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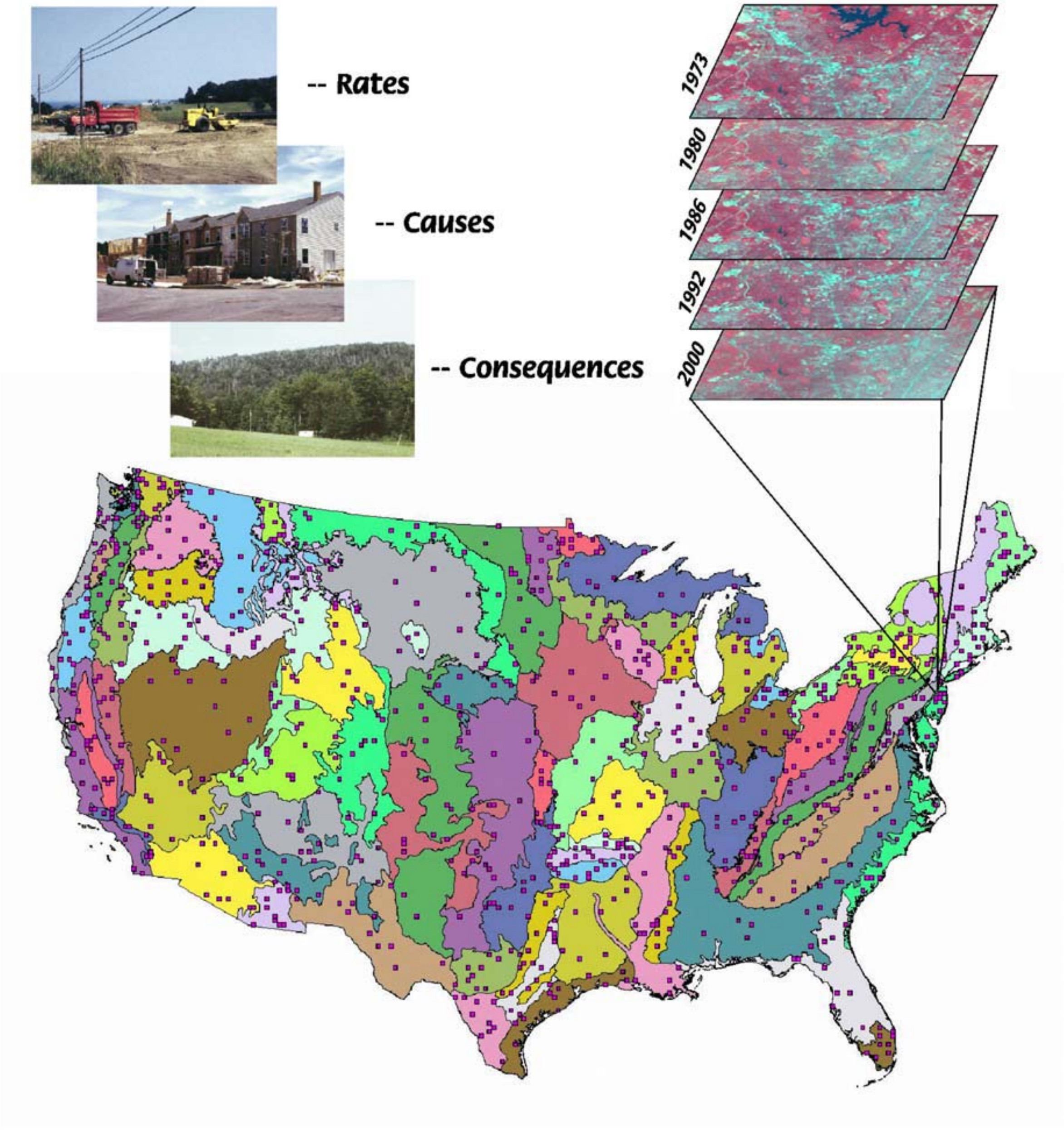
Land Cover Trends: Rates, Causes, and Consequences of Late-Twentieth Century U.S. Land Cover Change



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Land Cover Trends: Rates, Causes, and Consequences of Late-Twentieth Century U.S. Land Cover Change

Research Plan
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Notice

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Abstract

Information on the rates, driving forces, and consequences of land use and land cover change is important in studies addressing issues ranging from the health of aquatic resources to climate change. Land use and land cover changes occur at all scales, and changes at local scales can have dramatic, cumulative impacts at broader scales. Consequently, land use and land cover changes are not just of concern at local and regional levels (i.e., because of impacts on land management practices, economic health and sustainability, and social processes), but globally as well. Unfortunately, there is a paucity of information on land use and land cover change except at very local levels. This four-year research project between the U.S. Geological Survey and the U.S. Environmental Protection Agency has a goal to document the types, geographic distributions, and rates of land cover change on a region-by-region basis over the past 30 years for the conterminous U.S., and to determine some of the key drivers and consequences of the changes. The objectives of the study are to:

- Develop a comprehensive methodology for using sampling and change analysis techniques and Landsat MSS and TM data for measuring regional land cover change across the U.S.
- Characterize the types, rates, and temporal variability of change for a 30-year period.
- Document regional driving forces and consequences of change.
- Prepare a national synthesis of land cover change.

The estimates of conterminous U.S. rates, driving forces, and consequences of land cover change will be developed for 84 ecoregions defined by Omernik of the U.S. Environmental Protection Agency. Using a 20 km by 20 km grid covering each ecoregion, a random sample of cells will be selected for each of the 84 ecoregions. The sample size will be based on the expected spatial variance of land cover change between grid blocks, a 1.0% margin of error and a 0.85 confidence level. Land cover data and change analyses will be developed for each ecoregion and summarized for the conterminous U.S. The analysis of change will be based on five dates of Landsat MSS and TM data (nominally 1973, 1980, 1986, 1992, and 2000). Data for each sample block will be geocoded, calibrated, and interpreted. The land cover change variables that will be mapped include: (1) general land cover type; (2) landscape biophysical properties; and (3) landscape pattern. The major emphasis will be placed on mapping the general land cover types and changes for each sample block. The biophysical variables (i.e., vegetated fraction, bare fraction, and shadow fraction), developed using spectral unmixing methods, will be used to understand landscape condition, such as successional or other gradual land cover transitions. Finally, landscape pattern metrics, describing the number, size, shape, and spatial relationship of land cover patches (where patch is a contiguous set of pixels of the same land cover type), will be generated from the general land cover data for each block. These will permit the analysis of the spatial dimension of land cover change, and will also contribute to the assessment of consequences of land cover change.

Our goal is to identify 1% change in general land cover within each ecoregion, at an 85% confidence level. Initially, we will test our ability to achieve this goal in five pilot regions: (1) Montana Valley and Foothill Prairies, (2) North Central Appalachians, (3) Northern Piedmont, (4) Southeastern Plains, and (5) Madrean Archipelago. Based on the results of the pilot tests, we will refine and apply an appropriate methodology to the remaining conterminous U.S. ecoregions.

Section 1

Project Rational

Local land use and land cover changes are fundamental agents of global climate change and are significant forces that impact biodiversity, water and radiation budgets, trace gas emissions, and ultimately, climate at all scales (Riebsame et al., 1994). At local and regional scales, land cover change can have profound impacts on aquatic systems due to new land use practices that adversely affect water quality and sedimentation (Lowrance et al., 1985). Such changes also modify the composition of plant communities through fragmentation, removal and introduction of species, alteration of nutrient and water pathways, and alteration of disturbance cycles (e.g., Ojima et al., 1994).

Land use and land cover changes are driven by: (1) natural processes, such as climate and atmospheric changes, wildfire, and pest infestation; (2) direct effects of human activity, such as deforestation and road-building; and (3) indirect effects of human activity, such as water diversion leading to lowering of the water table. Natural processes and human activities can both improve or degrade the state of the land, so it is essential to distinguish beneficial from detrimental changes (Turner and Meyer, 1991).

Land use and land cover changes occur at all scales, and changes at local scales can have dramatic, cumulative impacts at broader scales. Consequently, land use and land cover changes are not just of concern at local and regional levels (i.e., because of impacts on land management practices, economic health and sustainability, and social processes), but globally as well. The challenge facing policy-makers and scientists is that there is generally a lack of comprehensive data on the types and rates of land use and land cover changes, and even less systematic evidence on the causes and consequences of the changes. Lack of local and regional data of sufficient reliability and temporal and geographic detail frustrates attempts at fine-tuned assessments of the implications of such changes.

The impacts of land use and land cover change is critical to many government programs. For example, documenting the rates, driving forces, and consequences of change, particularly in aquatic resources, is a central focus in the U.S. Environmental Protection Agency's Landscape Sciences Program 10-year strategic plan (Jones, et al., 1999). The strategic plan has a goal to complete a national assessment of landscape change between the early 1970's and the early 2000's and to assess the consequences of those changes on aquatic resources. This aggressive goal is further institutionalized in the Agency's goals developed under the Government Performance Results Act.

1.1 Science Issues

The fundamental science questions associated with land use and land cover changes are:

- What are the types and geographic distributions of change?
- What are the overall rates of change by region and by sector (i.e., rates of conversion from agricultural to urban land cover)?
- How do the rates vary (a) locally and regionally and (b) temporally?

- What are the driving agents and consequences?

Developing our understanding in these areas will lead to improved ability to predict changes and, consequently, to improved policies for practical, regional management of environmental resources.

Specific answers to these questions are currently not available. While federal resource inventory programs, such as the U.S. Forest Service Forest Inventory and Analysis and the Natural Resources Conservation Service Natural Resources Inventory, provide some answers, they fall far short of providing the spatially explicit, thematically comprehensive data that are really required. On the other hand, initiating a program to develop periodic, wall-to-wall mapping of land cover change for the U.S. at a temporal interval appropriate for determining types, distributions, rates, agents, and consequences of change is cost-prohibitive. Consider, for example, that the current 1992 land cover inventory conducted by the USGS Land Cover Characterization Program will cost almost $10 million over 4 years. Providing two additional periods of coverage suitable for documenting land cover changes would require a minimum of $15 million over a four-year period. A more feasible and cost-effective strategy is to use a sampling approach that incorporates a temporal, spatial, and information resolution appropriate for regional and national evaluations.

As a first step in understanding the above science questions, this research project will focus on the following four hypotheses:

1. Rates and characteristics of land cover change vary over time and space.
2. Stratified random sampling, based on an ecoregion framework, can provide useful and efficient measures of the spatial characteristics of land cover change.
3. Satellite data, specifically Landsat MSS and TM, can be used to provide accurate estimates of regional land cover change which can then be aggregated to summarize change at a national level.
4. Landscape change metrics derived from satellite remotely sensed data (e.g., land cover type, biophysical measures, and landscape patterns) provide evidence of the driving forces and consequences of regional land cover change.

The four hypotheses form the foundation for important basic research, with a number of measurement components that can be addressed using remotely sensed data. Because of developments in large-area statistical sampling techniques, availability of recent (baseline) Landsat TM-derived land cover data and derivative products, availability and affordability of new satellite data (e.g., Landsat 7), and an established track record for successfully handling large-area analyses, our multidisciplinary team of scientists is well-poised to make substantial progress in addressing questions related to land use and land cover changes. Toward this end, we will use a geographic framework for selecting and acquiring regionally representative samples of remotely sensed and ancillary time series data in order to map the types, distributions, rates, agents, and consequences of land cover change in the U.S. over the latter portion of the twentieth century.

1.2 Project Goal and Objectives

Recognizing both the need and challenges for providing spatially-explicit contemporary land cover trends data, the goal of this four-year research project will be to document the types, geographic distributions, and rates of land cover change on a region-by-region basis over the past 30 years, and to determine some of the key drivers and consequences of the changes. The USGS EROS Data Center and the Landscape Ecology Branch of the EPA Las Vegas Laboratory will collaborate in this effort. The objectives for achieving this goal were defined to test the four hypotheses listed in the previous section. The objectives are to:

- Develop a comprehensive methodology for using sampling and change analysis techniques and Landsat MSS and TM data for measuring regional land cover change across the U.S. (hypothesis 2 and 3).
- Characterize the types, rates, and temporal variability of change for a 30-year period (hypothesis 1 and 2).
- Document regional driving forces and consequences of change (hypothesis 4).
- Prepare a national synthesis of land cover change (hypothesis 3).

