Appendixes 1–4

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Appendix 1. Map of Ecoregions in Conterminous United States

This volume—U.S. Geological Survey Professional Paper 1794–A, which covers 30 ecoregions in the Western United States—provides an assessment of the rates and causes of land-use and land-cover change in the Western United States region between 1973 and 2000. The other three volumes of this Professional Paper (1794–B, 1794–C, and 1794–D) provide similar analyses for the Great Plains, the Midwest–South Central United States, and the Eastern United States regions, respectively.

The map contained in this appendix (fig. 1.1) shows all 84 ecoregions in the conterminous United States, as originally defined by Omernik and others (1987) and later modified by the U.S. Environmental Protection Agency (1999), in addition to the ecoregions that are contained in the Western United States, Great Plains, Midwest–South Central United States, and Eastern United States regions. Also shown are the land-use/land-cover classes from the 2001 National Land-Cover Database (Homer and others, 2004).

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Ecoregion Abbreviations Used on Map

[Map is on following pages]

ACPB	Atlantic Coastal Pine Barrens Ecoregion
ANMM	Arizona/New Mexico Mountains Ecoregion
CR	Coast Range Ecoregion
CRK	Canadian Rockies Ecoregion
EGLHL	Eastern Great Lakes and Hudson Lowlands Ecoregion
HELP	Huron/Erie Lake Plains Ecoregion
LPH	Laurentian Plains and Hills Ecoregion
MACP	Middle Atlantic Coastal Plain Ecoregion
MRK	Middle Rockies Ecoregion
MVFP	Montana Valley and Foothill Prairies Ecoregion
MVLP	Mississippi Valley Loess Plains Ecoregion
NAPU	Northern Appalachian Plateau and Uplands Ecoregion
NCA	North Central Appalachians Ecoregion
NCHF	North Central Hardwood Forests Ecoregion
NECZ	Northeastern Coastal Zone Ecoregion
NEH	Northeastern Highlands Ecoregion
NLF	Northern Lakes and Forests Ecoregion
NMW	Northern Minnesota Wetlands Ecoregion
PL	Puget Lowland Ecoregion
SCCCOW	Southern and Central California Chaparral and Oak Woodlands Ecoregion
SCM	Southern California Mountains Ecoregion
SEWTP	Southeastern Wisconsin Till Plains Ecoregion
SFCP	Southern Florida Coastal Plain Ecoregion
TBP	Texas Blackland Prairies Ecoregion
WUM	Wasatch and Uinta Mountains Ecoregion
WV	Willamette Valley Ecoregion

Figure 1.1. Map of ecoregions in conterminous United States.


90°
80°
50°
40°
70°
30°
CANADA
Lake Agassiz Plain
NMW
Northern Lakes and Forests
Northern Glaciated Plains
NCHF
Driftless Area
SEWTP
NLF
HELP
Southern Michigan/ Northern Indiana Drift Plains
Western Corn Belt Plains
HELP
Erie Drift Plains
EGLHL
NAPU
NCA
NEH
NEH
NEH
NCA
Northeastern Highlands
LPH
NECZ
ACPB
Northern Piedmont
MACP
PLAINS
Central Irregular Plains
Central Corn Belt Plains
Eastern Corn Belt Plains
Western Allegheny Plateau
Atlantic Ocean
Plains
Flint Hills
Interior River Lowland
Central Appalachians
MIDWEST–SOUTH CENTRAL UNITED STATES
Interior Plateau
Ridge and Valley
Blue Ridge Mountains
MACP
Ozark Highlands
Boston Mountains
Arkansas Valley
Ouachita Mountains
Mississippi Alluvial Plain
Southwestern Appalachians
Piedmont
Middle Atlantic Coastal Plain
TBP
South Central Plains
EASTERN UNITED STATES
MVLP
Southeastern Plains
East Central Texas Plains
TBP
Western Gulf Coastal Plain
Southern Coastal Plain
SFCP
Gulf of Mexico
90°
80°
EXPLANATION
Land-use/land-cover class
Water
Developed
Barren
Forest
Grassland/Shrubland
Agriculture
Wetland
Ice/Snow
Ecoregion boundary
Major ecoregion group boundary

