both t_1 and t_2 dates and then compares the results. NALC proposes to use this technique when same season satellite data can not be acquired for t_1 and t_2. This case is expected to be rare (Elvidge et al. 1993).

Once the change or difference image has been created (excluding the post-classification technique), the question of what value constitutes land cover change still remains. Distinction of change from no change is typically defined as a threshold value (Singh 1989) that is some standard deviation unit from the mean (Stauffer and McKinney 1978, Ingram et al. 1981, Singh 1986, Fung and LeDrew

1988, Quarmby and Cushine 1989, Fung 1990). This is illustrated in Figure 4.5 as the area of black hatching. Fung and LeDrew (1988) found that 0.9σ and 1.0σ were optimal thresholds for Landsat MSS bands 2 and 4, respectively. A 1.0σ threshold was found to be optimal by Nelson (1983), Fung (1990), and Quarmby et al. (1987). NALAC is proposing to examine 0.25σ, 0.50σ, and 1.0σ change/no change thresholds. However, it is unclear at this time to what extent NALC will conduct field accuracy assessments of their change data on a routine basis. Woodwell (1983) recommends an interactive visual analysis because it minimizes incorporating trivial land cover changes, such as those due to crop rotations. In addition, this method helps eliminate identifying areas as change that are the result of anomalies such as cloud cover in one data set.

Woodwell's visual analysis could be set up on a computer screen as a block of six image sets split into three pairs. Each image pair would display "before" and "after" data, and the change identified by the different thresholds (e.g., 0.25, 0.50, 1.0) could be toggled on and off. Visual inspection of the change results could be compared to air photos and given an accuracy score using the equation (Cohen 1960, Bishop et al. 1975):

$$K = M\Sigma x_{ij} - \Sigma x_i \Sigma x_j / M^2 - \Sigma x_i x_j, \qquad (4)$$

where K is the Kappa coefficient, M is the total number of observations, x_{ij} are the diagonal elements, and xi and xj are the off diagonal elements of the 2x2 change/no change matrix shown in Table 4.2. The threshold with the highest Kappa coefficient (K) would be used for land cover change detection and subsequently to update landscape pattern. This method is proposed for accuracy assessment if the NALC program does not routinely supply accuracy estimates of their change detection results.

Table 4.2 Change Detection Matrix

		Satellite	
		Change	No Change
Control	Change	20	5
	No Change	5	20

The overall accuracy rates of previous change detection studies are about 80 percent (Table 4.3). This is the basis for EMAP-L's assumption that an 80 percent accuracy rate in land cover change detection can be achieved. However, it may be possible to do better. Turner (1987a) noted that land cover change is contagiously distributed. This covariance was not investigated in any of the change detection studies cited herein. Because EMAP-L will be conducting change detection over large geographic areas, it is possible that EMAP-L might capture some of the omitted change thereby increasing change detection accuracy. EMAP-L intends to investigate the phenomenon of contagion of land cover change to improve change detection accuracy.

Table 4.3 Reported Accuracy Assessments Of Change Detection Studies

Author(s)	Location	Data Type	Overall Bands	Accuracy (%)
Fung 1990	Ontario Canada	Landsat TM	DI 3 DI 4 DI 5	83.3 82.2 79.6
Quarmby & Cushine 1989	England	SPOT HRV Landsat M	HRV 3- TM 4	NR(!)
Jenson 1981	Denver CO	Landsat MSS	DI 5	77.0
Fung & LeDrew 1988	Ontario Canada	Landsat MSS	DI 7 DI 5	80.8 77.3
Ingram et al. 1981	Denver CO	Landsat MSS	DI 4 DI 5 DI 6 DI 7	84.9 83.8 81.5 72.4
Weismiller et al. 1977	Matagordo	Landsat MSS	DI	NR
Nelson 1983	Harrisburg, PA	Landsat MSS	DI 4 DI 5 DI 6 DI 7	83.3 80.6 86.8 84.2

DI = difference image
(!)= authors reported 15% omission error

Landsat MSS	Landsat TM	SPOT HRV
Band 4: 500- 600nm	Band 1: 450- 520nm	Band 1: 500-590nm
Band 5: 600- 700nm	Band 2: 520- 600nm	Band 2: 610-680nm
Band 6: 700- 800nm	Band 3: 630- 690nm	Band 3: 790-890nm
Band 7: 800-1100nm	Band 4: 760- 900nm	
	Band 5: 1550-1750nm	
	Band 7: 2080-2350nm	

4.3.2 Analyzing Landscape Change

Once the changes of individual pixels have been determined, two types of analyses will be carried out. The first analysis is simply to update the status and trends of landscape condition, as described above.