A central premise of the project strategy is the use of a geographic framework for providing unbiased estimates of regional land cover. Such an approach is sound (S. Stehman 1999, pers. commun.), and the benefits of geographically subdividing the U.S. in order to adequately sample regions of interest has already been demonstrated by the EPA in high-profile national aquatic resource surveys (Baker, 1990; Kaufmann et al. 1991; Linthurst et al. 1986). Geographers have long used regional frameworks because they capture the essence and potential of the landscape, without masking the roles of environmental, social, and economic forces (Turner and Meyer, 1991). Peplies and Honea (1992) argue that ecoregions, such as those defined by Omernik (1987), are the appropriate geographic framework for the study of environmental change. In fact, the International Geosphere-Biosphere Programme's Land Use Cover Change core science project has recommended that geographic regions be used as the strata to extrapolate land use change observations from local to regional to global levels (Turner et al., 1995).

Relationships between the ecological regions delineated by Omernik and remotely sensed land cover patterns have been noted, particularly in correlation with seasonal data (e.g., Ramsey et al. 1995; Loveland et al. 1991). Ecoregions are currently being used to stratify remotely sensed data for some parts of the U.S. in order to interpret and map land cover for the USGS/EPA Multi-Resolution Land Characterization (MRLC) project. The ecoregions have proven useful for other types of environmental interpretation as well, such as assessing patterns of aquatic resources (e.g., Larsen et al. 1988; Heiskary et al. 1987).

Because Omernik's ecoregion framework was developed by synthesizing information on climate, geology, physiography, soils, vegetation, hydrology, and human factors, the regions reflect patterns of land cover and land use potential that correlate strongly with patterns visible in remotely sensed data. The framework stratifies the nation into relatively homogenous units with respect to these factors. The character of each region establishes the range of land cover changes that can potentially occur. In effect, each ecoregion serves as a spatial model for the interplay between complex environmental and anthropogenic factors. These ecoregions have been demonstrated to be useful strata for predicting environmental responses, and are increasingly recognized as an important spatial framework for state-of-the-environment reporting. By sampling land cover change for each of the ecoregions, using selected epochs of data from the nearly 30-year record of Landsat 1-7 data, both regional and national characteristics of change can be determined.

1.3 Relevance to Other Programs

The EPA and USGS both recognize the necessity for land cover change data for use in environmental risk and monitoring research. The need is particularly well-defined in the most recent 10-year strategic plan for the EPA Land Sciences Program (Jones et al., 1999). This project will provide both organizations with land cover change statistics that will aid in establishing an intellectual framework of the temporal and spatial aspects of contemporary land use change. Additionally, the results of the project are likely to be relevant to a number of other environmental assessment, land management, and science programs:

- U.S. Global Change Research Program (USGCRP), including the land-use change and terrestrial and marine ecosystems science priority and the National and Regional Climate Assessment cross-cutting initiative
- The USGCRP Carbon Cycle Initiative which calls for the “evaluation of information from past and current land-use changes, both from remotely sensed and historical records, to assess how human activity has affected carbon storage on land.”
- NASA Land Cover and Land Use Change Program
- Department of the Interior Inventory and Monitoring Initiative
- USGS Land Use History of North America
- Heinz Center Environmental Report Card
- Association of American Geographers (AAG), with National Science Foundation support, ongoing project titled *Global Change and Local Places*, providing a model for interpretation of local driving forces and signals of climate change
- International Geosphere-Biosphere Program Land Use Research Cover Change Core Project
- North America Free Trade Agreement Committee on Environmental Cooperation
- Intergovernmental Panel on Climate Change

The potential links between the proposed project and other programs are numerous. A key element of the project will be liaisons with relevant programs, as well as support for key applications of our land cover change data.

Section 2

Review of Past Land Cover Trends Research

2.1 Land Cover Change Detection

There is considerable evidence demonstrating the use of Landsat data for investigating contemporary land cover change. It is noteworthy that while a great deal has been written regarding change detection techniques, very little guidance is available to address the special problems associated with large-area (regional to global) image processing, and even less guidance addressing large-area change detection (Dobson and Bright, 1994). Perhaps the most ambitious effort is the Humid Tropical Forest project, where Landsat imagery from the 1970’s to present were manually interpreted to identify patterns of deforestation across the humid tropics (Skole and Tucker, 1993). Most land cover change studies do not address land transformations for such a large area. The Coastal Change Analysis Project (C-CAP) is an ongoing study of land cover change in the coastal zones of the U.S. (Dobson et al., 1995). In this project, digital analyses of Landsat data have been used to track general land cover transformations. There are also examples of operational programs in which sampling strategies involving both field observation and air photo interpretation have been applied to determine the status and trends in land resources. Perhaps the best example is the National Resources Inventory of the U.S. Department of Agriculture Natural Resources Conservation Service. However, the use of Landsat data in a sample framework is not commonplace.

Numerous papers discuss the various change analysis techniques commonly used (Singh, 1989). There are two general approaches to change detection: (1) comparative analysis of independently produced classifications and (2) simultaneous analysis of multitemporal data. Examples of the simultaneous analysis techniques include image differencing, ratioing, principal component analysis (PCA), and change vector analysis. Each has advantages and disadvantages.

The most straightforward technique for detecting change is the comparison of land cover classifications from two dates. The use of independently produced classifications has the advantage of compensating for varied atmospheric and phenological conditions between dates, or even the use of different sensors between dates, because each classification is independently produced and mapped to a common thematic reference. The method has been criticized, however, because it tends to compound any errors that may have occurred in the two initial classifications (Gordon, 1980; Stow et al., 1980; Singh, 1989). The procedure has been widely used, and has successfully been employed for a variety of land cover change investigations, including assessing deforestation (Massart et al., 1995) urbanization (Dimyati et al., 1996), sand dune changes (Kumar et al., 1993), and conversion of semi-natural vegetation to agricultural grassland (Wilcock and Cooper, 1992).

Simple image differencing is another technique widely used for change detection. This technique involves taking the mathematical difference between geo-registered images from two dates. The input data can be radiometrically calibrated raw imagery, or transformed data such as NDVI imagery. The procedure has been used for coastal zone change detection (Weismiller et al., 1977), monitoring forest change (Vogelmann, 1988), and detecting urban expansion (Jensen and Toll, 1982). While often producing excellent results, it has been suggested that image differencing alone may be too simple a procedure to adequately describe many surface changes (Weismiller et al., 1977; Jensen and Toll, 1982;

Sohl, 1999). Other approaches used successfully to detect land cover change include image ratioing (Howarth and Wickware, 1981) and PCA (Johnston and Haas, 1985; Bryne et al., 1980; Ribed and Lopez, 1995). See Singh (1989) for a discussion of the strengths and weaknesses of these approaches.

Surface change can also be described by a spectral change vector, which represents the direction and magnitude of change from the first to the second date. An empirically derived or modeled threshold is used to determine the minimum magnitude that represents a change occurrence. Dwyer et al. (1997) used data from the brightness-greenness plane (Kauth and Thomas, 1976; Crist and Cicone, 1984) in the development of a change vector analysis (CVA) toolkit. Sohl (1999) successfully used this toolkit in the analysis of change in the United Arab Emirates. Change vector analysis has the advantage of providing a high level of information regarding the magnitude and nature of a surface change, and is well-suited for analyses in which continuous variables are measured, such as vegetation patterns along ecological transitions and gradients.

An alternative strategy for detecting change involves spectral mixture modeling, whereby a multispectral image is decomposed into spectral endmembers. There are numerous approaches to stratifying the image into vegetated and non-vegetated components (Cochrane and Souza, 1998; Foschi and Smith, 1997; Roberts et. al., 1993). The validation of spectral mixture modeling results can be difficult, especially for large areas, and the determination and selection of appropriate spectral endmembers is critical (Bateson and Curtiss, 1996; Tompkins et al., 1997). The spectral mixture modeling approach, however, can yield meaningful results if a well-documented and consistent approach is taken. Field validation of model results remains problematic, but if the modeling procedures are prescribed and adhered to, then the comparison of fractional endmember components from one date of imagery to another should yield consistent and interpretable results.

A number of change detection studies rely on combination or hybrid approaches that incorporate many of the features of the techniques outlined above, or incorporate techniques that do not easily fit into any of the above categories. Adams et al. (1995) measured changes in land cover by classifying images based on spectral endmember fractions over a period of 4 years, with class names representing both context and pixel history. Weismiller et al. (1977) tested the linking of decision tree classifiers for each of two dates, thereby introducing within the tree a logic for detecting the desired changes. Sohl (1999) used simple image differencing in combination with manually interpreted land cover information to describe changes in agricultural and forest cover in the United Arab Emirates.

The prerequisite preprocessing step to many change analysis techniques is to calibrate the images to a common radiometric reference. Ideally, this would involve the transformation of digital numbers to physical values of radiance or reflectance, but the information required for this is not widely available. A viable and widely used alternative is to perform a relative calibration between imagery from different dates. This usually involves the use of a linear transformation in which the additive component corrects for differences in atmospheric path radiance and the multiplicative component corrects for differences in detector calibration, sun angle, Earth-Sun distance, atmospheric attenuation, and phase angle conditions (Dwyer et al., 1997). Radiometric control sets representing temporally invariant features are used to derive gains and offsets for the linear transformation. These control sets can be derived from a variety of methods, including various methods identifying pseudo-invariant bright and dark targets (Caselles and Garcia, 1989; Hall et al., 1991), the use of ratios of near-infrared to red radiances to identify non-vegetated, non-water elements (Schott et al., 1988), and automated scattergram-controlled regression (Elvidge et al., 1995).

A major attribute of the landscape is its spatial pattern and structure. Lambin and Strahler (1994) showed that the detection of land-cover change processes by remote sensing is improved when using both spectral and spatial indicators of surface condition. They suggested that while spectral indicators are more sensitive to fluctuations in primary productivity associated with the interannual variability in climatic conditions, changes in landscape spatial pattern are more likely to reveal long term and long lasting land cover changes. A wide variety of landscape metrics have been developed (Riitters et al., 1995). Turner (1990) used patch size metrics, indices of dominance, and indices of contagion to describe changes in land use/land cover patterns in rural Georgia. Henderson and Walsh (1995) used measures of connectivity, fractal dimension, and indices of dominance and fragmentation to describe land-cover change on the North Carolina Piedmont.

2.2 Land Cover Change Accuracy Assessment

While a great deal has been written about change analysis techniques using remotely sensed data, very little has been written on the subject of accuracy assessment of change products. Even fewer articles have been written on accuracy assessment of large area change analysis databases. Standard accuracy assessment procedures for one-point-in-time land cover products can be extremely difficult to apply to multitemporal change analysis products. While accuracy assessment methods are well established for small areas and single time periods, the assessment of accuracies for large areas, past time periods, and change databases can become problematic (Dobson and Bright, 1994).

A standard accuracy assessment procedure for baseline land cover products involves the use of the error matrix. The error matrix is an effective descriptive tool for organizing and presenting accuracy assessment information and should be reported whenever feasible (Stehman, 1997). While the error matrix can be modified and used for change analysis products (Macleod and Congalton, 1998), it is difficult to apply to trend analysis or for adequately assessing more than a handful of categories of change.

The assessment of trends requires additional tools besides the error matrix. Correlation is an excellent tool, as it can quantify the agreement between reference and mapped data over several time periods. For example, given mapped- and reference-derived values of percent forest cover, a correlation approach could determine the level of agreement in the trends depicted in the data from the two sources. This approach has the potential for other metrics than just percent cover if appropriate reference data are available. The primary disadvantage of the approach is that errors of omission and commission can compensate for each other, contributing to misleading overall measures of change. Accuracy assessment of land cover classifications for individual dates could serve as a complement to the correlation values through the incorporation of spatially dependent information.

