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Land-cover change in the conterminous United States from 1973 to 2000

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ABSTRACT

Land-cover change in the conterminous United States was quantified by interpreting change from satellite imagery for a sample stratified by 84 ecoregions. Gross and net changes between 11 land-cover classes were estimated for 5 dates of Landsat imagery (1973, 1980, 1986, 1992, and 2000). An estimated 673,000 km^2(8.6%) of the United States' land area experienced a change in land cover at least one time during the study period. Forest cover experienced the largest net decline of any class with 97,000 km^2 lost between 1973 and 2000. The large decline in forest cover was prominent in the two regions with the highest percent of overall change, the Marine West Coast Forests (24.5% of the region experienced a change in at least one time period) and the Eastern Temperate Forests (11.4% of the region with at least one change). Agriculture declined by approximately 90,000 km^2 with the largest annual net loss of 12,000 km^2 yr^{-1} occurring between 1986 and 1992. Developed area increased by 33% and with the rate of conversion to developed accelerating rate over time. The time interval with the highest annual rate of change of 47,000 km^2 yr^{-1} (0.6% per year) was 1986–1992. This national synthesis documents a spatially and temporally dynamic era of land change between 1973 and 2000. These results quantify land change based on a nationally consistent monitoring protocol and contribute fundamental estimates critical to developing understanding of the causes and consequences of land change in the conterminous United States.

1. Introduction

Land-use and land-cover (LULC) change is a pervasive phenomenon impacting local-to global-scale processes and often involving the trade-off of meeting human needs and the preservation of ecosystem functions (Vitousek et al., 1997; DeFries et al., 2004). LULC change has emerged as a focus area in global change research (Committee on Global Change Research, 1999); in the U.S. it has been shown to directly impact weather and climate systems (Kalnay and Cai, 2003), surface radiative forcing (Sagan et al., 1979), and biogeochemical cycling (Houghton et al., 1999; Caspersen et al., 2000). While globally important, LULC change occurs locally, requiring integrative studies at finer geographic scales (Wilbanks and Kates, 1999). However, despite recent advances in terrestrial monitoring and observation, comprehensive mesoscale assessments spanning sufficiently long temporal periods, landscapes, and LULC classes are lacking.

The United States (U.S.) has several land-use or land-cover monitoring programs each of which contributes valuable information to our understanding of change but none of which individually offers a complete, nationally comprehensive assessment based on methods that are spatially and temporally consistent across the U.S. For example, statistical surveys such as the U.S. Department of Agriculture's (USDA) Forest Inventory and Analysis (Gillespie, 1999) and Natural Resources Inventory (NRI) (USDA, 2001) have been implemented, and the USDA Agricultural Census and the U.S. Census Bureau's decadal population census provide information on agricultural land use and population dynamics. However, these programs are limited to specific lands or land-use classes and therefore do not provide an adequate national synthesis of U.S. land change. Constructing a consistent and comprehensive land-cover change synthesis is also complicated by the fact that these survey and census programs use different spatial and temporal scales as well as different definitions of land-cover classes. For

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example, forest use may include areas without tree cover, such as recent clear-cuts, while a forest cover classification is most often characterized by the biophysical presence of vegetation meeting certain criteria. The different definitions of "forest" have led to recognition of the usefulness of different data sources for characterizing trends in forest cover (Drummond and Loveland, 2010).

In contrast to statistical surveys and census approaches to quantify land change, remote sensing offers another platform for monitoring. The relative rarity of land-cover change – particularly over short time intervals and large spatial extents – has made accurate mapping and estimation of regional land-cover change difficult. Early national-scale efforts relied either on coarse resolution sensors, such as AVHRR (Advanced Very High Resolution Radiometer), and focused on characterizing land cover at a single point in time (e.g., Loveland et al., 1991), or using moderate resolution imagery for single class mapping (Skole and Tucker, 1993) or regional studies (Dobson et al., 1995). More recently, the U.S. Geological Survey has used remote sensing to produce the National Land Cover Database (NLCD) of land-cover products mapped at a 30-m x 30-m pixel resolution. NLCD is currently available for three dates, 1992 (Vogelmann et al., 2001), 2001 (Homer et al., 2007), and 2006 (Fry et al., 2011). NLCD offers a promising future monitoring framework; however, the current NLCD data are not available for a sufficiently long temporal period. As an alternative to wall-to-wall maps, probability-based sampling has been shown to be an effective method for quantifying land-cover change using remote sensing, particularly for forest cover loss (Achard et al., 2002; Hansen et al., 2010).

Because of the extensive temporal record and relatively consistent spatial and radiometric characteristics, the Landsat series of earth observation satellite data offer a unique opportunity to characterize changes between major land-cover classes across a wide range of ecosystems. The Landsat archive, consisting of data acquired by 6 satellites over a period of 40 years, offers a consistent source of appropriate resolution observational data that is critical to permit quantification of land change over sufficiently long time periods.

The objective of the U.S. Geological Survey Land Cover Trends project (Loveland et al., 2002) was to estimate the rates and types of recent historical land-cover change across ecoregions of the conterminous U.S. (Loveland et al., 2002; Stehman et al., 2003a) (hereafter, we will omit the modifier "conterminous" but all references to the U.S. should be understood as meaning the conterminous U.S.). The major land-cover changes captured in this study represent processes associated with forest harvest; urbanization; agricultural intensification, deintensification, and abandonment; and mining. In this article we report broad-scale patterns of land-cover change augmenting the national results with regional results presented for the following six regions: Eastern Temperate Forests, Great Plains, Western Cordillera, Marine West Coast Forests, North American Deserts, and Mediterranean California (Fig. 1). National estimates of overall change are first summarized by the land change footprint (or change footprint) of the U.S., defined as the total area of land that experienced a change in land cover in at least one of the four time intervals (1973–1980, 1980–1986, 1986–1992, and 1992–2000) partitioning the 1973–2000 study period. Regional estimates of