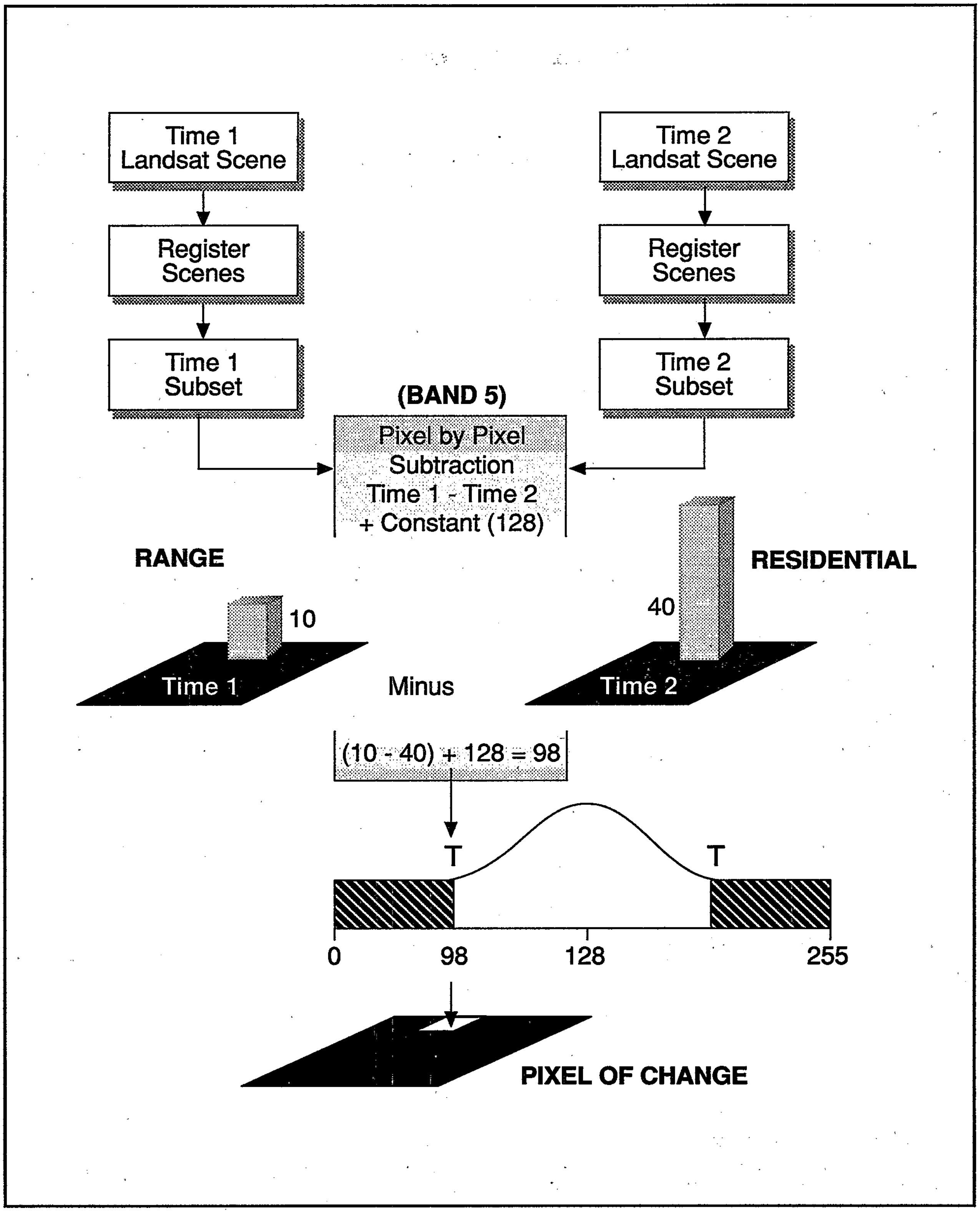


Figure 4.5 Image Substraction for Land Cover Change Detection

The second analysis is to determine whether or not the observed changes warrant in-depth evaluation of associations between observed landscape status and trends with environmental stressors. The second analysis requires additional explanation here.

The types and magnitude of change identified in Step 2 may trigger more in-depth assessments to be carried out in Step 3. A number of research criteria will be investigated for possible use, including the concept of "phase" change in landscape pattern state space. Despite the success of individual pattern indicators, no single index captures all of the relevant aspects of pattern. Therefore, a more complex method, involving at least two or three dimensions, is needed to classify pattern types. Each axis is normalized to unit length so that all indicators make equal contributions. The landscape unit is then represented by a point in this abstract state space.

In Figure 4.6, an undisturbed grassland landscape has high values for three indicators. A similar landscape, when converted to agricultural uses, has high dominance and contagion but low fractal dimension. Thus, the position of a landscape in the 3-dimensional state space illustrated in Figure 4.6 will immediately orient the viewer to the type of landscape pattern in the subject landscape unit. The approach also permits quantitative description of changes in a given landscape unit over time. Changes in land cover produce changes in indicator values and corresponding movement of the landscape unit in 3-dimensional state space. The distance moved is a measure of the amount of change in a landscape. This is calculated by the following equation:

$$\Psi = \sqrt{(X_1-X_2)^2+(Y_1-Y_2)^2+(Z_1-Z_2)^2} \qquad (5)$$

At some (as yet unknown) magnitude, this shift will represent a phase change in the landscape.

Another way to summarize changes in land cover between two times is through the use of transition matrices (see Table 2.1). The diagonal elements represent the degree to which land cover types do not change over time. If the rows and columns are chosen carefully, the transition matrix also provides a picture of disturbance regimes and succession. The upper triangular elements can represent succession and the lower triangular elements can represent disturbance (Hall et al. 1991a).

In some cases, an indicator value is expected to change when the underlying sample unit changes in some important way. For example, as large natural forest patches are fragmented into small, regular patches by urban development, both the shape and size of the associated landscape sample units vary predictably. This correlation is important, especially because one of the two ways proposed for defining landscape objects (i.e., as LPTs) yield landscape populations that may change over time. Comparisons of some indicators over time or space may have to be conditioned upon the size of the underlying landscape units, for example, by covariance analysis.

4.3.3 In-depth assessment of Landscape Condition and Associations with Stressors

Change detection analyses will identify areas undergoing a level of change in landscape pattern that will be likely correlated with changes in conditions of landscape values. In these areas, we will conduct in-depth analyses of landscape condition. In-depth analysis of landscape condition refers to greater specificity in the calculation of landscape indicators, and this often requires use of ancillary data. For example, within areas undergoing rapid change, we may calculate landscape pattern indicators on the scale of a "patch" to evaluate within-patch composition and structure relative to landscape sustainability. Landscape indicator measurements at this scale would require use of ancillary data such as aerial photography.

We also propose to evaluate associations between landscapes undergoing significant change with anthropogenic and natural stressors. We anticipate using ancillary data on stressors, including U.S. Census Bureau data, NRI data, and USGS digital data on roads (to name a few) to determine these associations. Most of these data will come in the form of GIS coverages.

We also will analyze landscape condition as it relates to conditions of other ecological resources imbedded within landscapes, such as Federally-listed species, breeding birds, and those of EMAP-Resource Groups (e.g., streams). This will require use of ancillary data (e.g., U.S. Breeding Bird Survey) and data generated by EMAP Resource Groups.

The primary differences between an in-depth analysis and a status report are increased specificity of landscape condition indicators and the introduction of ancillary data for more in-depth analysis.