Accuracy assessment of a large area change database is an extremely challenging task. A complete, quantitative accuracy assessment may prove to be more expensive and labor intensive than the change database itself. Dobson (1992) goes so far to say that it is infeasible to provide a quantitative estimate of accuracy for a large spatial database. He states that a possible solution is to establish data quality objectives (DQOs) designed to serve expected uses, establish and consistently implement a set of protocols and procedures, and manage the data production process to meet the DQOs. Qualitative and simple quantitative analyses often prove to be much more feasible than a comprehensive quantitative analysis.

Section 3

Overall Project Strategy

The project will address the types, distributions, rates, drivers, and consequences of change for the conterminous U.S. between the early 1970's (nominally 1972-1973) and 2000. These issues will be investigated in two phases. First, a pilot phase will focus analysis on five ecoregions:

- Montana Valley and Foothill Prairies
- North Central Appalachians
- Northern Piedmont
- Southeastern Plains
- Madrean Archipelago

These ecoregions have been selected because they: (1) offer a wide range of challenges for sampling design, including steep environmental gradients, discontinuous and irregularly shaped strata, and a spectrum of spatial variability in land cover types and scales of pattern and (2) relate to key interests of the EPA Landscape Ecology Program, including assessment of hydrological dynamics of the Mid-Atlantic region and landscape change along environmental gradients (Jones et al. 1999). Appendix B provides a brief summary of the salient characteristics of each of the pilot ecoregions. In the pilot phase, the remote sensing methodology will be tested and refined, sampling issues will be thoroughly evaluated, and an approach for assessing the drivers and consequences of land cover change will be finalized.

The second phase will involve the complete analysis of all U.S. ecoregions. First priority will be the ecoregions in the Mid-Atlantic states, with the remaining ecoregions completed according to a schedule that will be negotiated with project collaborators.

3.1 Framework Elements

The project design consists of the following framework elements (note that each of these elements will be explained in more detail in Section 4):

Spatial Framework: The estimates of rates, driving forces, and consequences of land cover change will be developed for 84 ecoregions defined by Omernik (U.S. Environmental Protection Agency, 1999, a revision of Omernik, 1987). A 20 km by 20 km grid will be applied to each ecoregion to select a random sample of 400 km^2 blocks for land cover analysis. Sample size will be based on the expected spatial variance of land cover change among grid blocks, a 1 percent margin of error, and an 0.85 confidence level. Land cover data and change analyses will be developed for each ecoregion and summarized for the conterminous U.S.

Temporal Framework: Five dates of Landsat MSS and TM data will be obtained, geocoded, and interpreted for each sample block to provide land cover data on a 6-8 year cycle. The period center-points for these dates are:

- *1973 Landsat MSS* – from the North American Landscape Characterization (NALC) data set

- *1980 Landsat MSS* – new acquisitions
- *1986 Landsat MSS* – from the NALC data set
- *1992 Landsat MSS* – from the NALC data set, and Landsat TM – from the MRLC data set
- *2000 Landsat TM* – from the upcoming MRLC 2000 data set

Existing, preprocessed multi-spectral data, or satellite data in which the acquisitions are already planned, will account for 80-90% of the required imagery.

Land Cover Change Variables: Rather than develop a single set of land cover attributes, a database of key land cover variables will be generated. Land cover change analysis will be done for each sample block within each of the 84 ecoregions for the five periods. Three types of land cover variables will be mapped or derived: (1) general land cover type; (2) landscape biophysical properties; and (3) landscape pattern.

Major emphasis will be placed on mapping the following general land cover types for each sample block (class definitions are in Appendix A):

- Urban and Built-Up
- Agriculture (Cropland and Pasture)
- Forests and Woodlands
- Rangeland/Grassland
- Wetland
- Water Bodies
- Snow and Ice
- Natural Barren
- Disturbed or Transitional

To aid in interpreting land cover from the 5 dates of satellite data, and for use in understanding successional or other gradual land cover transitions, a set of landscape biophysical properties will be calculated. The following variables and their planned roles are:

- *Percent Tree Cover* – explains forest regeneration, timber encroachment, or seral stage
- *Percent Shadow* – explains forest regeneration, timber encroachment, or seral stage
- *Unvegetated Fraction* – relates to desertification processes or urban intensification

Landscape pattern metrics, describing the number, size, shape, and spatial relationship of land cover patches (where patch is a contiguous set of pixels assigned to the same land cover type), will be generated from the general land cover data for each block. The landscape configuration metrics and general land cover types strongly enhance one another. While it is possible for the relative abundance of land cover types to remain constant through time, their spatial configuration may change. The landscape metrics will permit the analysis of the spatial dimension of land cover change, and will also contribute to the assessment of consequences of land cover change.

3.2 Data Quality Objectives

Our goal is to identify 1% change in general land cover within each ecoregion, at an 85% confidence level. Key steps that will be taken to reach this goal include:

- Verification of the registration accuracy of the Landsat MSS, TM, and ETM data (objective is sub-pixel accuracy)
- Use of 1992 baseline MRLC land cover data with 85% overall land cover accuracy
- Validation, to the extent possible based on availability of source materials, of the general land cover change maps

The methods that will be used to achieve the goal and objectives are explained throughout Section 4.

Section 4

Methodology

The technical strategy used in this project has been designed to be extendible to other regions if essential elements (e.g., suitable ecoregions framework, moderate resolution satellite data) are available. For example, the scope of this project could be expanded beyond the conterminous U.S. to Alaska and Hawaii, since compatible ecoregion frames exist. In addition, Omernik has worked with others to develop an ecoregion map for the Western Hemisphere, so this approach could be applied throughout the Americas. However, the scope of the current initiative is limited to the conterminous U.S.

The technical methodology will generally involve a series of steps that address sampling, mapping, analyzing and documenting land cover trends, their causes, and the subsequent consequences. Generally, analysis will focus on one ecoregion at a time so that the analysts can be immersed in the unique issues and landscape patterns and conditions of that region. The following sections describe the steps of the methodology.

4.1 Ecoregion Profiles and Ancillary Databases

At the onset of each ecoregion assessment, geographic profiles and ancillary databases will be prepared. The geographic profiles will involve documenting population trends over the past 30 years, and the identification of key social, economic, and environmental issues that occurred during this term. The profiles will provide the context for the interpretation of the land cover data. Examples of the types of issues that need to be identified include:

- Economic health of key urban centers, to provide clues about the types of urban change that may have occurred.
- In areas dominated by public lands, a review of land management policies and practices (i.e., logging rates, fire protection) to aid in interpreting land cover change.
- A review of farm legislation in agricultural areas, to provide insights into the likelihood of agricultural expansion or reduction.
- Climate data for all areas, to evaluate evidence of trends over the past 40 years and to identify potential subtle changes in land cover condition.

The ancillary databases that will be assembled will vary according to the unique characteristics of each ecoregion. Databases that will be needed for all regions include key population variables (e.g., population density, total population, population dynamics), land ownership, wetlands distributions, existing land cover maps, and climate data.

4.2 Ecoregion Sampling

Assessment of land cover change at the population level (the entire U.S.) is impractical, both in terms of cost and processing time. The project objective is to assess change by sampling a portion of the conterminous U.S. and estimating change from only the sample data. Since our interests lie in assessing patterns, as well as relative abundance, of land cover types, the sample block size must capture the spatial configuration within and among land cover types. Through investigation of various block sizes, it was determined that a 20 km by 20 km block is large enough to adequately capture this information and yet is small enough to allow for rapid analysis and processing.

The occurrence of partial blocks (blocks falling on ecoregion boundaries) poses a problem. Formulas for estimating change when both full and partial blocks are present in an ecoregion are relatively straightforward, but accounting for partial blocks can make sample size planning extremely difficult. For this reason, we have used the simple case of all blocks being complete in order to simplify sample size planning. The data from a sample block can be used in the analysis of change for more than one ecoregion, but the sampling requires that it be identified initially with a single stratum. This was done by initially assigning 20 km blocks to the ecoregion making up the majority of the block.

The primary problem is determining the number of these 20 km by 20 km blocks that are required to adequately address the objective of estimating land cover change on an ecoregion by ecoregion basis. By initially assigning each block to a single stratum, we can use a standard sample size formula for simple random sampling. The planned sample size (Cochran, 1977) for an ecoregion is thus given by:

$$k = 1 / (1/k_o + 1/K) \quad \text{where:}$$

k = planned sample size
K = number of 20 km by 20 km blocks in the ecoregion
k_o = $(z\sigma/m)^2$ with:
  z = a percentile from the standard normal distribution
  σ = standard deviation of the number of change pixels (in each block) for the collection of all K blocks
m = margin of error (in pixels per block)

The number of K blocks in each ecoregion is determined when all 20 km blocks covering the conterminous U.S. are initially assigned to an ecoregion using the majority rule. The *z* value and the margin of error were tested empirically to determine acceptable and feasible values. The sample size equation was shown to be very sensitive to changes in the *z* value and the margin of error. Some compromises needed to be made with regard to confidence intervals and margins of error in order to achieve sample sizes that were feasible. For example, in many cases, over half of the 20 km blocks in an ecoregion would need to be sampled to provide margins of error of 555 pixels per block (±0.5%) or less. In order to achieve feasible sample sizes, it was necessary to select a margin of error of 1111 pixels per block (±1%) and a confidence interval of 85%.

The final piece of information required to calculated sample size for an ecoregion is a σ, the standard deviation of the number of change pixels (in each block) for the collection of all K blocks. In effect, a measure of the distribution of change within an ecoregion is required. If change is distributed uniformly across an ecoregion, σ would be low, resulting in a lower number of required sample sites. If the change were clustered in a few locations, σ would have a high value and a higher number of sample sites would be required. Unfortunately, this information requires a prior knowledge of the distribution of change in an ecoregion, information that this project in part intends to derive. To obtain estimates of σ, NOAA Coastal Change Analysis Program (C-CAP) data were obtained for the Chesapeake area and the San Francisco area. The C-CAP program uses remotely sensed imagery to determine land cover change between two dates. The dates for the two data sets were roughly 6 years apart, very comparable to what this project proposes. The land cover information for the two C-CAP dates were aggregated to match the land cover classes proposed by this project, and a change image was created. A 20 km grid was overlain on the change image, the number of pixels in each 20 km block were obtained, and σ values were calculated. The procedure to calculate σ was repeated for subsets within the C-CAP data sets which represented ecoregions or portions of ecoregions. Ideally, this information would be available for each ecoregion prior to calculating sample size, but in lieu of such data, the estimates derived from the C-CAP data were used as a substitute for the σ value. A constant, high estimate of σ was used for all ecoregion sample site planning. This high estimate of σ will ensure that ecoregions with great variability in change pixels between blocks would be sampled adequately, but likely results in oversampling (with regard to targeted precision marks) for ecoregions with relatively even distributions of change.

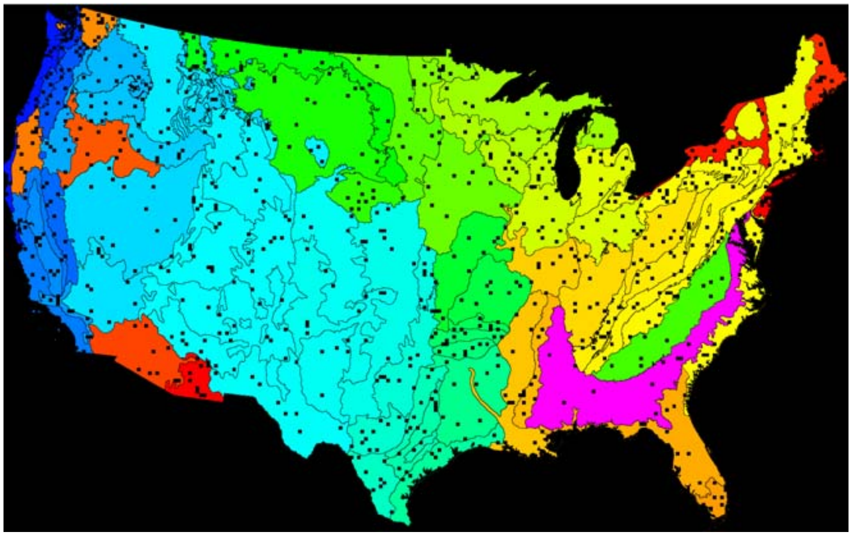

Figure 1. Distribution of 20 km by 20 km sample blocks using the pilot test sampling parameters.