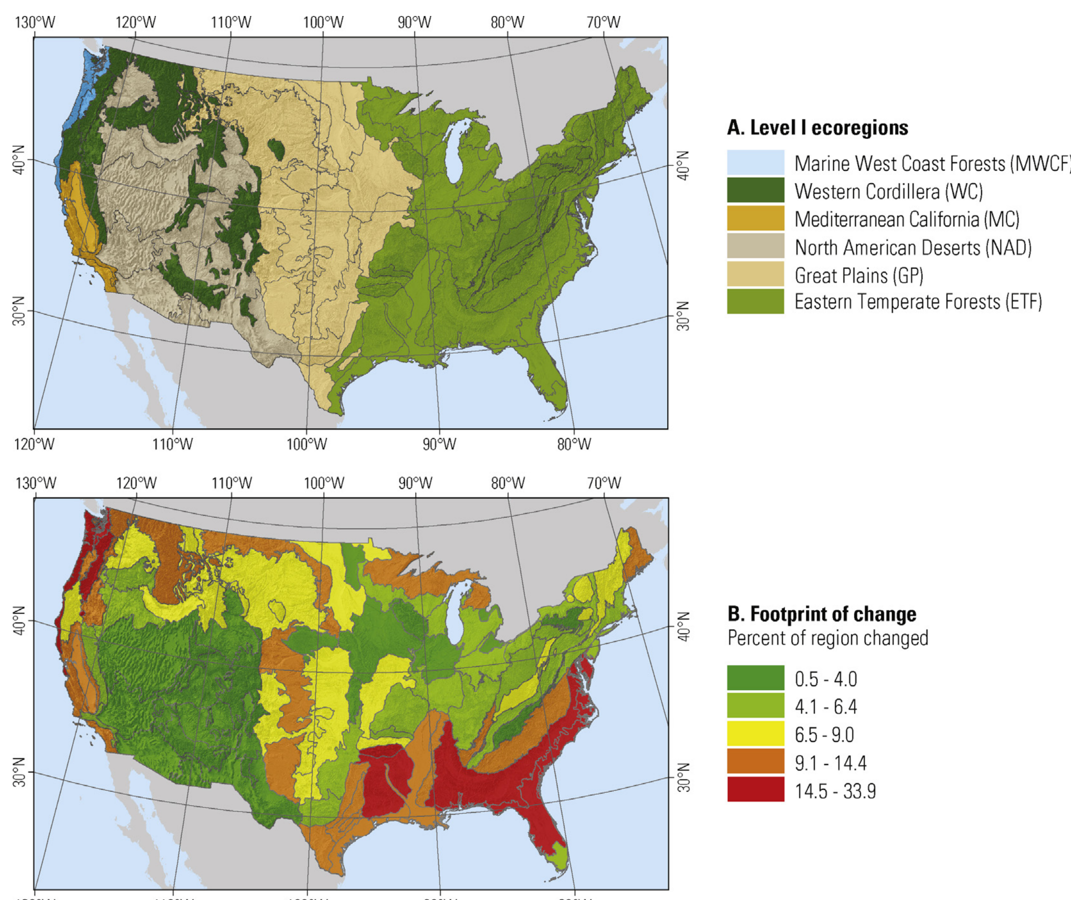

Fig. 1. (A) Six reporting regions partitioning the conterminous United States (MWCF is Marine West Coast Forests, MC is Mediterranean California, WC is Western Cordillera, NAD is North American Deserts, GP is Great Plains, and ETF is Eastern Temperate Forests), and (B) the estimated land change footprint, or the area that changed at least one time between 1973 and 2000 (% of ecoregion area).

overall change follow based on the land change footprint of the six major regions. Results are then presented for three major types of change observed nationally: forest cover decline, urban expansion (increasing development), and agriculture loss. Complete results can be found in Dataset S1. Although the primary objective is to quantify land change, explanations of potential driving forces accompany some of the estimates of change. In depth regional analyses and studies focusing on causes and consequences of change based on the data collected in this study are in progress or in press, for example, land-cover change in California (Sleeter, 2008; Sleeter et al., 2010) and the western U.S. (Sleeter et al., 2012a; Soulard and Sleeter, 2012), the Great Plains (Drummond, 2007; Drummond et al., 2012) and the eastern U.S. (Drummond and Loveland, 2010; Napton et al., 2010; Auch et al., 2012; Sohl and Sohl, 2012).

2. Materials and methods

A stratified random sample of 2688 10-km × 10-km blocks (some ecoregions used 20-km × 20-km blocks) was selected from 84 ecoregion strata in the U.S. (Fig. 2) (Loveland et al., 2002; Stehman et al., 2003a). Ecoregions originally developed by Omernik (1987) and later modified by the U.S. Environmental Protection Agency (1999) provided the spatial framework for the sampling design and analysis (Fig. 1, Table S1). Ecoregions have been demonstrated to be an effective framework for characterizing changes in U.S. land cover (Gallant et al., 2004). Land cover was classified according to a modified version of the Anderson Level I classification scheme (Anderson et al., 1976) consisting of 11 land cover classes, water, developed, mining, barren, forest, grassland/shrubland, agriculture, wetland, snow/ice and two disturbance classes: mechanical (anthropogenic) and nonmechanical (natural) (Table 1). Landsat MSS, TM, and ETM+ images were used by interpreters to identify and map changes in LULC between successive image dates. After classification, images were compared to determine for each sample block the area of each possible type of change between the 11 land cover classes. The four change intervals, 1973–1980, 1980–1986, 1986–1992, and 1992–2000, were selected to take advantage of time and cost savings gained by using Landsat data that had already been radiometrically and geometrically corrected. Annual rates of change were computed to allow comparisons between the different length time periods. It is important to note that while annualizing the period estimates provides a means of comparing the varying length temporal intervals, the annual rates ignore inter-period changes that may have been missed using our 6–8 year change intervals.

Methods used for this research are described in detail in Loveland et al. (2002) and Stehman et al. (2003a, b). Here we provide a brief overview of the major methodological components of the research, including spatial and temporal sampling, the classification system used to characterize land-cover change, techniques to classify land change, and finally the statistical estimation of change.

2.1. Ecoregion stratification and sample selection

The regional stratification of the conterminous United States (U.S.) was based on the 1999 version of the EPA's Level III ecoregions of the U.S. (EPA, 1999) (Fig. 2). A fixed grid of 10-km × 10-km blocks (9 of the first ecoregions processed used 20-km × 20-km blocks) was overlaid on the ecoregion map and each block was assigned to an ecoregion based on the location of the center point of the block. Sliver (incomplete) blocks were found along coastlines and international borders. In these instances, the sliver blocks were attached to an adjacent "parent" block to ensure that the area of the sliver blocks was eligible to be sampled. A

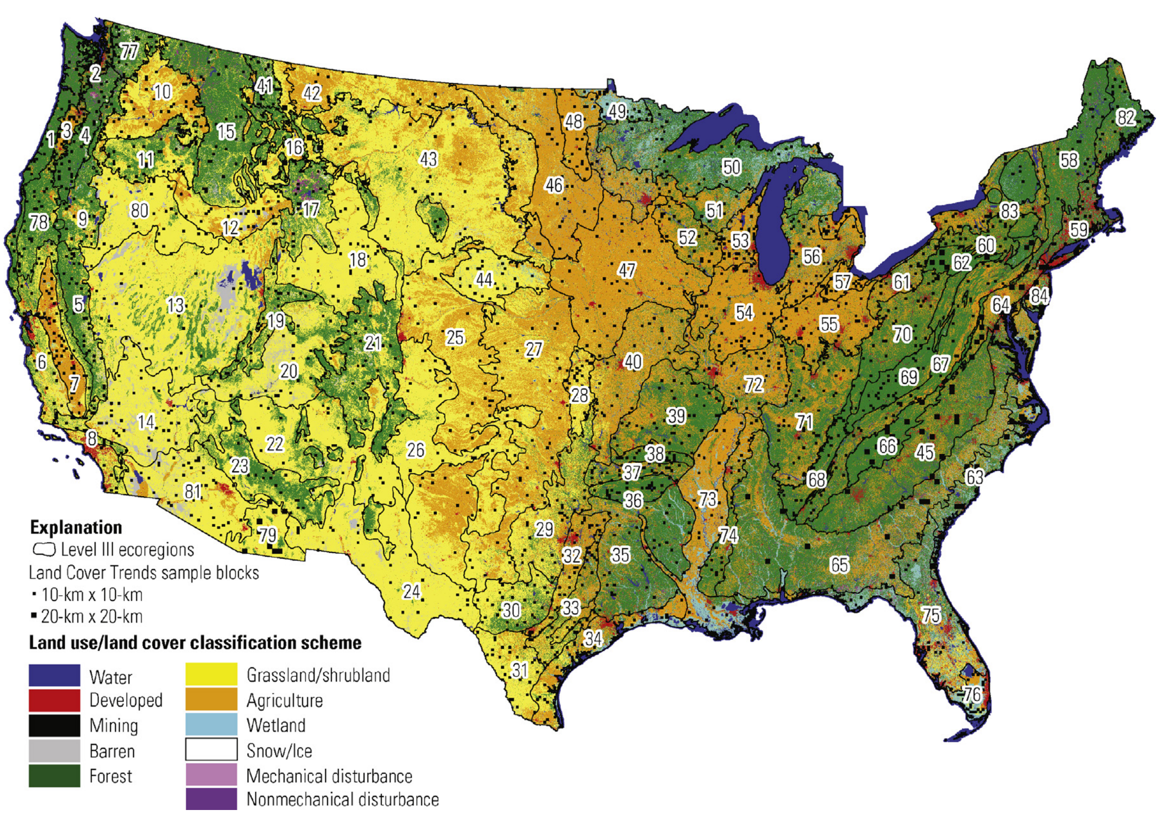

Fig. 2. Ecoregions, sample blocks, and 1992 land cover reclassified from the 1992 NLCD to the Table S1 classification (see Table S2 for "crosswalk" between classification schemes). Black lines are ecoregion boundaries and black boxes are the 2688 sample blocks. Ecoregion numbers are shown in Table S2.