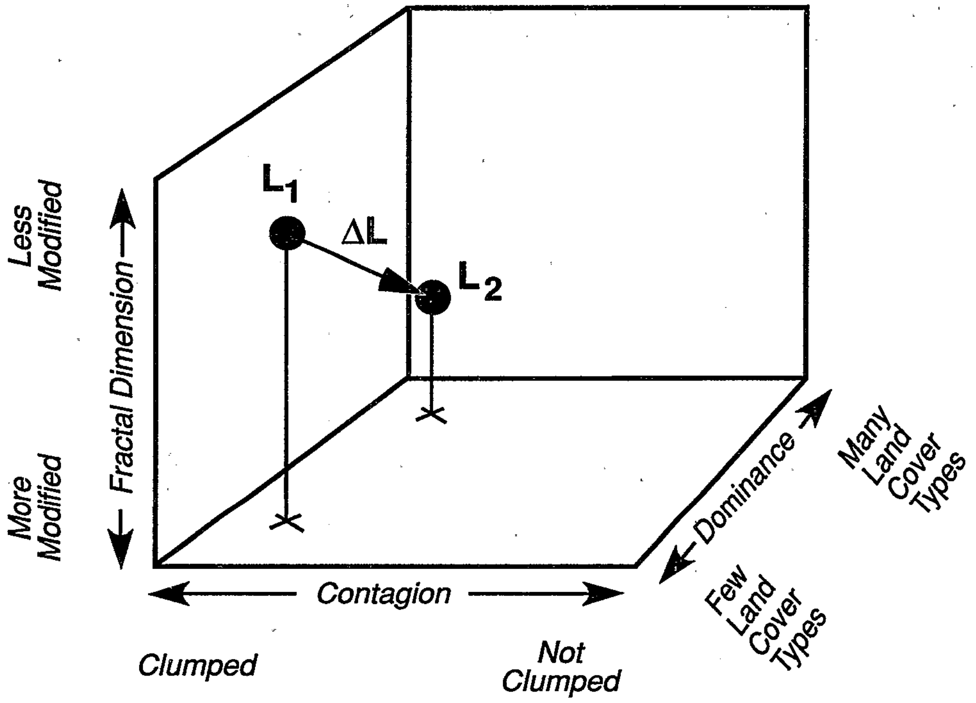


Figure 4.6 Three-dimensional landscape indicator space

5.0 IMPLEMENTATION OF EMAP-LANDSCAPES

EMAP-L proposes to implement its program simultaneously along two lines: (1) a series of pilots to address research and development issues and (2) determination of landscape status and trends within pilot areas for those indicators ready for implementation. Additionally, EMAP-L will conduct workshops and focused research on landscape values, assessment questions, and conceptual models.

EMAP-L is proposing two general pilot areas: one in the east and one in the west. The eastern pilot will be in the Mid-Atlantic Region of the United States. In FY94, work will be initiated in the Chesapeake Bay watershed part of this region; work will be expanded to the remainder of the area in FY95. The western pilot will be initiated in FY95. The location of the western pilot has not been determined although the Pacific Northwest, Rio Grande Basin, and Colorado Plateau are the leading candidates. The following criteria have been and will continue to be used for selection of pilot areas: (1) extensive existing remote sensing and GIS databases; (2) diverse or different landscape mosaics and conditions; (3) regional management focus and landscape emphasis with a number of participating organizations; (4) significant potential for collaboration with other EMAP Resource Groups and other Federal programs (e.g., GAP).

5.1 RESEARCH AND DEVELOPMENT

Research and development will address issues that must be resolved in order to fully implement the three-step landscape monitoring approach. These include (1) refining landscape values upon which the program will be based; (2) developing additional assessment questions related to each landscape value; (3) refining landscape conceptual models related to each value; (4) determining which landscape units and scales are appropriate for evaluating landscape values and associated assessment questions; (5) developing and testing landscape indicators and associated analysis techniques; and (6) developing and testing the three-step monitoring approach including key components in each step. Table 5.1 summarizes a preliminary list of research questions to be addressed by EMAP-L. Findings in each of these areas will be used to modify and implement key components of the three-step monitoring approach.

5.1.1 Landscape Values/Assessment Questions/Conceptual Models

Our aim is to identify societal values that relate, in part, to status and trends in the condition of landscapes. Biotic integrity and diversity, watershed integrity, and landscape sustainability and resiliency are the primary landscape values to be addressed by the landscape monitoring program. Research is needed to refine the landscape values and to list assessment questions relative to each value which help to define the scope of the monitoring. We propose to conduct an extensive literature review of societal values related to landscapes and to hold workshops and meetings with scientists, managers, and the public representing different regions of the United States to refine landscape values and to develop assessment questions. Additionally, we propose to compile existing conceptual models relevant to each landscape value and to refine models, as necessary.

5.1.2 Landscape Indicators

A key component of the landscape monitoring approach is the set of landscape indicators that associate landscape patterns to landscape values. We

Table 5.1 Preliminary list of research and development questions to be addressed by EMAP-Landscapes

Landscape Values and Assessment Questions

1. What are the primary hypotheses of association between landscape values and stressors and how do they vary by region?
2. What variation is there in the application of these landscape values to different regions of the country?
3. What is the specific set of assessment questions relative to landscape values?

Landscape Conceptual Models and Indicators

4. What models of landscape function, structure, and composition best describe landscape values?
5. What fundamental spatial and temporal scales are revealed by these models?
6. Which of the some 40 existing landscape indicators are independent and sensitive enough to describe status and trends of landscapes?
7. What are the levels of sensitivity (e.g., related to status and trends) of candidate landscape indicators? Do these sensitivities vary by region and scale?
8. To what degree do differences in classification of imagery affect landscape indicator performance? How do different levels of classification accuracy affect indicator performance?
9. What accuracy assessment sampling scheme is necessary to achieve a minimum of 80% accuracy for each ecological resource class used in the landscape analysis?
10. What spatial and temporal scales within each general landscape classification are important in describing status and trends in landscapes?
11. How do decisions about landscape units (e.g., type, size, shape, and scale) affect indicator performance?

Three-Step Monitoring Paradigm

12. Does land cover change detected using AVHRR accurately represent the change that would be detected using Landsat MSS?
13. What density and extent of land cover change detected with Landsat MSS and TM is necessary to trigger Step 2 characterization of land scape pattern and trends?
14. Do the improved sensor characteristics of Landsat TM as compared to MSS provide significantly more accurate land cover change detection results for Anderson (1976) Level I land cover categories?
15. What is the minimum size of landscape unit characterization (watersheds and landscape pattern types) relative to the density and extent of land cover change observed in Step 1? And does this size vary across the continental United States?
16. How well do selected landscape indicators relate to landscape values (e.g., watershed integrity), and can the variance in these indicators be used to construct nominal/subnominal boundaries for different landscape patterns (Step 3)?
17. What are the relative advantages of calculating landscape indicators from wall-to-wall imagery versus "sub-samples" of images?

have identified a preliminary list of landscape indicators (Table 5.2) and propose to compare these to landscape models developed for each landscape value; this will help us eliminate some of candidate indicators and identify others.

As the list of potential indicators grows, they will be subjected to a series of quality tests. Existing literature (e.g., O'Neill et al. 1988a) indicates that it is necessary to determine the range for each indicator of existing data for a wide variety of landscapes. The indicator may have a potential range from 1.0 to 2.0. But if diverse landscapes actually range from 1.3 to 1.35, the indicator may be of little use in discriminating patterns of real landscapes.