The sample size formula given above is based on a Gaussian distribution of the number of change pixels per block. With 111,111 pixels in each 20 km X 20 km block, the number of change pixels per block should follow a fairly smooth distribution. However, the actual distribution is likely to be skewed right. Once the project is underway and real data on the distribution of change are available, planning formulas accounting for non-normality will be explored to determine how strong an effect this would have on sample size planning computation. In ecoregions where change is rare (e.g., near 0 - 1%), assuming a Gaussian distribution may even result in the collection of too many samples.

The effect of classification error on sample size planning also needs to be explored. The effect of map error would be to require a larger sample size. At this stage, it is unclear if formulae are available which compute sample sizes in the presence of classification error, and if such formulae are available, estimates of the magnitude of classification error would need to be calculated. This will require investigation after the project begins, but it is likely the needed increase in the number of blocks will only be on the order of 10% (around 1 additional block per ecoregion).

Given the effects of a non-normal distribution and of classification error, a small number of additional sampling blocks may be required above and beyond those called for by the sampling formula outlined above. Using the high estimate of σ and rounding sample size estimates up to the nearest whole integer will likely ensure an adequate number of sample blocks. If data from the pilot ecoregions indicate the necessity for more samples in a given ecoregion, additional random samples will be selected. The formula above will be used to calculate preliminary sample sizes, and a simple random sample will be obtained for the strata of blocks associated with each ecoregion. This will result in approximately 800 sample blocks across the conterminous U.S. for each of five sample periods (i.e., approximately 4000 individual date-blocks for the entire assessment). The pilot project will allow us to evaluate the sampling scheme, including issues related to block size, sampling density, and targeted precision marks.

4.3 Satellite Databases

All Landsat MSS and TM scenes covering the sample blocks will be assembled initially as path/row sets for use in the land cover characterization and change analysis. Coverage for 1973 and 1986 will come from the NALC archive, the 1992 data will include both the NALC MSS data and the MRLC TM coverage, and the 2000 data will be ETM scenes acquired for MRLC 2000. Landsat MSS data for the 1980 period will need to be acquired. To the extent possible, the new acquisitions must match the approximate growing season periods of the 1973, 1986 and 1992 NALC coverage to avoid misclassification of change due to phenological differences.

The use of cloud-free imagery is important. When scenes with cloud cover are encountered, we will, whenever possible, replace cloud-covered portions of images with data that is cloud-free. When this is not feasible, we will treat the cloud-covered portion of the sample as “no data”.

The most critical image geometry issue is accurate scene-to-scene registration. NALC MSS and MRLC TM data are each georeferenced to root mean square errors of 1 pixel or less, but are provided in different projections. All NALC MSS scenes and all new MSS or ETM acquisitions will be geocoded to a common Albers equal area map projection, the base projection of the MRLC TM data sets. MRLC TM data, the majority of the NALC MSS data, and all new data acquisitions will be terrain corrected. However, approximately one-third of NALC path/rows were processed prior to the implementation of terrain-correction techniques. It is not anticipated this will cause any major problem, as these early NALC scenes are primarily located in areas with negligible terrain variability.

The remaining task associated with this step is a relative radiometric calibration of the Landsat satellite images. The 1992 date will serve as a baseline for both MSS and TM data sets, with 1973, 1980, and 1986 MSS data radiometrically calibrated to the 1992 NALC MSS imagery and year 2000 ETM data radiometrically calibrated to 1992 MRLC TM data. Staying with MSS to MSS comparisons and ETM to TM comparisons eliminates the need for cross-sensor calibration (i.e., MSS to TM). The relative calibration of the satellite imagery will correct for differences in atmospheric path radiance, detector calibration, sun angle, earth-Sun distance, atmospheric attenuation, and phase angle conditions. Radiometric control sets representing temporally invariant features will be used to derive gains and offsets for a linear transformation. Depending on individual sample block characteristics, one of the following methods will be used to define control sets: (1) identifying pseudo-invariant bright and dark targets, (2) defining control sets from brightness-greenness scatterplots that represent bright and dark pixels with low vegetation content, (3) selecting a control set corresponding to soil line pixels defined in a brightness-greenness scatterplot, or (4) using automated scattergram-controlled regression.

4.4 Land Cover Biophysical Properties

We will independently focus on the analysis of the changes to state and condition of natural vegetation. Spectral unmixing will complement sampling strategies for mapping land cover change, and in particular will facilitate development of quantitative metrics that can be qualitatively assessed with respect to the phenologic characteristics of vegetation, definitive land cover conversions, and other potential anthropogenic or climatic influences.

Using spectral unmixing and regression techniques, percent tree cover, percent shadow, and unvegetated fraction will be calculated. The biophysical composition of the landscape is an integral component to the assessment of ecoregion health and functional potential. Landsat MSS and TM data for multiple dates will be used to decompose the landscape into fractional endmembers representing relative proportions of percent tree cover (based on the amount of woody biomass), unvegetated fraction (i.e., bare soil, rock, developed structures), and percent shadow. The satellite data will be spectrally unmixed using methods described by Adams et al. (1993) and Roberts et al. (1993) to determine changes in the relative proportions of these three biophysical variables.

Our use of endmembers correlating to the three biophysical properties is for use in interpreting or identifying gradual or subtle changes in the condition of the landscape that may be important in determining the driving forces of change (i.e., climate-induced, land management policies, etc.). The calculated variables will be used in a qualitative fashion. This is necessary because of the challenge in quantifying the relationship between endmembers and actual landscape conditions when image quality and phenological conditions are inconsistent. In order to use the results in a quantitative way, an extensive and impractical amount of calibration data would be needed. In cases where we will investigate shifts in environmental gradients (see the following discussion of the Madrean Archipelogo, Section 4.4.1), we will use large scale aerial photography to calibrate the endmembers.

The use of biophysical characteristics of land cover may provide useful information on the condition of land cover. However, there is little operational evidence of the utility and consistency of this information. We consider this element of the project to be experimental and will carefully evaluate the quality and meaning of the information derived using spectral unmixing at the end of the pilot phase. If the pilot phase results are determined to be useful, we will continue generating and interpreting these data for the remainder of the project.

4.4.1 Assessment of Environmental Gradients

An parallel investigation of the role of the NALC MSS and MRLC TM data will be carried out in the Madrean Archipelago ecoregion in southeastern Arizona. This ecoregion has both steep and gradual environmental gradients. The lower elevations have transitions between desert grassland basins and arid shrublands. Scattered mountain islands with elevations over 2500m have vegetation with distinct zonation. Transitions range from arid scrub vegetation to chaparral, oak woodlands, and needleleaf forests at the highest elevations. The combination of both steep and gradual gradients provide an opportunity to investigate the ability to detect subtle environmental change along both gradients using the 1972-1992 NALC data, and 2000 Landsat ETM scenes.

The nature of vegetation changes that may be occurring will be difficult to detect using general land cover maps since the change is most likely manifested through changes in vegetation condition. Thus, we will test the potential for using biophysical measures (see Section 4.4) to determine shifts in vegetation characteristics. In particular, we will study changes in the unvegetated fraction to see if there are changes in the positions of the grassland basins from the more sparsely vegetated shrub regions, and will use both unvegetated fraction and percent tree cover to identify subtle changes along the mountain island topographic gradient. To improve our ability to accurately map percent tree cover and the unvegetated fraction, we will use large scale aerial photos (e.g., BLM and USFS resource photography) as calibration sources to estimate percent cover. The analysis will involve calculation and calibration of biophysical characteristics for bisecting transects and sample blocks, comparison of the metrics for each date to identify anomalies, testing of the statistical significance of the change, and an assessment of climate trends, land management practices (to the extent possible), and other resource records to determine the meaning of the anomalies. A scientific paper summarizing the methods, results, and potential for using NALC data for monitoring change along environmental gradients will be prepared at the end of the investigation.

4.5 Land Cover Change Analysis

The primary image analysis task of this project is determining general land cover transformations over the past 30 years. The land cover data sets are also needed for the calculation of landscape metrics that provide measures of the changes in landscape configuration. To describe land cover change within and between ecoregions, information regarding land cover classes and conversions between land cover classes is required.

4.5.1 Land Cover Change Mapping

There are numerous approaches to characterizing land cover change, and each has a set of strengths and weaknesses. Because no single approach is optimal for all types of landscapes and land cover features, we plan to use a hybrid of available approaches; specific methods will depend on the characteristics of specific ecoregions. We plan to use a combination of simultaneous analysis techniques (e.g., CVA, image differencing), comparative analysis of independently produced classifications and manual interpretations.

Processing will begin with the 1992 MRLC land cover database. This database, with classes aggregated to general land cover types, will serve as the land cover baseline. Land cover for the 1973, 1980, and 1986 periods can be back-classified using 1992 as the template, and changes can be forward classified for the 2000 data. One advantage of using 1992 MRLC land cover data is that it will have known classification accuracy (preliminary results show that at the level of generalization needed for this project, the overall accuracy is about 85-90%), and thus will provide an excellent reference data set. Additionally, rates of change numbers derived from the trends assessments, combined with the complete 1992 national land cover classification, will provide a detailed enumeration of actual land cover that can be used to estimate carbon stocks. The rates of land change from this period can be used to assess progress in balancing carbon sources and sinks. Since the baseline period for the framework convention on climate change is 1990, the statistics from this period will be relevant for a national carbon assessment.

One of the primary approaches that will be employed is an enhanced change vector approach. Beginning with the 1992 and 1986 MSS imagery, we plan to use the change vector analysis (CVA) tools created by Dwyer et al. (1997) to produce a "first-cut" mask depicting areas of possible change. These tools will provide information regarding change in the brightness/greenness plane, with an empirically derived threshold being selected to assign pixels to a "no change" or "possible change" category. Using manual interpretation, each contiguous group of "possible change" pixels will be analyzed. Groups of pixels not representing real land cover change will be manually coded to a null value, while groups of pixels representing a specific type of land cover change will be manually coded to the representative class value. A change mask is thus created which represents specific land cover changes from 1992 to 1986. This change mask is then applied to the 1992 MRLC land cover image to create a 1986 land cover image. The process is then repeated to back-classify for the earlier dates, and forward classify to the 2000 date.

Although the use of data from different sensors poses a serious challenge to many change analyses, we plan to use post-classification comparisons to address this problem. The Landsat TM and MSS will both be mapped to common thematic references, using an approach similar to the one outlined above. Comparisons between land cover data for each of the dates will thus provide a means for equating results.

It is recognized that post-classification comparison has been criticized because it has the tendency to compound errors found in the two individual classifications. We believe three factors will enable us to obtain highly accurate change information from the individual classifications:

1. We plan to rely heavily on manual interpretations to derive change information. It is recognized that automated approaches alone can not approach the level of accuracy that can be obtained by incorporating manual interpretation.
2. It is believed the relatively small size of the individual sample blocks will allow for accurate land cover mapping.
3. Stratifying by ecoregion, coupled with the relatively small sample area, will result in less land cover heterogeneity being addressed within an analysis. This should improve our ability to identify important distinctions.