Table 1
Land-cover classes and descriptions.

Class	Description
Water	Areas persistently covered with water, such as streams, canals, lakes, reservoirs, bays, or oceans.
Developed	Areas of intensive use with much of the land covered with structures or anthropogenic impervious surfaces (e.g., high-density residential, commercial, industrial, roads, etc.) or less intensive uses where the land cover matrix includes both vegetation and structures (e.g., low-density residential, recreational facilities, cemeteries, parking lots, utility corridors, etc.), including any land functionally related to urban or built-up environments (e.g., parks, golf courses, etc.).
Mining	Areas with extractive mining activities that have a significant surface expression. This includes (to the extent that these features can be detected) mining buildings, quarry pits, overburden, leach, evaporative, tailings, or other related components.
Barren	Land comprised of soils, sand, or rocks where less than 10 percent of the area is vegetated. Barren lands are usually naturally occurring.
Forest	Tree-covered land where the tree-cover density is greater than 10 percent. Note that cleared forest land (i.e., clear-cuts) is mapped according to current cover (e.g., mechanically disturbed or grassland/shrubland).
Grassland/shrubland	Land predominately covered with grasses, forbs, or shrubs. The vegetated cover must comprise at least 10 percent of the area.
Agriculture	Land in either a vegetated or an unvegetated state used for the production of food and fiber. This includes cultivated and uncultivated croplands, hay lands, pasture, orchards, vineyards, and confined livestock operations. Note that forest plantations are considered forests regardless of the use of the wood products.
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.
Snow/ice	Land where the accumulation of snow and ice does not completely melt during the summer period (e.g., alpine glaciers and snowfields).
Mechanical disturbance	Land in an altered and often unvegetated state that, due to disturbances by mechanical means, is in transition from one cover type to another. Mechanical disturbances include forest clear-cutting, earthmoving, scraping, chaining, reservoir drawdown, and other similar human-induced changes.
Nonmechanical disturbance	Land in an altered and often unvegetated state that, due to disturbances by non-mechanical means, is in transition from one cover type to another. Non-mechanical disturbances are caused by fire, wind, floods, animals, and other similar phenomena.

simple random sample was chosen from each ecoregion (stratum) with the sample size per ecoregion based on ecoregion size and the expected variability of change within the ecoregion (Stehman et al., 2003a, b). The first ecoregions sampled had the 20-km $\times$ 20-km sample blocks, but early results for these ecoregions indicated that more precise change estimates would be obtained if the block size was reduced. Sample sizes ranged from 9 to 11 blocks for ecoregions using the 20-km blocks and 25 to 48 sample blocks for ecoregions using the 10-km blocks. For some results reported in this article, Level III ecoregions were aggregated into six macro-scale regions similar to Level I ecoregions (Table S1).

2.2. Temporal sampling and landsat data collections

Temporal sampling was designed to utilize as many low-cost or free geometrically and radiometrically corrected datasets as possible while preserving a 6–8 year interval between observations. Equal length time periods would have been preferable, but the time and cost savings associated with using existing satellite data drove the decision to use time periods of different length (note that this study was initiated prior to the 2008 decision to make Landsat data available at no cost; future efforts to document change may afford more regular or frequent analyses). The five dates were 1973, 1980, 1986, 1992, and 2000 with images collected $\pm$1 year from the center point dates. Landsat Multispectral Scanner (MSS) triplicates from the North American Landscape Characterization (NALC) program (Lunetta and Sturdevant, 1993) were collected for 1973, 1986, and 1992. These data were precision and terrain corrected and registered to a common map base to ensure accurate pixel-to-pixel registration. For 1992 we also procured Landsat Thematic Mapper (TM) data from the Multi-Resolution Land Characteristics (MRLC) project which consists of precision and terrain corrected 30-m Landsat TM data used for production of the 1992 National Land Cover Dataset (NLCD). For 2000, we used Landsat Enhanced Thematic Mapper Plus (ETM+) data from the MRLC 2001 collection. This collection typically included three or more ETM+ acquisitions collected between 1999 and 2002. In some cases TM data from Landsat 5 were also included. The only new data acquisition required was for 1980. These data were ordered with Level 1 systematic processing with terrain correction. All Landsat data were processed to an Albers Conical Equal Area projection with MSS data reprojected to 60-m resolution and TM and ETM+ to 30-m resolution.

2.3. Classification scheme

Two primary factors affected the design of our classification system. The first factor was recognizing that the use of moderate-resolution imagery Landsat TM/ETM+ and MSS would necessitate a land cover classification system that was fairly general in order to achieve high interpretation accuracy and consistency. Our ability to identify and map land cover was limited 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 classes that captured the land cover changes of interest. Since we were interested in land-use change with land cover serving as a surrogate for land use, we decided to use the Anderson Level I classes (Anderson et al., 1976) because this classification scheme was designed to provide land-use surrogates. To characterize lands that were in transition between cover types, we modified the Anderson system by adding two disturbance categories; mechanically disturbed (human-induced) and non-mechanically disturbed (natural) (Table 1). The mechanically disturbed class was used to capture areas that had been recently disturbed by mechanical means and was particularly useful for identifying areas that had experienced forest clear-cut logging. Mechanically disturbed lands also included other relatively minor changes such as reservoir drawdown, scraping, earthmoving, and chaining, and other human-induced changes. The non-mechanically disturbed class was used to capture land altered by disturbances, such as wildfire, and to a lesser extent, winds, floods, animals (e.g. beetle infestation), and other similar phenomena.

2.4. Mapping baseline land cover

We used the 1992 NLCD (Vogelmann et al., 2001) as a starting point for land-cover mapping. NLCD land cover was extracted for each sample block and then reclassified to match our classification