Appendix 2. Abbreviations for Western United States Ecoregions

ANMM	Arizona/New Mexico Mountains Ecoregion
ANMP	Arizona/New Mexico Plateau Ecoregion
BLM	Blue Mountains Ecoregion
C	Cascades Ecoregion
CBR	Central Basin and Range Ecoregion
CCV	Central California Valley Ecoregion
CD	Chihuahuan Deserts Ecoregion
CLMP	Columbia Plateau Ecoregion
CLRP	Colorado Plateaus Ecoregion
CR	Coast Range Ecoregion
CRK	Canadian Rockies Ecoregion
ECSF	Eastern Cascades Slopes and Foothills Ecoregion
KM	Klamath Mountains Ecoregion
MA	Madrean Archipelago Ecoregion
MBR	Mojave Basin and Range Ecoregion
MRK	Middle Rockies Ecoregion
MVFP	Montana Valley and Foothill Prairies Ecoregion
NBR	Northern Basin and Range Ecoregion
NC	North Cascades Ecoregion
NRK	Northern Rockies Ecoregion
PL	Puget Lowland Ecoregion
SBR	Sonoran Basin and Range Ecoregion
SCCCOW	Southern and Central California Chaparral and Oak Woodlands Ecoregion
SCM	Southern California Mountains Ecoregion
SN	Sierra Nevada Ecoregion
SRB	Snake River Basin Ecoregion
SRK	Southern Rockies Ecoregion
WB	Wyoming Basin Ecoregion
WUM	Wasatch and Uinta Mountains Ecoregion
WV	Willamette Valley Ecoregion

Appendix 3. Land-Cover Classification System Used in “Status and Trends of Land Change” Study

This analysis of land-use/land-cover change during the 1973–2000 study period is based on land-cover classifications mapped for five study dates—1973, 1980, 1986, 1992, and 2000. The use of moderate-resolution imagery—Landsat Multispectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper Plus—necessitated a land-cover classification system that was fairly general in order to achieve high levels of accuracy and consistency in the interpretations. The classification system also needed to contain classes that could be used as an appropriate surrogate for land use. This classification, which is based on the Anderson Level I classes (Anderson and others, 1976), was used because the classes have been designed as use surrogates, but this system has been further modified by adding two transitional disturbance categories, mechanically disturbed (human induced) and nonmechanically disturbed (natural).

The classification system used consists of the following 11 general land-cover classes: water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, nonmechanically disturbed, and ice/snow. Classes are defined as follows:

Water—Areas that are persistently covered with water, such as perennial streams, canals, rivers, lakes, reservoirs, bays, and oceans.

Developed—Areas of intensive use, in which much of the land is covered with structures or other anthropogenically induced, impermeable surfaces (for example, high-density residential, commercial, and industrial areas, as well as roads, highways, and other transportation corridors), or less intensive use, in which the land-cover matrix includes both vegetation and structures (for example, low-density residential areas, recreational facilities, cemeteries, parking lots, and utility corridors). Land that is functionally related to urban or built-up environments (for example, parks and golf courses) is also included.

Mechanically disturbed—Land in an altered and often unvegetated state owing to disturbance by mechanical (that is, human) means. Mechanically disturbed land is in transition from one land-cover class to another. Processes leading to mechanical disturbance include forest clearcutting, earthmoving, scraping, chaining, reservoir drawdown, and other types of anthropogenically induced changes.

Mining—Areas of extractive mining activities that have significant surface expression, including mining buildings and apparatus, quarry pits, evaporation and leach ponds, tailings and overburden piles, and other components related to mining, to the extent that these features can be detected.

Barren—Areas of bare soil, sand, or rock, in which less than 10 percent of the area is vegetated. Barren lands generally are naturally occurring.

Forest—Tree-covered land where the tree-cover density is greater than 10 percent. Cleared forest land is mapped (according to land cover at the time of the imagery) as either mechanically disturbed or grassland/shrubland.

Grassland/Shrubland—Land that is predominately covered with grasses, forbs, or shrubs. Vegetated cover must make up at least 10 percent of the area.

Agriculture—Land, in either a vegetated or an unvegetated state, used for the production of food or fiber. This includes cultivated and uncultivated croplands, hay lands, pasture, orchards, vineyards, and confined-livestock operations. However, forest plantations always are classified as forest, regardless of how the wood products are used.