4.5.2 Accuracy Assessment/Validation of Results

While there is much value in assessing the accuracy of land cover and land cover change products, it is extremely difficult to implement a consistent, comprehensive, quantitative accuracy assessment for such a large area change database. One of the primary difficulties with the accuracy assessment of change products is acquiring an adequate database of historical reference materials. Contemporaneous (same year, same season) historical aerial photography is the preferred source of historical reference information, but it is highly improbable that such material will consistently be available. It will likely be necessary to incorporate a variety of historical reference materials, which will differ from ecoregion to ecoregion. These may include historical aerial photography, satellite imagery, other local change analysis studies, or other data sources.

Even if adequate historical reference materials can be obtained, classical accuracy assessment procedures cannot be easily applied to the results of this project. While the error matrix can be adapted for use in land cover change analysis studies, it becomes impractical when dealing with the numbers of change categories that this project will include, and it is not applicable to the assessment of trends. Given adequate reference material, a correlation approach may be used as an additional approach to analyze trends as it can quantify the agreement between disparate references and mapped data. The use of correlation as a validation tool has the added advantage of applicability to any of our measured variables, given adequate reference material. However, it does not provide the necessary unbiased accuracy information. Thus, a standard accuracy assessment of the individual dates of land cover classifications is our first priority.

Comparisons (consistency checks) between results from small, localized studies and our efforts will provide an additional means of assessing accuracy. While not as desirable as comprehensive, quantitative accuracy assessment procedures, consistency checks can provide strong evidence that our procedures produce meaningful information. Direct comparison of our product against a validated localized study provides indirect evidence of our product accuracy.

The validation of such a large area change database has never been attempted, and more research is required to finalize our validation approach. Our first step will be to investigate the availability of historical aerial photography and other data sources. The choice of validation methodologies will depend on the type of historical reference material available; thus, validation methodologies will vary among ecoregions. Correlation procedures, accuracy assessment of individual date classifications, and consistency will be used in combination to validate our change analyses products.

4.6 Landscape Configuration Metrics

We will calculate a suite of standard metrics that describe the number, size, shape, and spatial relationship of patches of land cover types in each sample block and time period. Calculation of these metrics is completely operational through GIS techniques and landscape metrics software (e.g., FRAGSTATS), and is appropriate for national and regional assessments. We will include an analysis similar to that shown in Figure 2 for assessing and interpreting changes in patch size and number across time and across ecoregions. A number of metrics have been developed to describe and quantify elements of patch shape complexity and spatial configuration relative to other patch types; however, it is not clear which will prove to be the most informative and interpretable over large areas. Therefore, some experimentation during the pilot phase of this project will help us determine the set of metrics that will be applied for the second phase of the project.

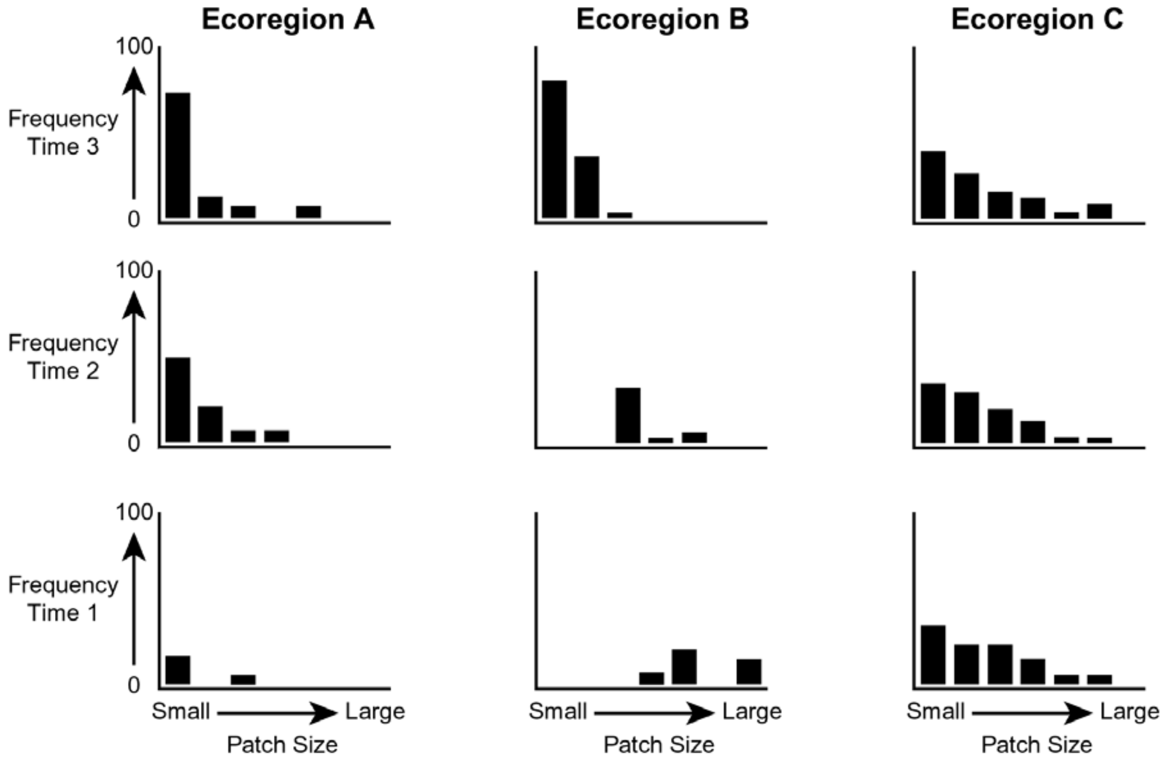

Figure 2. An example temporal comparison of patch size and frequency for a land cover type across three ecoregions. Columns represent ecoregions and rows correspond to time (where bottom to top row = past to present). The x-axis represents patch size class and the y-axis indicates number of patches. In Ecoregion A, the number of patches has increased dramatically over time, such as might happen where woodlands have colonized prairies as a result of wildfire suppression. Ecoregion B shows a case where large, spatially continuous patches have become highly fragmented over time, as has happened with some forests in the U.S. In Ecoregion C, patch size and frequency have remained fairly constant through time.

Associated with land cover patch analyses are issues about minimum mapping unit, edge effects, and accuracy of output:

- *Minimum Mapping Unit* – We propose a minimum mapping unit of two hectares for calculation of landscape metrics. This unit is resolvable on both MSS and TM data and should be useful for many scientific and management applications.

- *Edge Effects* – Landscape patches will be truncated along the edges of sampling blocks. Underway is an experiment to quantify the effects of artificial edges imposed by the sampling blocks. Results from this experiment will help us develop a protocol for handling “edge-affected” patches. For example, a given buffer distance from a block edge may provide us with sufficient information on the full patch characteristics for, say, 70% of the patches along a block edge.

- *Patch Accuracy* – Patch accuracy is not the same as land cover classification accuracy and cannot inherently be determined by the same assessment methods. Very little research has been done on this topic (See Hess, 1994; Hess and Bay, 1997; Wickham et al. 1997). For the current study, we do not propose to report on patch accuracy for each ecoregion; rather, we have designed a complementary study to determine whether general rules are applicable regarding the effects of misclassification errors on patches. This complementary study will use land cover and accuracy assessment data obtained from another project, the MRLC land cover classification project. The benefits of the MRLC data are that:

    1. The land cover classification scheme nests within the one proposed for the Trends Project;
    2. the classification was derived from TM data;
    3. the accuracy assessment was designed, reviewed, and implemented in a statistically rigorous fashion;
    4. data are already available for large portions of the U.S. and will be available for the entire conterminous U.S. within the coming year; and
    5. accuracy data have been obtained in a sufficiently dense, geographically well-distributed frequency for providing information on spatial distributions of different types of classification error. From these MRLC data we will investigate the effects of a range of misclassification rates (spatially distributed in a manner indicated by the accuracy assessment data) for different patch metrics (corresponding with those selected for the Trends Project) and across different ecoregions. We will investigate which relationships between land cover classification errors and patch effects are consistent among ecoregions and which are specific to within-region characteristics.

Analysis of patch accuracy will be addressed at two levels: the individual patch and the patch “population.” At the population level, we will compare patch size frequency distributions (as in the histograms in Figure 2) for given land cover types across a range of land cover misclassification rates. This analysis ignores the geographic location of individual patches and focuses on determining error rate thresholds for detectable differences in patch size frequency for an ecoregion. At the individual patch level, assessment will focus on the effects of classification errors on individual patches. Here, we are interested in thresholds of misclassification rates that begin to decompose single patches into multiple patches or begin to aggregate patches. Since the type and spatial distribution of classification errors will vary from ecoregion to ecoregion, our interpretation of the effects of errors on individual patches will vary according to within-region characteristics.

4.7 Ecoregion Trends Analysis

We are primarily interested in analyzing temporal series of our land cover variables to address questions relating to: (1) the predominant types of land cover conversions occurring within each ecoregion, (2) the estimated rates of change for these conversions, and (3) whether the types and rates of change are constant or variable across time. A series of interpretive products, such as change vector maps (Dwyer et al. 1997) and post-classification comparisons, will be generated toward these ends.

- *Land Cover Types* – Global summary statistics will be calculated across blocks for each ecoregion for each time period in order to assess regionwide changes in relative abundance. A change matrix will be constructed for each (temporally) consecutive pair of land cover layers that will indicate the types of conversions that have occurred. A "conversion type" map will show the geographic distribution of conversion types. We will look for spatial correlations between conversion types and selected environmental factors, such as terrain characteristics, proximity to urban development, economic conditions, etc., in order to improve our understanding of potential drivers of change. From these foundations we can explore the feasibility of developing pixel-based transition probabilities so that predictive maps can be compiled for future scenarios of land cover.

- *Biophysical Attributes* – We will examine changes in each attribute by land cover type per ecoregion. Canopy density, percent shadow, and unvegetated fraction can be represented graphically as maps, boxplots, histograms, and/or cumulative frequency diagrams for each time period. Additionally, the amount of change (i.e., image differencing) between time periods can also be represented in these ways. General rate of change across the five time periods can be estimated using the Sen slope estimator (Sen, 1968 in Gilbert, 1987). Estimate rates of change can be graphically displayed on maps in order to depict their spatial distribution and to suggest correlations with other environmental variables. Since data are limited to 4 time-steps, determination of statistical significance regarding trends in biophysical attributes is problematic. However, the degree of temporal constancy or variability in change rates can still be addressed if project analysts define thresholds that are ecologically or economically meaningful.

- *Landscape Metrics* – The number and sizes of patches for individual cover types will be compared over time within and across ecoregions. Patch distribution can be graphically displayed as histograms (e.g., see Figure 2). As with the analysis of changes in land cover types, we will look for spatial correlation changes in patch characteristics and other environmental factors. Shape and spatial configuration metrics tend to be continuous variables, and as such, can be handled similarly to the analyses of biophysical attributes.

4.8 Assessment of Land Cover Change Drivers and Consequences

In a separate research initiative, we will work toward the identification of the most significant driving forces of land cover change occurring in each ecoregion. The local human activities that express the driving forces in each ecoreigon will be determined and will be assessed by measuring the rates and types of change, landscape pattern changes, and other relevant sources of data (e.g., demographic profiles, economic reviews, public policies, etc.). Examples of the issues that will be addressed include:

- What are the likely driving forces of local land cover transformation?
- What are the connections between land cover change and changes in (the driving forces) economic, social, and environmental conditions?
- What are the local human activities (proximate sources of change) that are altering land cover transformation?
- What are the likely consequences of ecoregion land cover change at the regional, national, and global scales?
- What are the regional responses to land cover change?

A geographic framework and methodology for assessing the causes and consequences of change will be developed during the first year of the project. The implementation of the methodology may be more appropriately done through a consortium of universities that each focus on a particular part of the country. We will pursue implementations options following the completion of the assessment strategy.

4.9 National Synthesis

The ecoregion results will be summarized to identify:

a. National rates of land cover change;

b. the primary types of conversion occurring;

c. the regions having the most dynamic land cover change rates; and

d. the periods over the past 30 years in which land cover transformations have been most dynamic. The methods used in the ecoregions trends analyses will be used to assess overall rates of land cover change. Ecoregional comparisons will be made to understand the connections between driving forces and impacts associated with certain landscapes. In addition, other regional summaries (i.e., Great Plains, Pacific Northwest, Desert Southwest, etc.) may be produced to provide different scales and perspectives of analysis.