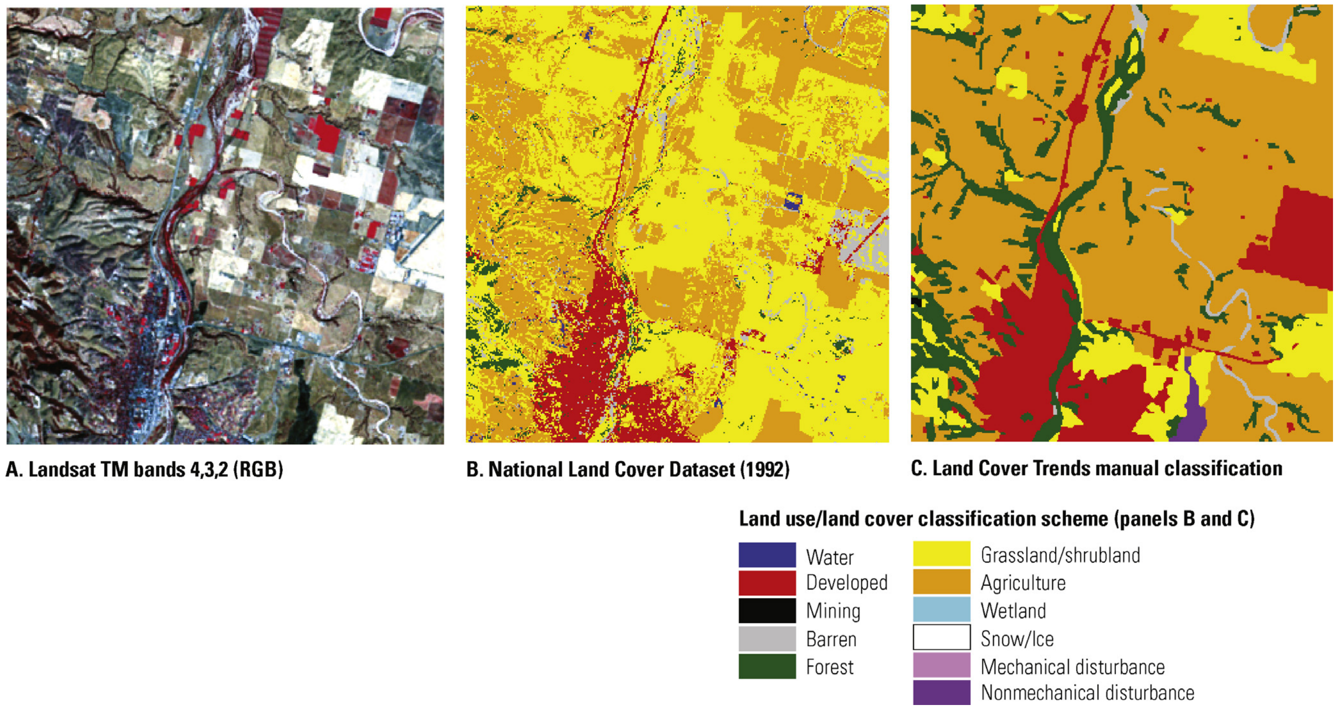

Fig. 3. Example of Landsat TM (A), 1992 NLCD (B) and interpreted Trends land cover map (C). The example is from the Southern and Central California Chaparral and Oak Woodlands Ecoregion. The legend shows the classification scheme used for this assessment and corresponding to the maps in panel B and C. The NLCD map in panel B was reclassified to match the Land Cover Trends classification scheme (see Table S2 for "crosswalk" between classification schemes).

scheme (Table S2). Image interpreters then manually evaluated the reclassified NLCD by examining Landsat data and other ancillary sources such as aerial photography and topographic maps and, using a minimum mapping unit of 60-m $\times$ 60-m, modified the NLCD product to produce a starting land-cover map for each sample block (Fig. 3). The overall accuracy of the 1992 NLCD ranged from 70 to 83% in the four eastern federal regions of the U.S. Environmental Protection Agency (EPA) (Stehman et al., 2003a, b) and from 74 to 85% in the six western EPA federal regions (Wickham et al., 2004), with considerable variation in class-specific user's and producer's accuracies among regions. The reclassification, or interpreter "clean-up" process, of the 1992 NLCD often resulted in substantial remapping of LULC to produce a reliable starting point for change mapping.

2.5. Mapping land-cover change

Mapping land-cover change for each sample block required image interpreters to visually inspect Landsat image pairs while looking for areas that experienced a change. Analysis was first conducted between the 1992 and 2000 dates. The land cover map modified from the 1992 NLCD was used as a base for the 2000 year with areas of change identified and recoded in the 2000 land cover image. Upon completion of the 2000 date, both the 1992 and 2000 land cover images were resampled to 60-m resolution using the nearest neighbor technique. The new 60-m data from 1992 were then used as a starting point for interpreting the 1986 land cover. Any change identified by comparing the 1992 and 1986 image pairs was recoded into the 1986 land cover product. This process was repeated until all five dates were complete. Upon completion of land-cover mapping, land-cover change images were produced using simple thematic image differencing between each successive image pair. This resulted in 4 temporal periods of change images for each sample block. Additionally, spatial land change "footprint" maps were produced showing the number of times each 60-m pixel within a sample block experienced a change (Fig. 4). Fig. 5 shows an example of Landsat imagery, sample block interpretation, and land-cover change images.

Validation of land cover mapping was achieved through an ecoregion review process where all sample blocks were examined by the full team of image interpreters, including those who did not interpret sample blocks for the ecoregion being subjected to the quality assessment. This approach allowed for an independent critique of mapping while ensuring general consistency with national-scale project methodology and objectives. Areas of disagreement identified in the ecoregion review process were reclassified to ensure as accurate a classification as possible. The goal of the mapping effort was to achieve as high of rates of accuracy as possible using Landsat data as the primary interpretative source. Additionally, interpreters regularly utilized other ancillary sources of data, such as aerial photographs and topographic maps, when conducting change mapping to further increase the accuracy of Landsat-based interpretations.

2.6. Statistical estimation

Stratified random sampling formulas are used for estimating area and standard errors. The 84 Level III ecoregions are the strata for the sampling design. Let $y_{h,u}$ denote an area for sample block u of stratum h (e.g., $y_{h,u}$ is the area of forest in 1992 for sample block u in one of the 84 ecoregion strata, or $y_{h,u}$ is the area of gross change of forest to developed from 1986 to 1992 in block u of stratum h), and N_h and n_h denote the number of blocks and number of blocks sampled in stratum h (Table S1). For stratum h, the estimated total area is

$$\widehat{Y}_h = N_h \bar{y}_h$$

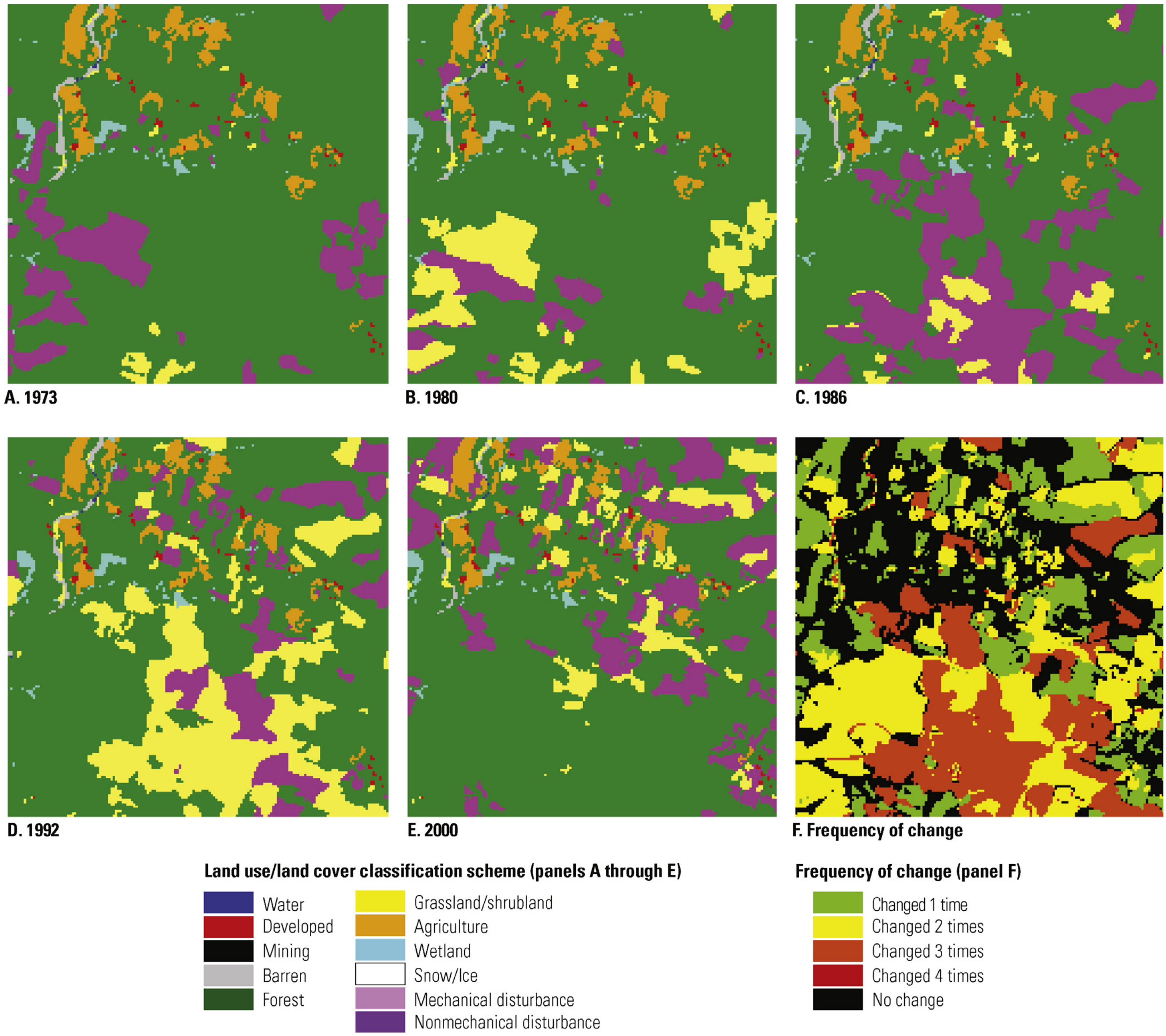

Fig. 4. Example of the five LULC images used to calculate the land change footprint (bottom right image) which quantifies the number of times each pixel experienced a change in land cover during the four time intervals. This example is from a sample block located in the Coast Range ecoregion.