Wetland—Land where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands usually contain both water and vegetated cover.

Nonmechanically disturbed—Land in an altered and often unvegetated state owing to disturbance by nonmechanical (that is, natural) means. Nonmechanically disturbed land is in transition from one land-cover class to another. Causes of nonmechanical disturbance include fire, wind, floods, animals, and other similar phenomena.

Ice/Snow—Land where the accumulation of snow and ice does not completely melt during the summer period (for example, alpine glaciers and perennial snowfields).

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Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A Land Use and Land Cover Classification System for Use with Remote Sensor Data: U.S. Geological Survey Professional Paper 964, 28 p. (Available at http://pubs.usgs.gov/pp/0964/report.pdf.)

Appendix 4. Methodology Used in “Status and Trends of Land Change” Study

This appendix describes the methodology used to determine the temporal and spatial rates, trends, and types of change documented in this “Status and Trends of Land Change” study. The methodology is based on a statistical sampling approach, manual classification of land use and land cover, and postclassification comparisons of land cover over five different study dates (Loveland and others, 2002). U.S. Environmental Protection Agency’s (1999) Level III ecoregions provided the geographic framework for regional land-cover change estimates, and land-use/land-cover change was estimated on an ecoregion-by-ecoregion basis using a probability sample of randomly selected blocks within each of 84 ecoregions across the conterminous United States. For each sample block, five dates of Landsat imagery were interpreted in order to map land use and land cover, using a classification system that consists of 11 general land-cover classes (see appendix 3, entitled “Land-Cover Classification System Used in ‘Status and Trends of Land Change’ Study”). The resulting land-cover data for each sample block were used to determine change for four time periods, and sample-block data were used to calculate change estimates for each ecoregion.

Sampling Strategy

In this study, a sampling strategy was used as a cost-efficient method for characterizing land-cover change in an area as large as the conterminous United States. The study used a stratified random sample of 2,688 square blocks (fig. 4.1); a random sample of these blocks was independently selected for each ecoregion analyzed. Because the study used a probability sample, the estimates of land-use/land-cover change that are derived can be considered as categorically representative of the population (Kish, 1987).

The size of each sample block in this study, as well as the sampling density (that is, the number of sample blocks analyzed per ecoregion), was based on a compromise between two conflicting objectives: (1) estimating change in land-cover area, and (2) estimating change in landscape pattern. Larger numbers of smaller sample blocks would result in more precise estimates of change in land-cover area, whereas smaller numbers of larger sample blocks would be more desirable for characterizing landscape pattern.

Size of Samples

In the initial study design, a 20 × 20 km (400 km^2) sample-block size was used, and nine ecoregions were analyzed, each analysis consisting of 9 to 11 sample blocks. On the basis of results from these initial ecoregion analyses, a decision was made to use a higher density of smaller (10 × 10 km; 100 km^2) sample blocks for the remainder of the ecoregion analyses in order to maximize the precision of the land-cover change estimates.

Sampling Density

The sampling density was determined by both the project requirements for precision in the change estimates and the expected characteristics of change within the ecoregion being studied. As precision requirements increase, so must the sampling density. Similarly, a greater sampling density is required when areas of change are expected to be less evenly distributed throughout an ecoregion.

In this study, the target precision level was to map gross overall change to within a ±1% margin of error at an 85% confidence level for each ecoregion. On the basis of this target precision level and the expected characteristics of change within all 84 ecoregions in the conterminous United States, it was determined that between 25 and 48 of the 10 × 10 km sample blocks per ecoregion would likely be needed to adequately characterize overall change in each ecoregion.

Implementation of the Sampling Strategy

The sampling strategy outlined above was fairly straightforward to implement. A regular grid of 10 × 10 km (or, in a few cases, 20 × 20 km) sample blocks was overlain on an ecoregion map of the conterminous United States. Blocks whose centers fell within the boundaries of an ecoregion were highlighted as potentially valid sample blocks for that ecoregion and then were assigned a unique numerical value from 1 to N. A random number generator was then used to select sample blocks, one at a time, until the desired number was reached. Thus, each sample block within an ecoregion had an equal probability of being included in the final sample analysis.