We will test for sensitivity by randomly varying pixels on existing landscape data sets; sensitivity tests will be conducted in pilot areas. A sensitive index will change with few pixel changes, whereas an insensitive index will change only slowly. Insensitive indicators may be useful for general classification purposes but will not be relied upon for trend analysis. On the other hand, an overly sensitive indicator may jump to the opposite end of its range with very few pixel changes and may be useless for overall assessment purposes.

Landscape indicators will be tested for their response (or sensitivity) to grain size and the number of classes. Indicator responses as a function of the number of classes are important because classified imagery is likely to have a wide range in the number of classes (e.g., 8-class NALC versus 25- to 30-class GAP analysis data).

The indicators will be tested for independence by calculating multiple indicators on existing landscape data and calculating covariances. Experience has shown that different indicators may, in fact, be capturing the same aspects of pattern; these tests will be conducted on pilot areas.

The indicators will be subjected to uncertainty analysis by field tests. The tests will be conducted in collaboration with EMAP resource groups and other programs working in the field (e.g., U.S. Soil

Conservation Service's NRI). The suite of indicators will be calculated from imagery and will be tested for accuracy, sensitivity to change, etc., via ground truth. These tests will be conducted in pilot areas.

Finally, it is a research issue to determine thresholds of landscape indicator values as they pertain to landscape condition and each landscape value.

Indicators that pass through these tests will be implemented within the region in which they were tested. It is likely that some implemented landscape indicators will be dropped in favor of indicators with greater resolving power; these latter indicators will come from ongoing research and development activities within and outside the EMAP-L program.

5.1.3 Three-step Monitoring Approach

Implementing EMAP-L's three-step monitoring approach involves answering many technical and methodological questions; these include evaluating indicators, as well as other issues (see Table 5.1). EMAP-L will address these issues through pilot studies and simulations.

We propose to acquire multi-date Landsat-MSS (early 1970s, 1980s, and 1990s), and Landsat-TM coverages for each of the pilot areas. One objective is to evaluate the decision criteria (e.g., the magnitude and distribution of change) used to trigger Step 3 analysis. We will test Step 3 association analyses by comparing landscape indicators in areas undergoing known changes with data on both natural (e.g., climate, fire, floods) and anthropogenic (e.g., land use type and distribution) stresses.

A second objective is to compare landscape indicator values derived from Landsat-MSS images with those derived from Landsat-TM. If Landsat-MSS indicator values are similar to those derived from Landsat-TM, then there is an opportunity to conduct a retrospective analysis of landscape status and change, with a baseline of the early 1970s; these data will then be comparable to future estimates of landscape status and trends derived from Landsat-TM. The major advantage of using these data is that EMAP-L could produce an assessment of landscape status and trends within pilot areas and, potentially, over most of the United States. A similar Landsat-MSS database is being used to evaluate land cover change over the entire Australian continent (Dean Graetz, CSIRO-Australia, personal communications).

EMAP-L will evaluate the use of different ecoregional approaches (e.g., Bailey, Omernick, and Kuchler) to characterize landscapes and two methods of classifying landscapes within ecoregions: by watersheds and by land cover pattern types (Wickham and Norton 1994). EMAP-L will also evaluate the relative advantages and disadvantages of calculating landscape indicators on a "sub-sample" of landscapes (e.g., a randomly selected subset of the total landscapes) versus all landscapes within a region.

Finally, the hypothesis that annual AVHRR and other agency data are sufficient to detect landscape changes between 10-year status and trends reports must also be tested. The basic concept is to perform change detection analysis using annual AVHRR data and other agency data, and to estimate landscape change and to compare these results to those derived from Landsat-TM and Landsat-MSS data. The objective is to estimate the risk of missing a significant change in land cover between 10-year resamples.

5.2 IMPLEMENTATION OF LANDSCAPE MONITORING

The rate of implementation of EMAP-Landscapes will depend on our success in resolving key technical issues and on funding scenarios. Implementation of the program nationally will proceed by (1) increasing the area of pilot studies to cover applicable natural regions (e.g., Bailey's ecoregions) and (2) adding on new regions. The schedule for adding on new regions will be coordinated with EMAP-LC and EMAP Resource Groups. Coordination with EMAP Resource Groups will be important especially when both landscape and Resource Group level data (e.g., fine scale habitat characteristics) are needed to address a common value (e.g., biotic diversity).

We anticipate initiating status and trends assessments in pilot areas for those indicators ready for implementation (see Table 5.2). As other indicators pass through a series of sensitivity and uncertainty analysis, they will be added to the status and trends assessments.

Table 5.2 Status and Utility of Landscape Indicators

	Status(a)	Utility(b)
WATERSHED INTEGRITY INDICATORS		
Dominance	C	ST
Fractal dimension	C	ST
Contagion	C	ST
Lacunarity	A	ST
Erosion risk	A	D
Flood indicator	A	D
Riparian zones	C	D
Loss of wetlands	C	D
Agriculture near water	B	D
Miles of new roads	B	D
Amounts of agriculture and urban	C	D,ST
Watershed/water quality indicator	A	D
LANDSCAPE STABILITY AND RESILIENCE INDICATORS		
Dominance	C	ST
Fractal dimension	C	ST
Contagion	C	ST
Lacunarity	A	ST
Diffusion rates	A	D
Percolation backbone	B	D
Percolation thresholds	B	D
Miles of roads	B	D
Recovery time	A	D
Land cover transition matrix	A	D
BIOTIC INTEGRITY AND DIVERSITY INDICATORS		
Dominance	C	ST
Fractal dimension	C	ST
Contagion	C	ST
Lacunarity	A	ST
Change of habitat	C	D,ST
Habitat for endangered species	C	D
Loss of rare land cover	C	D
Corridors between patches	B	D,ST
Amount of Edges	C	D,ST
Edge amount per patch size	B	D,ST
Patch size distribution	C	D,ST
Largest patch	B	D,ST
Inter-patch distances	B	D,ST
Linear configurations	A	D,ST
Actual vs. Potential vegetation	B	D
Wildlife potential	A	D,ST
Miles of new roads	B	D
Diffusion rates	A	D
Percolation backbone	B	D
Percolation thresholds	B	D
Resource utilization scale	B	D,ST
Scales of pattern	A	D,ST
Cellular automata	A	D
Pixel transitions	A	D

(a) Status categorizes each indicator as:
A = Requiring further conceptual development
B = Requiring testing for feasibility/sensitivity
C = Ready for field tests and implementation
(b) Utility categorizes each indicator for use in:
ST = Status and trends assessments
D = Diagnostic or association assessments

Our ability to produce retrospective change and trend analysis within pilot areas over the next 3-5 years will depend on results of research on Landsat-MSS, as well as funding to label Landsat-MSS provided by NALC. If both of these conditions are met, we propose to produce an initial landscape status assessment (T_0) for the early 1970s. A second status assessment would be produced from the mid-1980s data, and differences between the early 1970 and mid-1980 images (t_0 - t_1) would be used to identify areas undergoing changes in landscape pattern. We would then conduct Step 3 assessments in areas meeting change criteria. We would repeat this process by comparing mid-1980s and early 1990s data (t_1 - t_2). By the mid to late 1990s, Landsat-TM should be available for the entire country. Landsat-TM would be used for the fourth sample in the series (t_2 - t_3).