where $\bar{y}_h$ is the mean of the $y_{h,u}$ values from the blocks sampled in stratum h. To estimate a total for an aggregation of ecoregions (e.g., a national total or a total for one of the six reporting regions), the estimator is

$$\hat{Y} = \sum_{h=1}^{H} \hat{Y}_h = \sum_{h=1}^{H} N_h \bar{y}_h$$

where H is the number of strata (ecoregions) within the target region of interest (e.g., $H = 84$ for a national estimate, and $H = 15$ for a Great Plains region estimate combining sample blocks from 15 ecoregions). The estimated variance of $\hat{Y}$ is

$$\hat{V}(\hat{Y}) = \sum_{h=1}^{H} N_h^2 \left(1 - \frac{n_h}{N_h}\right) \frac{s_{yh}^2}{n_h}$$

where s_{yh}^2 is the sample variance of the $y_{h,u}$ values in stratum h. The standard error is computed as the square root of the estimated variance. These same formulas, with one modification, apply to estimating net change. For each sample block, $y_{h,u}$ is defined as the net change (difference) in area for the two dates. The sample variance, s_{yh}^2, is then the variance of the differences and this accounts for the correlation of observations taken at two dates from the same sample blocks.

Design-based inference (Särndal et al., 1992) is the framework in which properties of the estimators are defined. In design-based inference, the observations for each sample block are regarded as fixed quantities (not random variables). Any measurement error associated with each observation is assumed to be random with a mean of 0 and the variability of repeated measurements of the same observation (i.e., if the entire interpretation and ecoregion review process were to be repeated many times) is assumed to be negligible relative to the variability associated the sampling process (it is the latter variability that is quantified by the standard error of each estimator). Särndal et al. (1992, Chapter 16) provide a general introduction to measurement error in survey sampling.

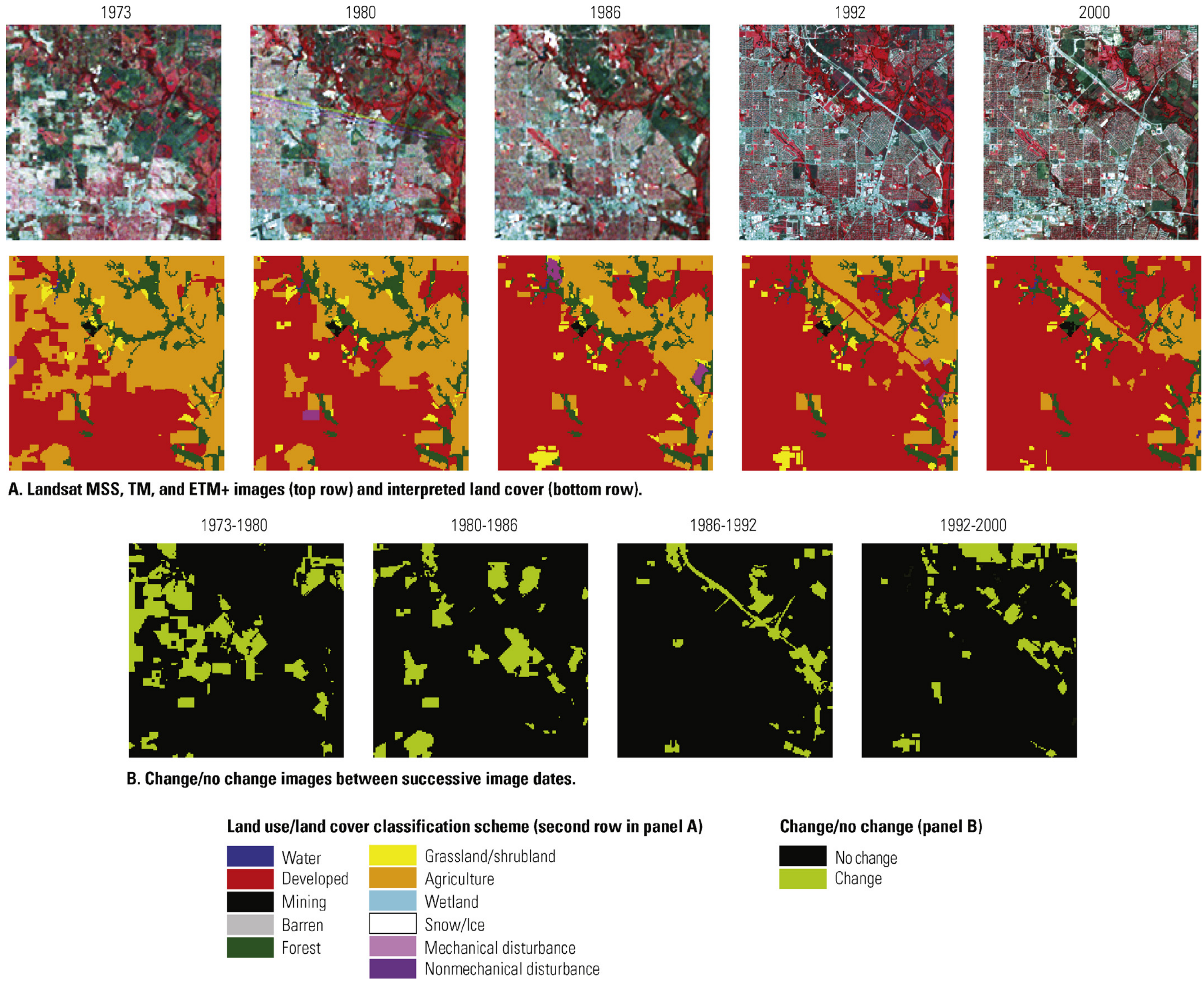

Fig. 5. Land-cover interpretation and corresponding change images produced from manual interpretation of Landsat data. The top row in panel A contains Landsat MSS (first three images), TM (fourth image) and ETM+ (last image) images. The second row in panel A depicts the interpreted land cover. Panel B displays the change and no change areas for the four temporal intervals. The example is from the Texas Blackland Prairies ecoregion.

3. Results

This study focused on describing the geographic, temporal, and thematic dimensions of 1973–2000 U.S. land cover change. To aid in understanding these three dimensions, we will first describe the geography of change – the land change footprint as it varies by ecoregion and through time (Section 3.1), and then present the thematic transformations and how they vary over time (Section 3.2). The thematic dimensions will focus on the three primary transformations – forests and agricultural loss, and urban expansion. At the national scale, our results show LULC change to be relatively rare, affecting 8.6% of the nation's land area over our 27-year study period; however, change was highly variable across ecological regions, ranging from as little as 0.5% to greater than 33%, with the highest rates occurring between 1986 and 1992. Cumulatively, LULC change resulted in the rapid expansion of developed lands and declines in forests and agriculture. Furthermore, the area of disturbed lands increased significantly through time. Throughout the presentation of results we utilize 6 broad ecological regions as a means of providing geographic context, and illustrate the large degree of spatial variability in our results.