Although the number of sample blocks selected and analyzed was based on both the target precision level and the expected characteristics of change within the ecoregion, unexpected heterogeneity in the distribution of change could still result in the estimates of change having levels of precision that are lower than desired. Should this occur, the sampling strategy allowed for the selection and interpretation of additional sample blocks. The inclusion of these reserve blocks allowed the analysis to achieve change estimates that have acceptable levels of precision.

Geographic Framework

A central premise of the study design was the use of a geographic framework to provide regional land-cover change estimates. 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). This “Status and Trends of Land Change” study chose to use ecoregions, as originally defined by Omernik (1987) and later modified by the U.S. Environmental Protection Agency (1999), as the framework from which to tell the regional story of change.

Ecoregions were chosen as the unit of analysis because (1) they provide a means to localize estimates of the rates and driving forces of change, (2) they were developed by synthesizing information on a wide variety of factors (for example, climate, geology, physiography, soils, vegetation, hydrology, and human influences) and, therefore, should reflect both current land-use and land-cover types and future change trajectories, and (3) they provide a framework that can be extended globally.

Landsat Data

Landsat satellite imagery was the primary source of data used for detecting land-cover change in this study. Data from the Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) instruments were acquired from the Landsat data archive: Landsat MSS datasets are available from late-1972 through late-1992; Landsat TM data are available from 1982 to the present; and Landsat ETM+ data are available from 1999 to the present. Each of these products provided a consistent, synoptic, multispectral view of the land surface from which land cover could be interpreted for the period between 1973 and 2000. To analyze trends in land-use/land-cover change throughout this period, five target study dates spaced at semiregular intervals (1973, 1980, 1986, 1992, and 2000) were selected. Landsat imagery corresponding to each 10 × 10 km (or 20 × 20 km) sample block was extracted from full Landsat scenes, resulting in five dates of satellite imagery for each sample block.

To reduce expenses, the initial data-acquisition strategy was to use existing geoprocessed Landsat datasets as the primary input data source. Four of the five dates of Landsat MSS, TM, and ETM+ data were available in a geocoded format as a result of processing done for two previous projects: (1) the North American Landscape Characterization (NALC) project produced 1973, 1986, and 1992 geocoded Landsat MSS datasets for the conterminous United States and Mexico (Lunetta and others, 1998), and (2) the 1992 TM and 2000 ETM+ data came from the Multiresolution Landscape Characterization initiative (Loveland and Shaw, 1996). New 1980 Landsat MSS acquisitions were obtained in order to maintain the six- to eight-year interval between the five target dates.

The Landsat MSS, TM, and ETM+ scenes obtained were previously georeferenced to root-mean-square error of 1 pixel or less but to differing map projections. For this study, all scenes were translated to a common Albers equal-area projection. Most of the NALC MSS data had also been terrain-corrected, but approximately one-third of the NALC data (path and rows) had been processed before the implementation of terrain-correction techniques. However, this was not considered a problem because the early NALC scenes were located primarily in areas with negligible terrain variability.

Ancillary Data

Additional ancillary data were acquired to aid interpreters in delineating land use and land cover from the Landsat data. For example, aerial photography was acquired for each sample block to provide a high-resolution data source to help with difficult interpretations. The National Aerial Photography Program (NAPP) generally provided one or two dates of color-infrared (CIR) and (or) black-and-white aerial photographs from 1987 to the present. The National High Altitude Photograph (NHAP) Program generally provided one date of CIR and (or) black-and-white aerial photographs between 1980 and 1986. Aerial photographs were not consistently available for dates prior to 1980 but were acquired when available. Although the Landsat imagery was always used as the source material for delineating land use and land cover, these higher resolution aerial photographs were invaluable for assisting in the interpretation of the imagery. Topographic maps, census data, other electronic sources of aerial photographs (for example, Google Earth), and digital raster graphics were among the other sources of information that interpreters found useful when processing the data.

Land-Cover Classification Scheme

The analysis of land use and land cover change during the 1973 to 2000 study period was based on classifications of land cover for the five target dates mentioned previously. The classification system used consists of the following 11 general land-cover classes: water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, nonmechanically disturbed, and ice/snow. See appendix 3, entitled "Land-Cover Classification System Used in 'Status and Trends of Land Change' Study," for definitions of these 11 classifications.