5.3 COLLABORATIVE EFFORTS PROPOSED BY EMAP-L

EMAP-L anticipates close collaboration with EMAP Resource Groups and other monitoring and assessment programs as described below.

- EMAP and the Biological Diversity Research Consortium propose to jointly investigate the condition of biological diversity components (e.g., habitat condition, species richness) on regional and national scales. EMAP-L will use assessments of landscape status and trends to help characterize risk to biological diversity components.

- EMAP-LC has entered into an agreement with the USGS National Aquatic Water Quality Assessment Program, NOAA's Coastwatch Change Analysis Program, and the U.S. National Biological Survey's GAP Analysis Program to acquire and classify wall-to-wall Landsat-TM imagery for the United States. EMAP-L proposes to work with this group in obtaining Landsat-TM data for calculating landscape indicators.

- NALC, in collaboration with the USGS EROS Data Center, is processing Landsat-MSS data for three time periods in a large portion of the United States. NALC is also developing change detection techniques for use with these data. EMAP-L proposes to collaborate with NALC and to use NALC's Landsat-MSS data to begin testing EMAP-L's monitoring strategy within pilot areas.

- EMAP-L and EMAP-LC will work closely on a number of issues, including development of landscape classifications for calculating landscape indicators and accuracy assessment protocols.

- EMAP-L anticipates collaborating with EMAP Resource Groups to address common societal values such as biotic diversity within the pilot areas, and to obtain ground truth of remote sensing data.

- EMAP-L anticipates working closely with EPA regional offices and EPA's Risk Assessment Forum on issues relating to characterization and assessment of regional ecological risks. The degree of collaboration will depend on mutual interests and benefits for specific questions.

5.4 PROJECT MILESTONES/ACTIVITIES

A general schedule of EMAP-L activities and milestones anticipated over the next 5 years is listed in Table 5.3. Dates listed for activities and milestones represent EMAP-L's best estimates based on budget projects. However, dates listed for activities and milestones are likely to deviate from those listed, especially in latter years.

Additionally, pilot studies other than those listed may be initiated in FY94 - 98 due to changes in EMAP and EPA priorities.