3.1. The land change footprint

The land change footprint is the amount of land that changed at least one time over the course of the full study period and was estimated at 673,000 km^2(8.6%) of the U.S. between 1973 and 2000. Most of the changed area only experienced a change in a single time period (63.1%), while 30.5% changed two times, and 5.9% changed three times. Multiple changes were generally attributable to cyclic land change processes, such as forest harvest and regrowth, while locations changing only once were more typically associated with unidirectional processes such as urbanization.

The land change footprint was distributed heterogeneously across space (Fig. 1B) and time (Fig. 6). The change footprint in individual ecoregions over the 27-year period ranged from 0.5% to 33.8% (percent of ecoregion area) with a median of 6.5% for the 84 ecoregions. The rates and types of land-cover change varied temporally as different change agents such as government policy, environmental regulation, global and national economic conditions, and regional weather and climate variability interacted in different ways to affect regional land-use demand (e.g., Brown

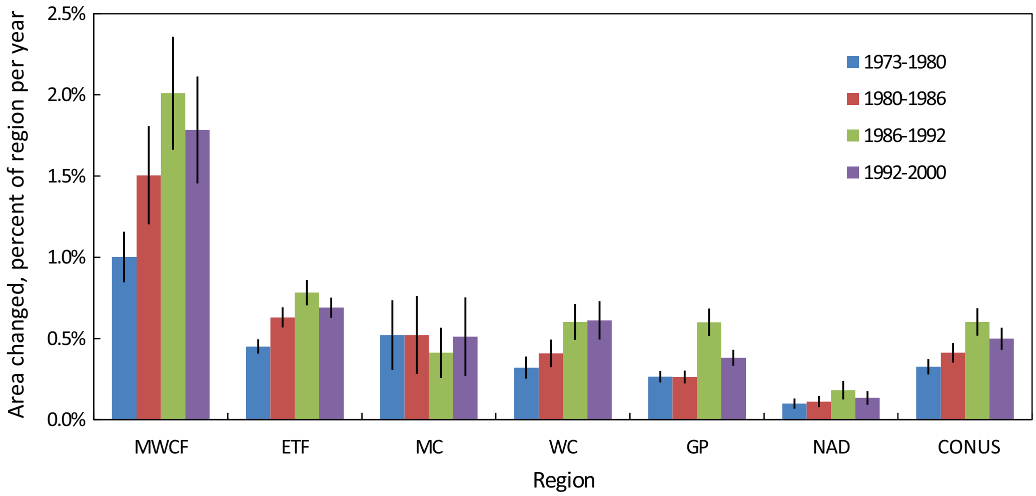

Fig. 6. Estimated annual rate of land change (percent of region per year) by time interval and region (error bars represent standard error). The regions are Marine West Coast Forests (MWCF), Eastern Temperate Forests (ETF), Mediterranean California (MC), Western Cordillera (WC), Great Plains (GP), North American Deserts (NAD) and the conterminous United States (CONUS).

et al., 2005; Lubowski et al., 2008; Wright and Wimberly, 2013). The highest annual rate of change among the four time periods occurred between 1986 and 1992 with an estimated rate of 47,000 $km^2 yr^{-1}$ (Dataset S1). This period was characterized by the convergence of high rates of timber harvest (see Section 3.2.1), rapid urbanization (see Section 3.2.2), and initiation of a large federal program designed to conserve marginal farmland (see Section 3.2.3; Sullivan et al., 2004).

Of the six major regions of the U.S., the Marine West Coast Forests had the highest land change footprint (on a percent area basis) with an estimated 24.5% of the region experiencing a change in land cover between 1973 and 2000. This region, which covers less than 100,000 km^2 in coastal California, Oregon and Washington, has an extensive forestry legacy and two major metropolitan regions (Portland, Oregon and Seattle, Washington). Forest management practices and expansion of developed areas (USDA, 2001; Hobbs and Stoops, 2002; Auch et al., 2004) were the major contributors to overall change. The highest annual rate of change in this region was 2.1% between 1986 and 1992. This trend was largely driven by a steady increase in forest harvest activity throughout the region in response to increased demands for high quality old growth timber (Daniels, 2005).

The second highest land change footprint occurred in the Eastern Temperate Forests where an estimated 11.4% of the region experienced a change in land cover. Given its large size, more than half of the change footprint in the U.S. was located in this region. Two of the ecoregions with the highest percent area of change were found in the Eastern Temperate Forests; the Ouachita Mountains had the highest change of any ecoregion at 33.8% and the South-Central Plains had a change footprint of 27.1%. The three ecoregions with the largest change in terms of area were all in the Eastern Temperate Forests. These were the Southeastern Plains (68,508 km^2), the South-Central Plains (42,179 km^2), and the Southern Coastal Plain (35,603 km^2) ecoregions. The common theme in each of these ecoregions was the presence of intensive forestry activities, although reforestation of agricultural areas, urban-industrial expansion, and mining contributed to high rates of change in some ecoregions (USDA, 2001; Drummond and Loveland, 2010). As with the Marine West Coast Forests, the Eastern Temperate Forests experienced a peak annual rate of land change between 1986 and 1992 at approximately 24,000 $km^2 yr^{-1}$.

The Mediterranean California region encompasses three highly diverse ecoregions including the nation's most populous ecoregion, the Southern and Central California Chaparral and Oak Woodlands (from here on called the "Oak Woodlands"), which includes the San Diego, Los Angeles, and San Francisco-San Jose metropolitan areas. The land change footprint in Mediterranean California was estimated at 9.9%. With the exception of the 1986–1992 period (680 $km^2 yr^{-1}$), change was consistent over time at approximately 850 km^2 annually. However, the driving forces of change were spatially variable. Urbanization and wildfire were important contributors of change in the Oak Woodlands, while agricultural gross changes (gains and losses), driven in part by pressure for new urban lands and climate variability, were important in the Central California Valley (Sleeter, 2008). Here the annual rate of change was lower between 1986 and 1992 (680 $km^2 yr^{-1}$) owing at least partially to a period of extended and prolonged drought.

In the Western Cordillera, the land change footprint was estimated at 8.3% with the region accounting for approximately 11% of the national estimated change. Land change in this region was primarily associated with forest disturbance including logging, wildfire, and more recently, insect-related forest die-off (Westerling et al., 2006). The annual rate of change increased during the first two time periods but then leveled off at approximately 5700 $km^2 yr^{-1}$ for the 1986–1992 and 1992–2000 periods. The land change footprint in the Great Plains was 8.1% and the region accounted for 25% of national LULC change. The annual rate of change was twice as high between 1986 and 1992 (12,600 $km^2 yr^{-1}$) as it was in previous time periods and was largely the result of federal conservation policies in the 1985 U.S. Farm Bill that were designed to conserve highly erodible lands through conversion of agriculture to natural land covers (Drummond, 2007).

The region with the lowest land change footprint was the North American Deserts at 2.7%. However, drivers of spatial variability in land change were highly localized, with agricultural change affecting ecoregions such as the Columbia Plateau and Snake River Plain, urbanization playing an important role in the Mojave Basin and Range, and mining driving change in the Wyoming Basin and Central Basin and Range. The fluctuation in the spatial extent of water, wetlands, and barren was also important at a local scale as changes were driven in response to land management practices and regional climate and weather variability (Barnett and Pierce, 2008; Auch et al., 2011; Soulard and Sleeter, 2012). As in other regions, the 1986–1992 period had the highest rate of land-cover change, although the driving forces varied across ecoregion. For example, CRP enrollments in the Columbia Plateau drove high rates of change regionally (Sullivan et al., 2004), while urbanization in the Mojave Basin and Range was the dominant driver of high land-cover change during the same period.

3.2. Land cover transformations

Land cover transformations refer to the change in land cover from one type to another. We tracked transformations in land cover across 9 general land-cover classes and 2 disturbed classes. The majority of change across the U.S. involved the conversion to or from forest, agriculture, or development. While regionally important in some ecoregions, other changes such as those involving water, wetlands, barren land, mining, and snow/ice, account for a small overall percentage of the national-scale land transformations; changes in grassland/shrubland are discussed in the context of development and agriculture transformations below. As such, from a national perspective this section focuses on the changes involving the three primary land-cover classes that were most dynamic over the study period: forest, development, and agriculture.