Two primary factors affected the design of the classification system. The first factor was recognizing that the use of moderate-resolution Landsat imagery would necessitate a land-cover classification system that was fairly general in order to achieve high interpretation accuracy and consistency. The ability to identify and map land cover would be limited both by the technical specifications of the Landsat MSS, TM, and ETM sensors and by the local and regional landscape characteristics that affect the form and contrast visible in satellite imagery. This would be especially true when interpreting Landsat MSS data.

The second factor involved choosing land-cover classes that captured the land-cover changes of interest. Because the project's interest was in land-use change, with land cover serving as a surrogate for land use, the decision was to use the Anderson Level I classes (Anderson and others, 1976) because they were designed as use surrogates. However, the Anderson system was selectively modified by adding two disturbance categories, mechanically disturbed (human induced) and nonmechanically disturbed (natural).

Manual Land-Cover Delineation

Land-cover delineation for each sample block began with the creation of a baseline reference land-cover dataset. The 1992 date usually was the starting point owing to the availability of the 30-m-resolution 1992 National Land Cover Data (NLCD) dataset (Vogelmann and others, 2001). The NLCD dataset provided a starting template after the more detailed NLCD classes were aggregated to match the general land-cover classification described above.

The NLCD data first were manually edited on the computer screen, using on-screen interpretation methods, while using the 1992 Landsat TM data and the NAPP aerial photographs as interpretation aids. This cleanup procedure to improve the NLCD classification accuracy was carried out because the NLCD data were created using automated image-processing procedures, and they were not meant for use in local- or ecoregional-scale assessments. A minimum mapping unit of 60 m^2 was used for this study. Thus, features having ground footprints less than 60 m wide generally were not mapped, resulting in the exclusion of high-contrast features such as roads, which have a distinct spectral signature but have ground dimensions of less than 60 m.

To carry out the NLCD editing for a particular sample block, the analyst displayed the NLCD data alongside the 1992 Landsat TM data on the computer screen. These data sources, along with hard-copy prints of NAPP aerial photography roughly corresponding to the 1992 date, were visually inspected by the analyst to determine if any corrections were needed in the sample block. The analyst manually delineated polygons that consisted of contiguous blocks of specific land-cover classes. Each of these polygons was then given a code value that corresponded to the land-cover classes outlined in the classification scheme in appendix 3. The process continued until the entire sample block was manually inspected, mapped, and coded by the analyst.

To analyze change, land-cover classes for the 1973, 1980, 1986, and 2000 study dates were backward- or forward-classified using the 1992 land-cover dataset as the template. For example, creation of the 2000 land-cover product began by making an exact copy of the 1992 land-cover product. This copy served as a baseline for the 2000 land-cover product, in which identified changes between 1992 and 2000 were manually edited into the copied image. This baseline 2000 land-cover product was displayed on screen, along with the 1992 Landsat imagery and the 2000 Landsat imagery, allowing the analyst to pan through the entire area of the sample block while examining the 1992 and 2000 Landsat imagery and any relevant aerial photography for valid land-cover changes between the two study dates. Any identified land-cover changes were manually digitized on screen, and the land cover was recoded on the 2000 land-cover product.

Upon completion of the 2000 land-cover product, the same procedures were used to create the 1986, 1980, and 1973 land-cover products. This manual process eliminated errors that may occur between independently created land-cover products that are compared in a subsequent change analysis. Because only manually identified, delineated, and coded land-cover changes were analyzed during this phase, classification errors were greatly reduced.

Statistical Analysis

The resulting land-cover data for each sample block was used in postclassification comparisons to determine change between study years (fig. 4.2). Sample blocks within each ecoregion were used to generate change statistics for all 84 ecoregions. These statistics were used to determine the predominant types of land-cover conversions occurring within each ecoregion, the estimated rates of change for these conversions, and whether these types and rates of change are constant or variable across time. The analysis of change also involved looking for spatial correlations between conversion types and selected socioeconomic and environmental factors, such as timber production, agricultural yields, precipitation amounts, population levels, proximity to urban development, and overall economic conditions, in order to improve the understanding of potential drivers of change.