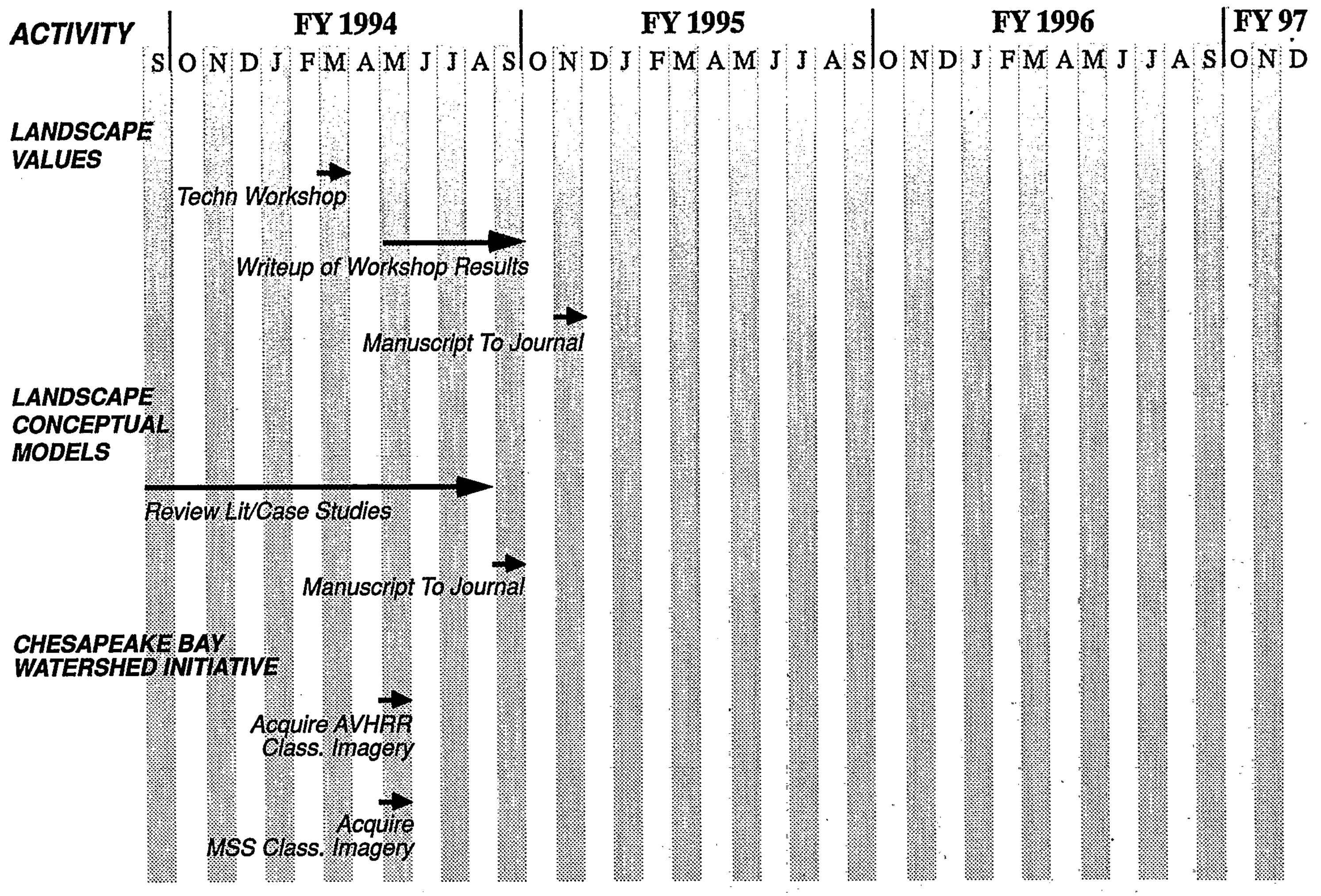


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs

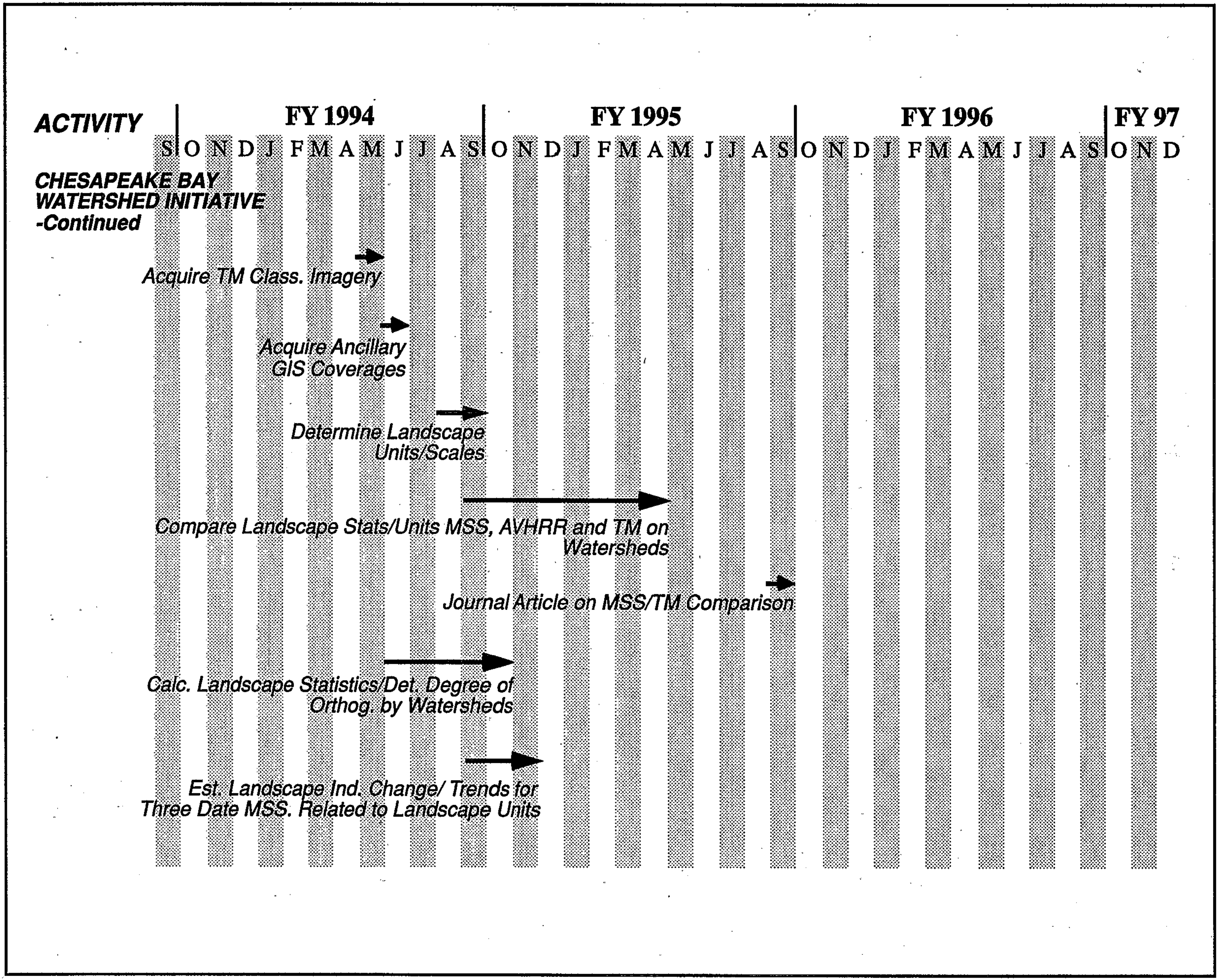


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs - continued

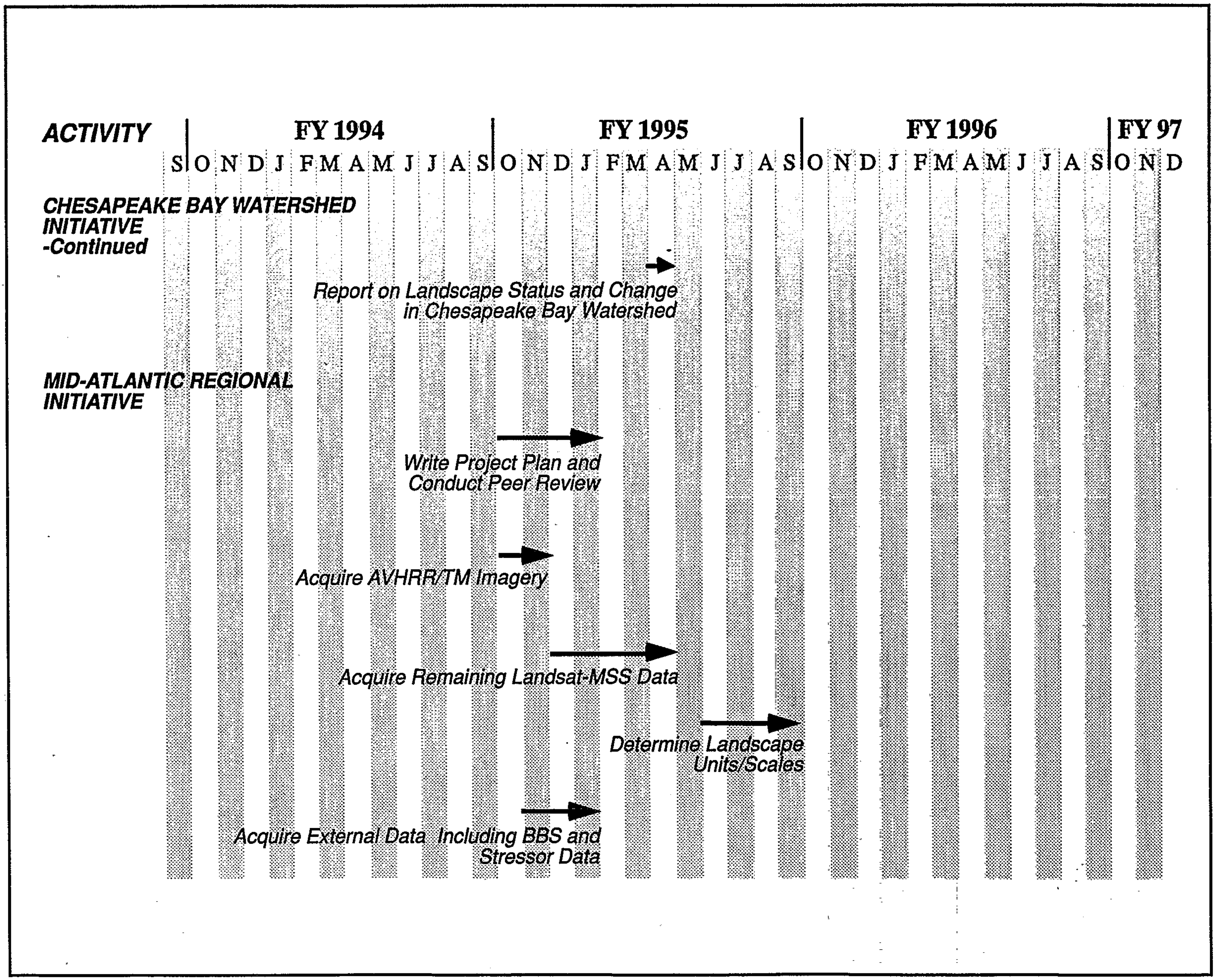