3.2.1. Forest cover

Forest land is defined as tree-covered land where the tree-crown areal density is greater than 10 percent (Table 1). The forest class therefore represents a biophysical state of forest cover irrespective of land use (e.g., an area that has been clear-cut or affected by a stand replacing wildfire would not be classified as forest even though the potential "use" of the land may eventually result in a return to forest cover).

3.2.1.1. Net forest change 1973–2000. Forests account for nearly one third of the land surface area of the U.S. (Homer et al., 2007; Fry et al., 2011). An estimated 16.6% (367,000 km^2) of the U.S. forest area experienced a change in land cover at least once between 1973 and 2000. Forest cover declined from an estimated 2,305,500 km^2 in 1973, to 2,208,300 km^2 in 2000, a net loss of 4.2% of 1973 forest area (Table 2). Our estimate is consistent with other forest assessment data for the U.S. For example, Hansen et al. (2010) used Landsat and MODIS (Moderate Resolution Imaging Spectroradiometer) to produce estimates of global gross forest cover loss and estimated 1,992,000 km^2 of forest in the United States in the year 2000, an estimate similar to ours considering their more conservative forest classification threshold of 25% canopy cover. The 2001 NLCD shows forests covered 2,022,412 km^2 based on a canopy cover requirement of 20% with minimum tree heights of 5 meters (Homer et al., 2007).

Forest-cover loss occurred throughout the United States as all six major regions had less forest cover in 2000 than in 1973 (Fig. 7). Combined, the Eastern Temperate Forests, Western Cordillera, and Marine West Coast Forests accounted for 94% of the net forest loss in the country. The Eastern Temperate Forests accounted for the most area change with a loss of 61,600 km^2, a decline of 4.4% of the region's forest cover and 63.3% of the total net forest loss estimated for the U.S. The Western Cordillera had the second highest amount of forest loss at 25,200 km^2, a decline of 4.5% of regional forest cover and 25.6% of the nation's net forest decline. The Marine West Coast Forests region had the highest annual rate of forest loss (7.6%) in terms of percent of area and accounted for 4.7% of the national net loss of forest. Net forest cover decline was ubiquitous across ecoregions with 72 of the 84 ecoregions analyzed experiencing a net decline in forest cover. Of the 42 ecoregions with greater than 30% forest cover, 39 experienced a net forest cover decline between 1973 and 2000.

3.2.1.2. Gross forest change 1973–2000. Examining gross forest cover loss and gross forest cover gain provides additional understanding of the forest-cover change dynamic. Nationally for 1973–2000, annual gross forest cover loss (11,300 km^2 yr^{-1}) outpaced gross forest cover gain (7700 km^2 yr^{-1}). Transition from forest to mechanical disturbance (i.e. logging) accounted for the largest area of gross forest-cover loss at 211,000 km^2, nearly seven times more area than any other type of forest loss transition. Change from forest to non-mechanical disturbance, developed, and agriculture each accounted for approximately 25,000 km^2 of gross forest cover loss.

The Eastern Temperate Forests accounted for 78% of the national area of gross loss of forest attributable to logging, 91% of the national gross loss attributable to agriculture, and 91% of the gross loss attributable to development. Gross forest cover gain in the Eastern Temperate Forests resulted primarily from post-disturbance regrowth and reforestation of agricultural lands. Reforestation accounted for 25,000 km^2 of gross forest gain between 1973 and 2000; however, these gains from reforestation were largely offset by conversion of forest into new agricultural areas as an estimated 23,000 km^2 of forest land were brought under cultivation. The rate of forest to agriculture conversion declined over time from 1100 km^2 yr^{-1}for 1973–1980 to 500 km^2 yr^{-1}for 1992–2000. The conversion of forests into new developed areas accounted for an estimated 24,000 km^2 and the annual rate of this conversion increased during the study period. During 1992–2000, approximately 1100 km^2 yr^{-1} of forest were being converted in the Eastern Temperate Forests, up from 700 km^2 yr^{-1} between 1973 and 1980. Driving forces of forest change were numerous. More forest was harvested in the South in 1986 than any time since the 1920s (Walker, 1991). The legacy of high interest rates of the late 1970s and the impacts of the early 1980s recession, coupled with a substantial amount of salvaged timber resulting from regional pine beetle outbreaks, caused increased cutting to make up for falling stumpage prices (Walker, 1991). The economic recovery by the second half of the 1980s allowed for more new construction; new housing starts in 1986 were higher than any other year between 1978 and 2003 (NAHB, 2012) and by 2000, southern ecoregions had become the nation's most important commercial forest region.

Gross forest-cover loss in the Western Cordillera was driven almost entirely by disturbance with an estimated 15% of the loss attributable to mechanical disturbance and 76% attributable to nonmechanical disturbance. The annual rate of mechanical disturbance accelerated, peaking at 1700 km^2 yr^{-1}between 1986 and 1992, before declining to 900 km^2 yr^{-1}between 1992 and 2000. Nonmechanical disturbances, primarily wildfire, accounted for approximately 19,000 km^2 of the gross forest cover loss in the Western Cordillera. An estimated 100 km^2 yr^{-1} of nonmechanical disturbance occurred in the Western Cordillera between 1973 and 1986 was followed by an increase to 900 km^2 yr^{-1} between 1986 and 1992, and 1500 km^2 yr^{-1} between 1992 and 2000. Increased fuel loads (Pimentel et al., 2000), the introduction and/or spread of invasive species (Whisenant, 1990), and changes and variability in regional climate have been linked to increased natural disturbance and forest die-off from insects and wildfire (Westerling et al., 2006).

Mechanical disturbance was the process most responsible for gross forest cover loss in the Marine West Coast Forests as an estimated 17% (15,000 km^2) of the region experienced a conversion from forest to mechanically disturbed. As in the Western Cordillera, logging increased through each time period, reaching a high of 800 km^2 yr^{-1} between 1986 and 1992 before declining to 600 km^2 yr^{-1} between 1992 and 2000. Declines in harvest in the region, particularly in the Cascades ecoregion, were driven at least partially by declining demand from Asian markets (Daniels, 2005),

Table 2
Estimated land-cover composition and 1973–2000 net change in class area for conterminous U.S. (national) and six reporting regions.