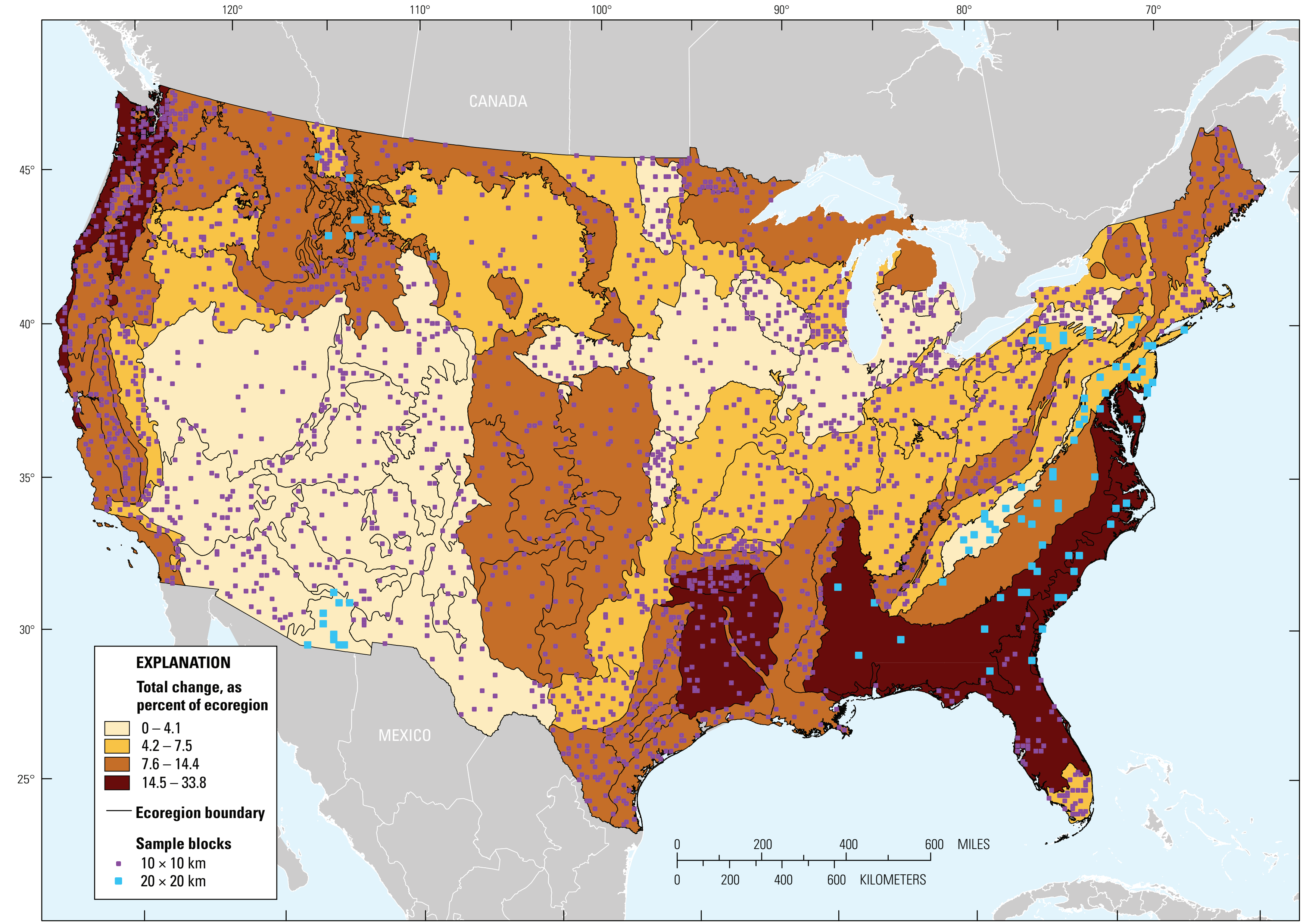

Figure 4.1. Map of ecoregions in conterminous United States, showing locations of 2,688 sample blocks that were used in "Status and Trends of Land Change" study (purple and blue squares indicate locations of 10 × 10 km and 20 × 20 km sample blocks, respectively). Also shown are amounts of total change in each ecoregion between 1973 and 2000, as percent of ecoregion.