Section 5

Planned Deliverables and Timelines

Because this is a research project with little precedent, there is some uncertainty in the timelines for the various project staff. In addition, the schedule for completion is dependent on overall funding and staffing. Thus, the timelines needed to complete the planned deliverables are tentative and will be refined annually. Our goal is to complete the analysis of the conterminous U.S. within 4 years.

Key output from the project are reports that deal with the four objectives stated in Section 1.2. The form of most reports will be peer-reviewed scientific papers. The types of reports that will be produced will generally provide:

- *Methodological Summaries* – Technical summaries of the methods used in the analysis, such as the overall design, change detection methods, and biophysical parameterization techniques, will be prepared for submission to remote sensing journals. Papers on the strategies for analyzing the causes and consequences of change will be written for geographic and ecological applications journals.

- *Topical Assessments* – Papers that address key issues investigated during the research will be sent to appropriate journals, defined based on the topic. Types of topics that will be analyzed include assessment of change along environmental gradients, impacts of key driving forces (e.g., Conservation Research Program), and other problems.

- *Geographic Analyses* – Summaries of land cover change findings for individual ecoregions will be produced as each ecoregion is completed. At a minimum, these will be released as USGS open-file reports. Ultimately, geographic treatments of the rates, drivers, and consequences of land cover change will be summarized for publication in a USGS-produced atlas of contemporary land cover change, which will include maps and summaries of ecoregion and national land cover trends characteristics.

In addition to documentation, all project data sets, including sources and results, will be released via an FTP site accessible through the World Wide Web. All data will be documented according to Federal Geographic Data Committee metadata standards. Management of the data will ultimately become an operational component of the USGS Land Cover Characterization Program. Thus, data produced through this project will become part of the long-term land cover archive that currently includes the MRLC, NALC, and global AVHRR and land cover data sets.

While most results will be geared to a scientific audience, efforts will also be made to communicate results to a broader audience. A project web site will be established to provide results, summaries of lessons learned over the course of the project, and access to all data sets produced by the project team. In addition, the web site will provide a means for sharing information on the application of project results.

As stated previously, the first year will involve developing, testing, and refining project methods in five pilot study areas (see Section 3). At the end of the first year (calendar year 1999), we will deliver the following:

- Geographic summaries of land cover trends for the five pilot ecoregions for the early 1970’s through 1992 period (note that the 2000 analysis cannot be completed until late-2000 because of the need to acquire 2000 growing season Landsat 7 ETM data).
- Web site on project activities

In the second year (calendar year 2000), we intend to complete the analysis of an additional 30 ecoregions. The specific ecoregions that will be completed will include those within the Mid-Atlantic states and additional ecoregions selected through discussion with project partners. We will also deliver:

- Manuscript on remote sensing aspects of the methodology
- Methodology and implementation plan for assessing the drivers and consequences of land cover change
- Geographic summaries of land cover trends for the early 1970’s through 1992 period for 30 additional ecoregions.
- Analysis of land cover change for the 1992 to 2000 period for the pilot regions and remaining ecoregions bisecting the Mid-Atlantic regions.
- Topical assessment of subtle environmental change in the Madrean Archipelago
- Topical report on the contemporary land cover history of the Mid-Atlantic region
- Others, TBD

Thirty ecoregions will be completed during the third year (2001). Again, the specific ecoregions will be determined in consultation with project collaborators. We plan to deliver:

- Analysis of land cover trends for the early 1970’s through 2000 for the first 60 additional ecoregions.
- Others, TBD

Finally, during the fourth year (2002), we will complete the remaining 20 ecoregions. We will also complete an assessment of the merits and feasibility for converting the research project to an operational activity within the USGS Land Cover Characterization Program. Deliverables for the last year of the project are expected to be:

- Analysis of land cover trends for the early 1970’s through 2000 for the remaining ecoregions.
- Geographic assessment of land cover trends, their drivers, and the subsequent consequences for the conterminous U.S.
- Atlas of conterminous U.S. land cover change
- Manuscript on national land cover trends
- Others, TBD

Section 6

Management Plan

The project will involve a core team comprised of Tom Loveland (Project Leader), Terry Sohl (geographic analysis, sampling), Kristi Sayler (geographic analysis and spectral unmixing), Jim Vogelmann (change analysis, MRLC 2000, and Landsat 7 issues), Alisa Gallant (ecoregion characteristics, landscape metrics, trends analysis), John Dwyer (change vector methods, spectral unmixing), and Greg Zylstra (radiometry, analytic methods) will all contribute. In the second year, a postdoctoral position will be added to the team. Resumes of key personnel are presented in Appendix D.

Because of the importance of statistical design, including sampling methods, accuracy assessment, and trends analysis, Dr. Steve Stehman (State University of New York, Syracuse) will serve as a statistics consultant throughout the project. In addition to his role in researching and advising the project team on key statistical design problems, he will meet with the team for approximately one week twice each year.

During FY2000, Dr. Darrell Napton (South Dakota State University) will spend a sabbatical at the EROS Data Center. He will focus on two issues: developing outlines for the ecoregion profiles and developing and testing a strategy for assessing the drivers and consequences of land use and land cover change.

In addition, we will establish collaborative relationships with scientists within the EPA Landscape Ecology Branch. This relationship will have two aspects. First, it will provide a means for prioritizing analysis, applying results, and gaining comments on project strengths and weaknesses. Second, because of their expertise in the application and interpretation of landscape metrics, we will solicit their direct input on the landscape metrics component of this project. Once this plan is approved, we will provide monthly status reports to EPA project monitors and interested technical staff. These reports will be distributed via email.

Finally, once each year, we will hold an “all-hands” project review where we will discuss all project findings, identify problems and solutions, discuss opportunities, and prepare a work plan for the following year. All work plans, research plans, proposals for expansion, and technical or scientific reports will be provided to all collaborators for review before being released to a broader audience.

Section 7

References

Adams, J.B., D.E. Sabol, V. Kapos, R.A. Filho, D.A. Roberts, M.O. Smith, and A.R. Gillespie, 1995. Classification of multispectral images based on fractions of endmembers: Application to land-cover change in the Brazilian Amazon, Remote Sensing of Environment 52: 137-154.

Baker, L.A., 1990. Current status of surface water acid-base chemistry. NAPAP SOS/T Report 9. In: National Acid Precipitation Assessment Program, Acidic Deposition: State of Science and Technology, Volume II.

Bateson, A. and B. Curtiss, 1996. A method for manual endmember selection and spectral unmixing, Remote Sensing of Environment 55: 229-243.

Bryne, G.F., P.F. Crapper, and K.K. Mayo, 1980. Monitoring land-cover change by principal component analysis of multitemporal Landsat data, Remote Sensing of Environment 10: 175-184.

Caselles, V., and M.J. Lopez Garcia, 1989. An alternative simple approach to estimate atmospheric correction in multitemporal studies, International Journal of Remote Sensing 10(6): 1127-1134.

Cochran, W.G., 1977. Sampling Techniques (3rd ed.), Wiley, NY.

Cochrane, M.A. and C.M. Souza, 1998. Linear mixture model classification of burned forests in the Eastern Amazon, International Journal Remote Sensing 19(17): 3433-3440.

Crist, E.P., and R.C. Cicone, 1984. A physically based transformation of Thematic Mapper data - The TM Tasseled Cap, IEEE Transactions on Geoscience and Remote Sensing 22: 256-263.

Dimyati, M., K. Mizuno, S. Kobayashi, and T. Kitamura, 1996. An analysis of land use/cover change using the combination of MSS Landsat and land use map – A case study in Yogyakarta, Indonesia, International Journal of Remote Sensing 17(5): 931-944.

Dobson, J.E., 1992. Global challenges demand more precision, better generalization, GIS World, October 1992: 68-69.

Dobson, J., and E. Bright, 1994. Large-area change analysis: The Coastwatch Change Analysis Project (C-CAP), Proceedings of Pecora 12, Sioux Falls, SD, August 24-26, 1993, American Society for Photogrammetry and Remote Sensing, Bethesda, MD: pp. 73-81.

Dobson, J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, H. Iredale III, J.R. Jensen, V.V. Klemas, R.J. Orth, and J.P. Thomas, 1995. NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation, NOAA Technical Report NMFS 123, Seattle, WA 92 p.

Dwyer, J., K. Sayler, and G. Zylstra, 1997. Landsat pathfinder data sets for landscape change analysis, Proceedings, International Geoscience and Remote Sensing Symposium, Lincoln, Nebraska, May 17-31, 1996: pp. 547-550.

Elvidge, C.D., D. Yuan, R. Weerackoon, and R. Lunetta, 1995. Relative radiometric normalization of Landsat multispectral scanner (MSS) data using an automatic scattergram-controlled regression, Photogrammetric Engineering and Remote Sensing 61: 1255-1260.

Foschi, P.G., and K.D. Smith, 1997. Detecting subpixel woody vegetation in digital imagery using two artificial intelligence approaches, Photogrammetric Engineering and Remote Sensing 63(5): 493-500.

Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring, Van Nostrand Reinhold, New York. 320 p.

Gordon, S.I., 1980. Utilizing Landsat imagery to monitor land-use change: A case study in Ohio, Remote Sensing of Environment 9: 189-196.

Hall, F.G., D.E. Strebel, J.E. Nickeson, and S.J. Goetz, 1991. Radiometric rectification: Toward a common radiometric response among multidate, multisensor images, Remote Sensing of Environment 35: 11-27.

Heiskary, S.A., C.B. Wilson, and D.P. Larsen, 1987. Analysis of regional patterns in lake water quality: Using ecoregions for lake management in Minnesota, Lake and Reservoir Management 3: 337-344.

Hess, G. 1994. Pattern and error in landscape ecology: A commentary. Landscape Ecology 9(1):3-5.

Hess, G. R. and J.M. Bay. 1997. Generating confidence intervals for composition-based landscape indexes. Landscape Ecology 12(5):309-320.

Henderson, B.M., and S.J. Walsh, 1995. Plowed, paved, or in succession: Land-cover change on the North Carolina Piedmont, Southeastern Geographer 35(2): 132-149.

Howarth, P.J., and G.M. Wickware, 1981. Procedures for change detection using Landsat digital data, International Journal of Remote Sensing 2(3): 277-291.

Jensen, J.R., and D.L. Toll, 1983. Detecting residential land-use development at the urban fringe, Photogrammetric Engineering and Remote Sensing 48(4): 629-643.

Johnston, D., and R. Haas, 1985. Change detection in rangeland environments using Landsat MSS data - A quantitative approach, Pecora 10 Proceedings: Remote Sensing in Forest and Range Management, Colorado State University, Fort Collins, Colorado, August 20-22: pp. 60-188.

Jones, K.B., L.R. Williams, A.M. Pitchford, T.E. Slonecker, J.D. Wickham, R.V. O'Neill, D. Garofalo, and W.G. Kepner, 1999. A national assessment of landscape change and impacts to aquatic resources: a 10-year strategic plan for the Landscape Sciences Program, U.S. Environmental Protection Agency, National Exposure Research Laboratory, Las Vegas, NV 73 p.

Kaufmann, P.R., A.T. Herlihy, M.E. Mitch, J.J. Messer, and W.S. Overton, 1991. Stream chemistry in the eastern United States. 1. Synoptic survey design, acid-base status, and regional patterns. Water Resources Research 27: 611-627.

Kauth, R.J., and G.S. Thomas, 1976. The tasseled cap - A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat, Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, LARS, Purdue University, West Lafayette, Indiana: pp. 4b41-4b51.

Kumar, M., E. Goossens, and R. Goossens, 1993. Assessment of sand dune change detection in Rajasthan (Thar) Desert, India, International Journal of Remote Sensing 14(9): 1689-1703.