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs - continued

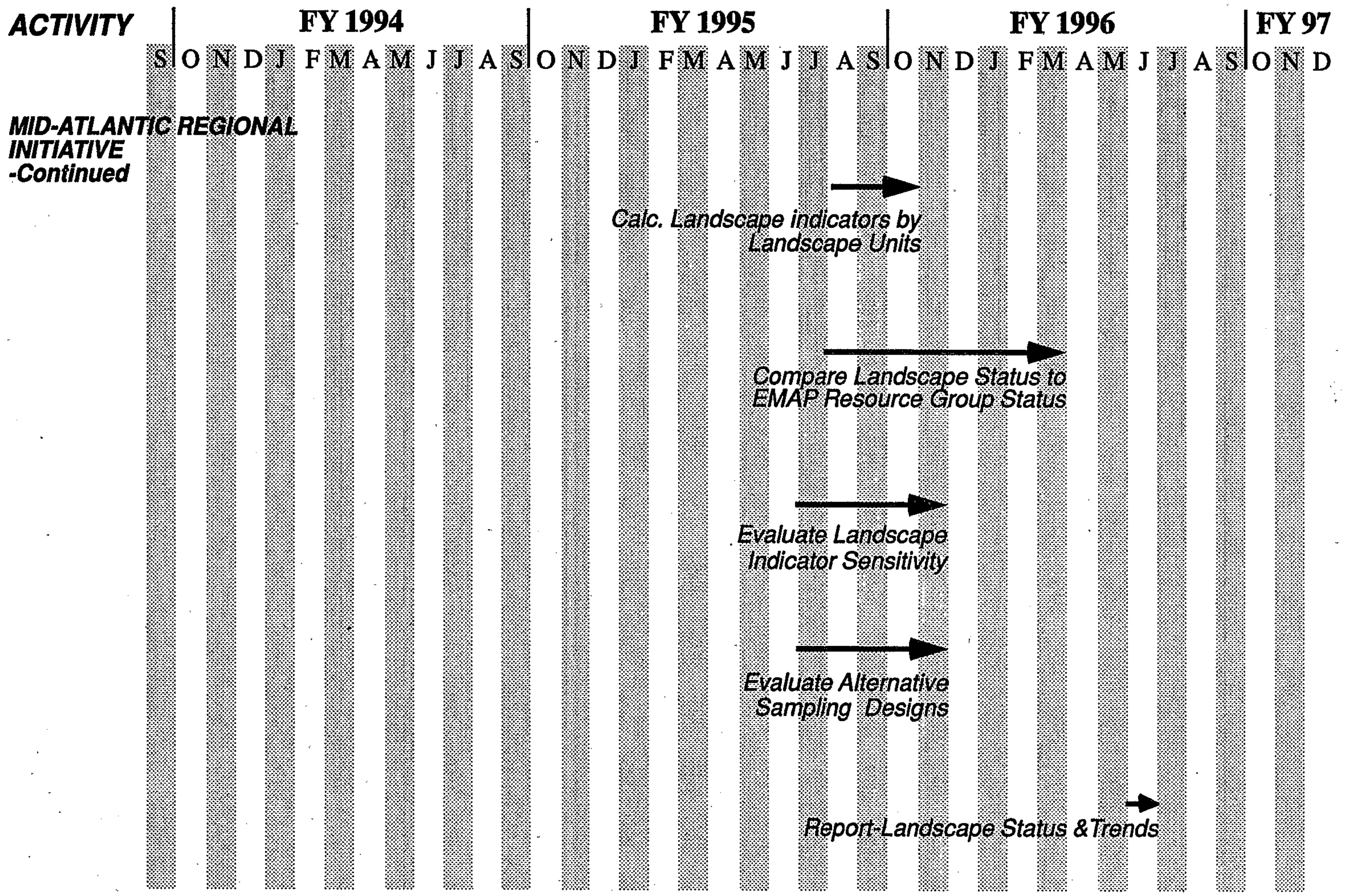


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs - continued

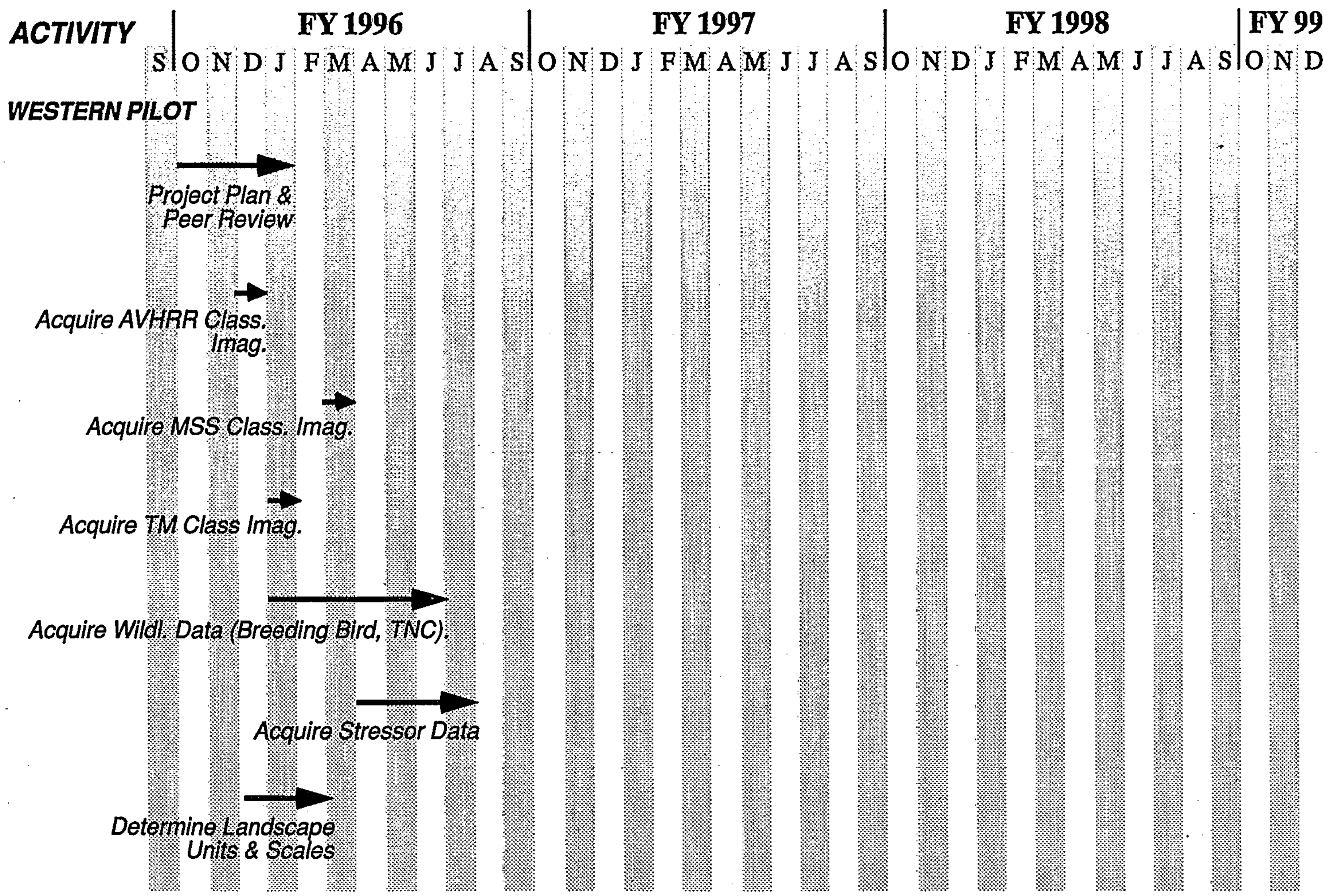