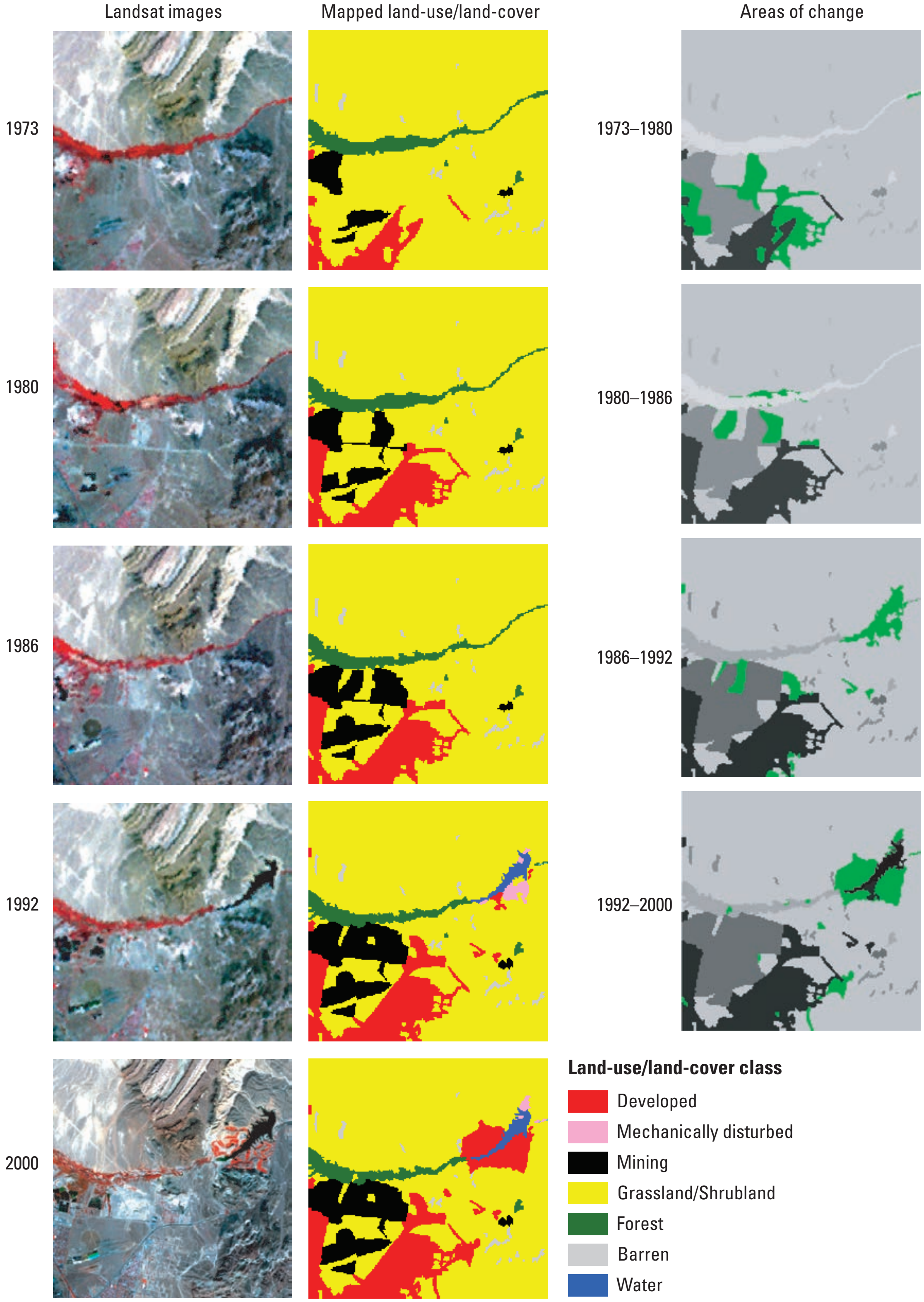

Figure 4.2. Example of data compiled for each sample block, showing sample block 14-0555 (located near Henderson, Nevada, in Mojave Basin and Range Ecoregion). Left column is satellite imagery collected for each of five years analyzed in study (imagery sources for study years: 1973, 1980, and 1986 are Landsat Multispectral Scanner (MSS) images; 1992 is Landsat Thematic Mapper (TM) image; 2000 is Landsat Enhanced Thematic Mapper (ETM) image). Center column is mapped land-use/land-cover data for each study year. Right column shows areas that changed (green areas) in each of four time periods between study years; light- and dark-gray-shaded areas show areas of previous change and represent overall land-change footprint throughout study period.

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