Lambin, E.F., and A.H. Strahler, 1994. Indicators of land-cover change for change-vector analysis in multitemporal space at coarse spatial scales, International Journal of Remote Sensing 15: 2099-2119.

Larsen, D.P., D.R. Dudley, and R.M. Hughes, 1988. A regional approach to assess attainable water quality: An Ohio case study, Journal of Soil and Water Conservation 43:171-176.

Linthurst, R.A., D.H. Landers, J.M. Eilers, D.F. Brakke, W.S. Overton, E.P. Meirer, and R.E. Crowe, 1986. Characteristics of lakes in the eastern United States. Vol. 1: Population descriptions and physicochemical relationships. EPA/600/4-86-007a. USEPA, Wash., D.C. 136 p.

Loveland, T.R., J.W. Merchant, D.O. Ohlen, and J.F. Brown, 1991. Development of a land-cover characteristics database for the conterminous U.S., Photogrammetric Engineering and Remote Sensing 57: 1453-1463.

Lowrance, R.R., R. Leonard, and J. Sheridan, 1985. Managing riparian ecosystems to control non-point pollution. Journal of Soil and Water Conservation 40: 87-91.

Lunetta, R.S., J.G. Lyon, B. Guindon, and C.D. Elvidge, 1998. North America landscape characterization data set development and data fusion issues, Photogrammetric Engineering and Remote Sensing 64(8): 821-829.

Macleod, R.D., and R.G. Congalton, 1998. A quantitative comparison of change-detection algorithms for monitoring eelgrass from remotely sensed data, Photogrammetric Engineering and Remote Sensing 64(3): 207-216.

Massart, M., M. Petillon, and E. Wolff, 1995. The impact of an agricultural development project on a tropical forest environment: The case of Shaba (Zaire), Photogrammetric Engineering and Remote Sensing 61(9): 1153-1158.

Ojima, D.S., K.A. Galvin, and B.L. Turner II, 1994. The global impact of land-use change, BioScience 44(5): 300-304.

Omernik, J.M., 1987. Ecoregions of the conterminous United States, Annals of the Association of American Geographers 77: 118-125.

Peplies, R.W. and R.B. Honea, 1992. Some classic regional models in relation to global change studies, 88th Annual Meeting, Association of American Geographers (Unpublished), San Diego, California 24 p.

Ramsey, R.D., A. Falconer, and J.R. Jensen. 1995. The relationship between NOAA-AVHRR NDVI and ecoregions in Utah, Photogrammetric Engineering and Remote Sensing 53: 188-198.

Ribed, P.S., and A.M. Lopez, 1995. Monitoring burnt areas by principal components analysis of multi-temporal TM data, International Journal of Remote Sensing 16(9): 1577-1587.

Riebsame, W.E., W.J. Parton, K.A. Galvin, I.C. Burke, L. Bohren, R. Young, and E. Knop, 1994. Integrated modeling of land use and cover change, BioScience 44(5): 350-356.

Riitters, K.H., R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones, and B.L. Jackson, 1995. A factor analysis of landscape pattern and structure metrics, Landscape Ecology 10(1): 23-39.

Roberts, D.A., J.B. Adams, and M.O. Smith, 1993. Green vegetation, nonphotosynthetic vegetation, and soil in AVIRIS data, Remote Sensing of Environment 14: 255-269.

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

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau, Journal of the American Statistical Association 63: 1379-1389.

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

Skole, D. and C. Tucker, 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988, Science 260: 1905-1910.

Sohl, T., 1999. Change analysis in the United Arab Emirates: An investigation of techniques, Photogrammetric Engineering and Remote Sensing 65(4): 475-484.

Stehman, S., 1997. Selecting and interpreting measures of thematic classification accuracy, Remote Sensing of Environment 62: 77-89.

Stow, D.A., L.R. Tinney, and J.E. Estes, 1980. Deriving land use/land cover change statistics from Landsat: A study of prime agricultural land, in Proceedings of the 14th International Symposium on Remote Sensing of Environment, Ann Arbor, MI, Environmental Research Institute of Michigan, Ann Arbor, MI: pp. 1227-1327.

Tompkins, S., J.F. Mustard, C.M. Pieters, and D.W. Forsyth, 1997. Optimization of endmembers for spectral mixture analysis, Remote Sensing of Environment 59: 472-489.

Turner, B.L. II and W.B. Meyer, 1991. Land use and land cover in global environmental change: Considerations for study, International Social Science Journal 130: 669-677.

Turner, B.L. II, D. Skole, S. Sanderson, G. Fischer, L. Fresco, and R. Leemans, 1995. Land-Use and Land-Cover Change: Science/Research Plan. IGBP Report No. 35, HDP Report No. 7, International Geosphere-Biosphere Programme, Stockholm, Sweden 132 p.

Turner, M.G., 1990. Landscape changes in nine rural counties in Georgia, Photogrammetric Engineering and Remote Sensing 56(3): 379-386.

U.S. Environmental Protection Agency, 1999. Level III ecoregions of the continental United States, U.S. Environmental Protection Agency – National Health and Environmental Effects Research Laboratory, Corvallis, Oregon.

Vogelmann, J.E., 1988. Detection of forest change in the Green Mountains of Vermont using Multispectral Scanner data, International Journal of Remote Sensing 9(7): 1187-1200.

Vogelmann, J.E., T. Sohl, and S.M. Howard, 1998. Regional characterization of land cover using multiple sources of data, Photogrammetric Engineering and Remote Sensing 64(1): 45-57.

Weismiller, R.A., S.J. Kristof, D.K. Scholz, P.E. Anuta, and S.A. Momin, 1977. Change detection in coastal zone environments, Photogrammetric Engineering and Remote Sensing 43(12): 1533-1539.

Wickham, J.D., R.V. O'Neill, K.H. Riitters, T.G. Wade, and K.B. Jones. 1997. Sensitivity of selected landscape pattern metrics to land-cover misclassification and differences in land-cover composition. Photogrammetric Engineering and Remote Sensing 63(4)397-402.

Wilcock, D. and A. Cooper, 1993. Monitoring losses of semi-natural vegetation to agricultural grassland from satellite imagery in the Antrim Coast and Glens AONB, Northern Ireland, Journal of Environmental Management 38: 57-169.

Appendix A

Land Cover Definitions

The following are the general land cover definitions that will be used in the project. To the extent possible, the definitions are based on the original Anderson et al. (1976) level I definitions so that land cover data developed through this project are consistent with those produced through other programs and projects. Note that a minimum mapping unit of 4 acres will be used to determine land cover.

Urban and Built-Up – Areas of intensive use with much of the land covered with structures (e.g., high density residential, commercial, industrial, transportation, mining, confined livestock operations), or less intensive uses where the land cover matrix includes both vegetation and structures (e.g., low density residential, recreational facilities, cemeteries, etc.), including any land functionally attached to the urban or built-up activity.

Agriculture (Cropland and Pasture) – Land in either a vegetated or unvegetated state used for the production of food and fiber. Note that forest plantations are considered as forests or woodlands regardless of the use of the wood products.

Forests and Woodlands – Tree-covered land where the tree cover density is greater than 10%. Note that cleared forest land (i.e., clear-cuts) will be mapped according to current cover (e.g., disturbed or transitional, rangeland/grassland).

Rangeland/Grassland – Land predominately covered with grasses, forbs, or shrubs. The vegetated cover must comprise at least 10% of the area.

Wetland – Lands where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands are comprised of water and vegetated cover.

Water Bodies – Areas persistently covered with water, such as streams, canals, lakes, reservoirs, bays, or oceans.

Snow and Ice – Land where the accumulation of snow and ice does not completely melt during the summer period.

Natural Barren – Land comprised of natural occurrences of soils, sand, or rocks where less than 10% of the area is vegetated.

Disturbed or Transitional – Land in an altered unvegetated state which is in transition from one cover type to another.

Appendix B

Description of Pilot Ecoregions

79 Madrean Archipelago

Land use: Mostly grazing. Some irrigated cropland (cotton, corn, alfalfa, sm. grains, other).

Concerns: Grazing practices can lead to invasion of brushy species and local gully erosion. Irrigated agriculture associated with declining water tables and a short supply or irrigation water.

Terrain: Elevations from 800-1400 m in basins, 1500->2500 m in mountains. SE-NW trending mountain ranges separated by relatively smooth valleys.

Climate: 275-375 mm ppt. annually (up to 900 mm in mtns.). More than half ppt. is in summer.

Water: All streams intermittent. Ground water used for irrigation.

Soils: Orthents, Ustolls, Argids, and Fluvents. Thermic temperature regime and aridic moisture regime.

PNV: Forest, savanna, and desert shrub vegetation.

Actual Vegetation: Desert grasslands in basins, mountains are characterized by a multitude of life zones, including the southernmost extension of spruce/fir forest.

Primary Natural Disturbances: Drought.

Primary Human Disturbances: Livestock grazing.

Pros & Cons for Trends Project:

Pros:

1) Distinguishing array of semiarid to arid vegetation communities over steep environmental gradients would be challenging,
2) The fate of this ecoregion is of interest to many because land management practices have resulted in T&E species (e.g., red squirrel) and because Native American groups and environmental and outdoor recreation lobbies are trying to stop the construction of a telescope on the largest (and most sacred) mountain (Mt. Graham) in the region,
3) Ecoregion is a relatively easy size and shape for sampling.

Cons:

1) Difficult to map vegetation in semiarid and arid systems,
2) Difficult to map land cover in mountainous terrain because of terrain effects.

65 Southeastern Plains

Land Use: 70% woodland, 15% cropland, 10% pasture, remaining is urban, rangeland, other. All woodland privately owned (including industry ownership). Timber production important. Cash crops include soybeans, corn, peanuts, cotton. Vegetable crops more locally important. Pastures used mostly for beef cattle, but some dairy cattle and hogs raised.

Concerns: Controlling soil erosion; improving drainage on low wetland areas.

Terrain: Low, rolling to irregular plains with gradual local relief. 25-200 m elevation, increasing gradually from the coastal plain toward the interior.

Climate: 1025-1525 mm ppt. annually, increasing from north to south. Minimum ppt. occurs in autumn.

Water: Abundant water from annual ppt., perennial streams, and groundwater. Domestic water supplies obtained from shallow wells; water for livestock from perennial streams and farm ponds.

Soils: Udults (Psamments and Udults in sand hills). Thermic temperature regime, udic moisture regime.

PNV: Mixed oak-pine and oak-hickory-pine forest.

Actual Vegetation: Evergreen needleleaf trees with scattered areas of cold-deciduous and evergreen broadleaf forest. Needleaf trees include loblolly, longleaf, slash, and shortleaf pines; broadleaf trees include sweetgum, yellow-poplar, and red and white oaks.

Primary Natural Disturbances: Wildfire; climate (hurricanes, occasional summer drought and winter ice storms, infrequent tornadoes); pest infestation.

Primary Human Disturbances: Clearing of natural veg. for crops, timber harvest.

Pros and Cons for Trends Project:

Pros:

1) High turnover rate of cover types at the local scale. It would be interesting to see whether they translate to any trends at the regional scale, or whether the local changes are just "system noise" (there is much interest among landscape ecologists in how processes and patterns at one scale relate to processes and patterns at another),

2) This is a good region for developing spatial metrics because of the potentially different local and regional pattern grains, and

3) The ecoregion is a broad, contiguous unit for sampling.

Cons:

1) The ecoregion is huge and most land is private so field reconnaissance can be complicated.

16 Montana Valley and Foothill Prairies

Land Use: Primarily farms and ranches. Some cropland is irrigated. Crops include potatoes, sugar beets, peas, hay, grain, and pasture. Dryland wheat farming occurs where annual ppt. is adequate. One third to 1/2 of the areas is in native grasses and shrubs. Beef cattle and sheep are the main livestock; dairying is important locally.

Concerns: Growing urbanization, rural development, shift in economic drivers.

Terrain: Nearly level to sloping valley floors, and sloping terraces and fans bordered by the steep mountains of the Northern Rockies Ecoregion. Some valleys modified by glacial deposits.