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs - continued

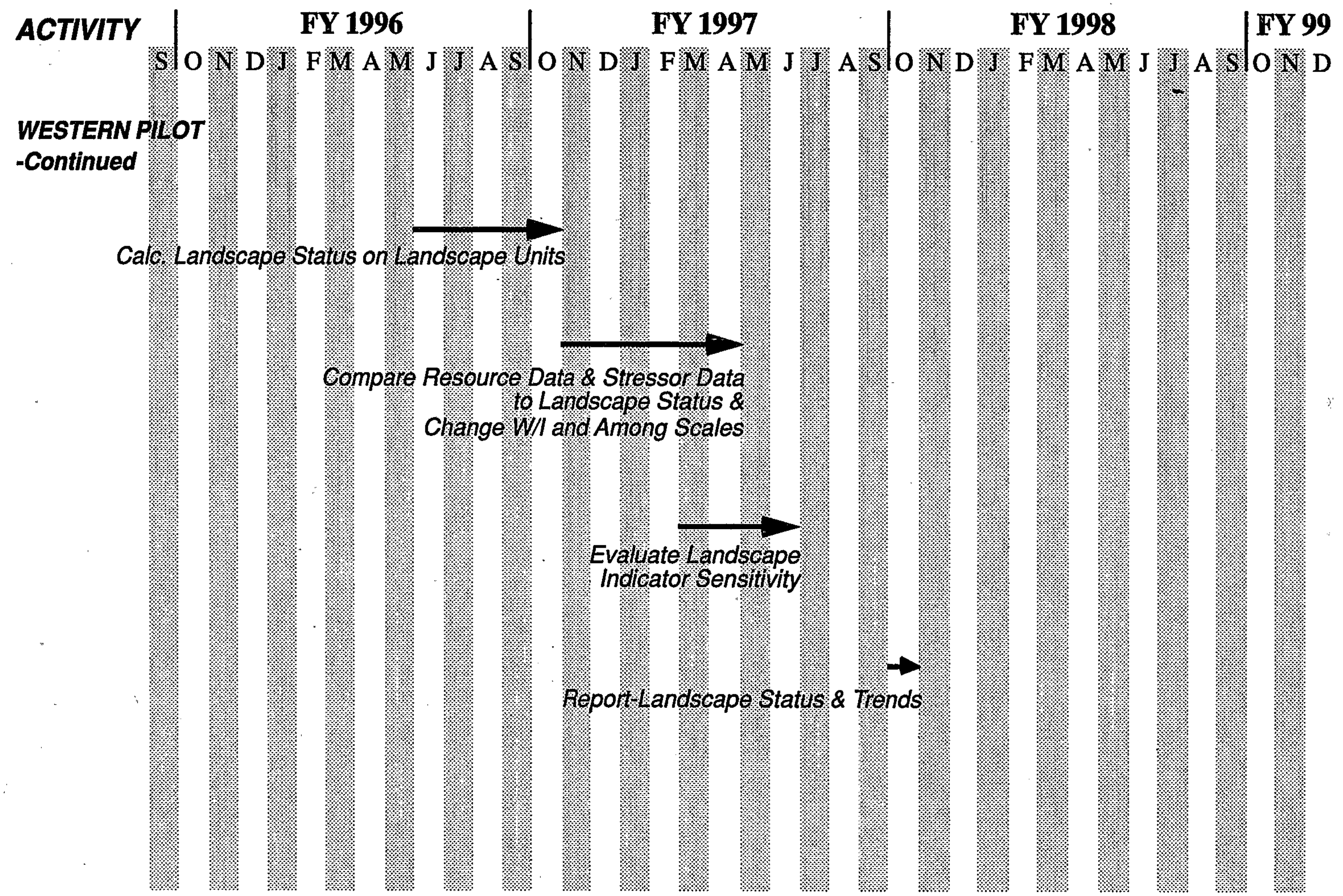


Table 5.3 Schedule of EMAP-L Activities and Expected Outputs - continued

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