Climate: <250 mm annual ppt., fairly equally distributed throughout the year (but a bit lower in summer).

Water: Perennial streamflow from snowmelt of surrounding mountains is generally adequate for current needs.

Soils: Orthids, Borolls, Argids with a frigid temperature regime.

PNV: Grassland, with shrubs and trees in riparian areas.

Actual Vegetation: Grasses and shrubs (where not used for cropland or urban settlement).

Primary Natural Disturbances: Wildfire, flooding, large mammal grazing.

Primary Human Disturbances: Agriculture (removal of natural vegetation, addition of farm chemicals to system, increased soil erosion, loss of wildlife habitat), domestic livestock overgrazing, fire suppression (allowing encroachment by woody species), human settlement.

Pros and Cons for Trends Project:

Pros:

1) A strong challenge for designing a sampling scheme,
2) Temporal analyses will illustrate land cover change patterns associated with shifts in economic and environmental drivers.

Cons:

1) A strong challenge for designing a sampling scheme,
2) Compiling a temporal data set of cloud-free imagery will be a challenge, and
3) A short growing/field season.

64 Northern Piedmont

Land Use: Complex mix of small farms interspersed with residential/commercial/industrial development, and scattered woodland. Farms primarily in crops except in northern New Jersey and in Virginia, where they are mostly in pasture and woodland. Major crop types include forage crops, soybeans, and grain for dairy cattle. Large centers of urbanization and industry.

Concerns: Spread of urban development is affecting water yields and groundwater recharge.

Terrain: Mostly gently sloping or sloping low rounded hills, irregular plains, and open valleys. Elevations range from sea level to > 300 m, but most are between 100 and 300 m. There are scattered serpentine barrens. Complex pattern of bedrock and surficial geology.

Climate: Humid continental, with cold winters and hot summers. Average annual ppt. from 900-1200 mm, primarily occurring in spring and early summer. Snow in winter.

Water: Mature, dendritic drainage network. Natural lakes rare to nonexistent. Small impoundments common along upper stream reaches. Some bogs, swamps, and salt marshes in areas adjacent to the Atlantic coast and Chesapeake Bay. Precipitation, perennial streams, springs, and groundwater provide ample water for farm, urban, and industrial uses.

Soils: Alfisols and Ultisols with a mesic temperature regime and an udic moisture regime, and mostly mixed mineralogy.

PNV: Deciduous hardwood forest of oaks, hickories, ash, elm, and yellow-poplar. Some oak/hickory/pine forest occurred along the Susquehanna River.

Actual Vegetation: Appalachian oak, sugar maple-mixed hardwoods, hemlock-mixed hardwoods, and oak-chestnut forests and woodlands. Eastern redcedar is common on many abandoned cropland areas.

Primary Natural Disturbances: Wildfire, pest infestation.

Primary Human Disturbances: Urban expansion, point/nonpoint source pollution.

Pros and Cons for Trends Project:

Pros: 1) Interesting in that patterns in vegetation and agriculture are strongly related to geologic formations and the intermingling effects of climate and terrain features on soil development from parent materials.

Cons: 1) Major land cover changes, associated with urban and industrial spread, may not particularly relate to ecoregion characteristics, so this may not provide an interesting ecoregion analysis.

62 North Central Appalachians

Land Use: Primarily forestry and recreation, some coal and gas extraction in the western portion (oil wells are common). Suburban and vacation development often near the larger lakes. Because soils are unsuited to agriculture, most of the ecoregion remains wooded.

Concerns: Pollution from mining and oil production.

Terrain: Elevated plateau of horizontally bedded strata result in areas of plateau surfaces, high hills, and low mountains. The eastern portion and the “fingers” of the western portion were glaciated. Hilltop elevations up to 700 m.

Climate: Cool summers and cold winters. Ppt. from 850-1270 mm, evenly distributed throughout year, occurring as snow in winter.

Water: Lots of surface water and wetlands.

Soils: Frigid, nutrient-poor soils derived from residuum, colluvium, and till.

PNV: Northern hardwood forest, scattered Appalachian oak forest, isolated highland pockets of spruce/fir.

Actual Vegetation: Mixed hardwoods predominate, but hemlock and pines also occur. Also, swamp vegetation (wooded and unwooded).

Primary Natural Disturbances: Tornadoes, wind throw, ice storms, and pest infestation.

Primary Human Disturbances: Rapid expansion of development, oil and gas extraction, timber harvest.

Pros and Cons for Trends Project:

Pros: 1) Complex and interesting terrain;

Cons: 1) Lots of wetlands and complex surface features, often hard to interpret from remotely sensed data,

2) The expansion of development, an important regional change, may be hard to detect because of the forest overstory and, if settlement patterns are dispersed, because of the limitations of our data’s spatial resolution.

Appendix C

Omernik Level III Ecoregions, Sample Information

(Based on: 20 Km Block Size
σ = 2500
1% margin of error
85% confidence interval)

Omernik Level III Ecoregion	Area in Hectares	# Total Blocks	# Sample Blocks	% area Sampled
1. Coast Range	5400000.0	135.00	8.93	6.62%
2. Puget Lowland	1647000.0	41.18	6.67	16.20%
3. Willamette Valley	1485000.0	37.13	6.42	17.28%
4. Cascades	4644000.0	116.10	8.72	7.51%
5. Sierra Nevada	5283000.0	132.08	8.91	6.74%
6. Southern and Central California Chaparral and Oak Woodlands	10053000.0	251.33	9.60	3.82%
7. Central California Valley	4599000.0	114.98	8.71	7.57%
8. Southern California Mountains	1791000.0	44.78	6.87	15.35%
9. Eastern Cascades Slopes and Foothills	5616000.0	140.40	8.99	6.40%
10. Columbia Plateau	9045000.0	226.13	9.50	4.20%
11. Blue Mountains	6480000.0	162.00	9.16	5.66%
12. Snake River Basin	6552000.0	163.80	9.17	5.60%
13. Central Basin and Range	34164000.0	854.10	10.22	1.20%
14. Mojave Basin and Range	13077000.0	326.93	9.79	2.99%
15. Northern Rockies	16902000.0	422.55	9.94	2.35%
16. Montana Valley and Foothill Prairies	6507000.0	162.68	9.17	5.63%
17. Middle Rockies	9288000.0	232.20	9.53	4.10%
18. Wyoming Basin	12816000.0	320.40	9.78	3.05%
19. Wasatch and Uinta Mountains	4464000.0	111.60	8.66	7.76%
20. Colorado Plateaus	12888000.0	322.20	9.78	3.04%
21. Southern Rockies	13770000.0	344.25	9.82	2.85%
22. Arizona/New Mexico Plateau	19188000.0	479.70	10.01	2.09%
23. Arizona/New Mexico Mountains	10908000.0	272.70	9.66	3.54%
24. Chihuahuan Deserts	17505000.0	437.63	9.96	2.28%
25. Western High Plains	28611000.0	715.28	10.16	1.42%
26. Southwestern Tablelands	15948000.0	398.70	9.91	2.49%
27. Central Great Plains	27378000.0	684.45	10.15	1.48%
28. Flint Hills	2754000.0	68.85	7.82	11.35%
29. Central Oklahoma/Texas Plains	10260000.0	256.50	9.61	3.75%
30. Edwards Plateau	5877000.0	146.93	9.04	6.16%
31. Southern Texas Plains	5427000.0	135.68	8.94	6.59%
32. Texas Blackland Prairies	5022000.0	125.55	8.84	7.04%

Appendix C, *Continued*

Omernik Level III Ecoregion	Area in Hectares	# Total Blocks	# Sample Blocks	% area Sampled
33. East Central Texas Plains	4374000.0	109.35	8.63	7.89%
34. Western Gulf Coastal Plain	6624000.0	165.60	9.19	5.55%
35. South Central Plains	15462000.0	386.55	9.89	2.56%
36. Ouachita Mountains	2637000.0	65.93	7.73	11.72%
37. Arkansas Valley	2646000.0	66.15	7.74	11.69%
38. Boston Mountains	1710000.0	42.75	6.76	15.82%
39. Ozark Highlands	10800000.0	270.00	9.65	3.58%
40. Central Irregular Plains	12285000.0	307.13	9.75	3.17%
41. Canadian Rockies	1962000.0	49.05	7.09	14.45%
42. Northwestern Glaciated Plains	16002000.0	400.05	9.91	2.48%
43. Northwestern Great Plains	34920000.0	873.00	10.22	1.17%
44. Nebraska Sand Hills	6255000.0	156.38	9.12	5.83%
45. Piedmont	16416000.0	410.40	9.93	2.42%
46. Northern Glaciated Plains	15390000.0	384.75	9.89	2.57%
47. Western Corn Belt Plains	20250000.0	506.25	10.03	1.98%
48. Lake Agassiz Plain	4149000.0	103.73	8.55	8.24%
49. Northern Minnesota Wetlands	2412000.0	60.30	7.54	12.51%
50. Northern Lakes and Forests	18396000.0	459.90	9.98	2.17%
51. North Central Hardwood Forests	8811000.0	220.28	9.48	4.30%
52. Driftless Area	4743000.0	118.58	8.75	7.38%
53. Southeastern Wisconsin Till Plains	3051000.0	76.28	8.02	10.51%
54. Central Corn Belt Plains	9828000.0	245.70	9.58	3.90%
55. Eastern Corn Belt Plains	8370000.0	209.25	9.43	4.51%
56. S. Michigan/N. Indiana Drift Plains	7209000.0	180.23	9.28	5.15%
57. Huron/Erie Lake Plains	2475000.0	61.88	7.60	12.28%
58. Northeastern Highlands	12699000.0	317.48	9.77	3.08%
59. Northeastern Coastal Zone	3474000.0	86.85	8.25	9.50%
60. Northern Appalachian Plateau and Uplands	3114000.0	77.85	8.05	10.35%
61. Erie Drift Plains	3051000.0	76.28	8.02	10.51%
62. North Central Appalachians	2916000.0	72.90	7.93	10.88%
63. Middle Atlantic Coastal Plain	8145000.0	203.63	9.41	4.62%
64. Northern Piedmont	3051000.0	76.28	8.02	10.51%
65. Southeastern Plains	33534000.0	838.35	10.21	1.22%
66. Blue Ridge Mountains	4698000.0	117.45	8.74	7.44%
67. Ridge and Valley	11547000.0	288.68	9.70	3.36%
68. Southwestern Appalachians	3564000.0	89.10	8.30	9.31%
69. Central Appalachians	5985000.0	149.63	9.07	6.06%
70. Western Allegheny Plateau	8460000.0	211.50	9.44	4.46%
71. Interior Plateau	12807000.0	320.18	9.78	3.05%
72. Interior River Lowland	9189000.0	229.73	9.52	4.14%

Appendix C, *Continued*

Omernik Level III Ecoregion	Area in Hectares	# Total Blocks	# Sample Blocks	% area Sampled
73. Mississippi Alluvial Plain	13356000.0	333.90	9.80	2.94%
74. Mississippi Valley Loess Plains	4572000.0	114.30	8.70	7.61%
75. Southern Coastal Plain	13014000.0	325.35	9.79	3.01%
76. Southern Florida Coastal Plain	2259000.0	56.48	7.40	13.11%
77. North Cascades	3033000.0	75.83	8.00	10.56%
78. Klamath Mountains	4851000.0	121.28	8.79	7.25%
79. Madrean Archipelago	4167000.0	104.18	8.56	8.21%
80. Northern Basin and Range	10962000.0	274.05	9.66	3.53%
81. Sonoran Basin and Range	11691000.0	292.28	9.71	3.32%
82. Laurentian Plains and Hills	4536000.0	113.40	8.69	7.66%
83. Eastern Great Lakes and Hudson Lowlands	5805000.0	145.13	9.03	6.22%
84. Atlantic Coastal Pine Barrens	1602000.0	40.05	6.60	16.49%
Total		**19465.20**	**755.12**	**6.62%**