	Area (km^2)					
National	1973	1980	1986	1992	2000	Net change
Water	194,237	197,217	200,839	199,581	207,430	13,193
Developed	235,461	252,350	266672	285369	312990	77529
Mechanical disturbance	38659	42368	55644	67688	73293	34634
Mining	13877	15874	16825	17235	17812	3935
Barren	65516	65390	64958	65323	65446	−69
Forest	2305566	2277778	2254588	2234558	2208293	−97273
Grassland/shrubland	2575125	2569731	2,568,919	2,622,304	2,623,884	48,759
Agriculture	2,125,437	2,137,088	2,132,841	2,060,969	2,035,930	−89,507
Wetland	300,767	297,246	293,466	294,407	287,127	−13,639
Nonmechanically disturbed	3550	3169	3463	10,785	26,055	22,505
Snow/ice	1939	1924	1917	1914	1873	−66
Marine West Coast Forests						
Water	5560	5553	5573	5562	5541	−19
Developed	5001	5396	5806	6282	6975	1974
Mechanical disturbance	2836	2356	3717	4879	4672	1835
Mining	78	94	103	113	124	45
Barren	750	735	700	696	695	−55
Forest	59,380	58381	56808	54437	54842	−4538
Grassland/shrubland	2980	4098	4056	5030	4370	1390
Agriculture	12061	12056	11904	11647	11460	−600
Wetland	1133	1120	1121	1104	1109	−24
Nonmechanically disturbed	8	0	0	39	0	−8
Snow/ice	17	17	17	17	17	0
Eastern Temperate Forests						
Water	146,836	149,300	151,508	152,872	154,361	7525
Developed	186,632	197,971	208,550	222,103	243,544	56,912
Mechanical disturbance	26,138	32,169	42,860	49,380	59,212	33,074
Mining	8561	9764	9870	9434	8946	385
Barren	3156	3155	2975	2914	2961	−195
Forest	1,402,393	1,380,900	1,362,148	1,353,678	1,340,799	−61,594
Grassland/shrubland	47,330	51,174	56,307	60,881	59,053	11,723
Agriculture	972,165	971,751	965,262	948,373	933,507	−38,658
Wetland	253,128	249,553	246,549	246,626	242,841	−10,287
Nonmechanically disturbed	162	760	471	238	1275	1113
Snow/ice	0	0	0	0	0	0
Mediterranean California						
Water	2950	3105	3031	2925	3066	115
Developed	10,066	11,078	11,716	12,658	13,574	3509
Mechanical disturbance	183	94	185	266	206	22
Mining	290	288	287	276	329	39
Barren	432	431	432	432	440	8
Forest	26,789	26,014	26,497	26,468	25,293	−1496
Grassland/shrubland	79,959	78,273	77,861	78,370	75,299	−4660
Agriculture	43553	43644	43,638	42,725	43,035	−517
Wetland	1316	1393	1446	1465	1438	122
Nonmechanically disturbed	426	1644	871	381	3285	2858
Snow/ice	0	0	0	0	0	0
Western Cordillera						
Water	8916	9051	8868	9049	9017	101
Developed	3872	4295	4530	4965	5375	1503
Mechanical disturbance	8672	6384	7871	10,237	7183	−1489
Mining	1164	1247	1385	1458	1519	355
Barren	15,536	15,556	15,624	15,579	15,625	89
Forest	559,749	556,313	553,557	544,829	534,552	−25,198
Grassland/shrubland	292,439	297,864	298146	299735	306663	14224
Agriculture	28409	28599	29418	27768	26349	−2060
Wetland	7053	6934	6961	6912	6910	−143
Nonmechanically disturbed	1122	704	594	6424	13805	12684
Snow/ice	1789	1774	1768	1764	1724	−66
Great Plains						
Water	24,813	24,529	25,721	24,596	30,187	5374
Developed	22,228	24,539	25,879	27,456	30,187	7959
Mechanical disturbance	566	633	655	1290	929	362
Mining	1112	1358	1700	2012	2418	1305
Barren	11,402	11,274	11,016	11,501	11,451	49
Forest	108,076	107,112	106,658	106,205	105,599	−2478
Grassland/shrubland	929,715	920,141	916,967	963,589	967,988	38,273
Agriculture	978,506	987,824	989,370	940,726	931,783	−46,723
Wetland	28,310	28,709	28,153	28,731	25,255	−3055
Nonmechanically disturbed	1390	0	0	13	324	−1066
Snow/ice	0	0	0	0	0	0

Table 2 (*Continued*)

National	Area (km^2) 1973	1980	1986	1992	2000	Net change
North American Deserts						
Water	5162	5678	6138	4578	5259	97
Developed	7663	9071	10,191	11,905	13,334	5671
Mechanical disturbance	262	731	355	1635	1091	829
Mining	2671	3123	3480	3942	4476	1804
Barren	34,240	34,238	34,211	34,200	34,275	35
Forest	149,178	149,058	148,920	148,942	147,209	−1969
Grassland/shrubland	1,222,702	1,218,181	1,215,582	1,214,699	1,210,510	−12,192
Agriculture	90,743	93,215	93,249	89,730	89,796	−947
Wetland	9827	9536	9237	9570	9575	−252
Nonmechanically disturbed	443	60	1527	3690	7367	6924
Snow/ice	133	133	133	133	133	0

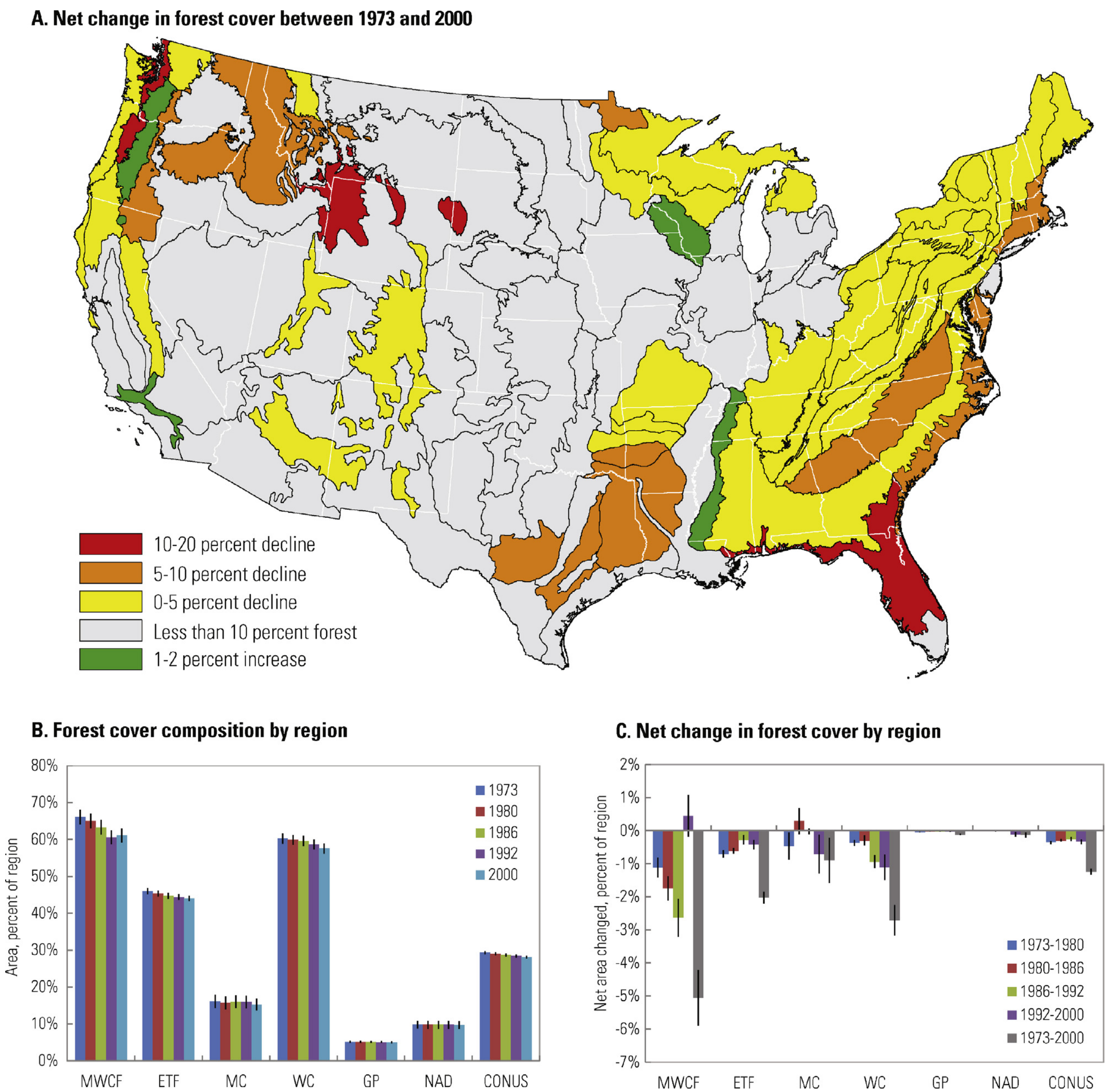

Fig. 7. (A) Map of level III ecoregions showing net change in forest cover between 1973 and 2000, expressed as a percent change in the class from 1973 (ecoregions with less than 10 percent forest cover in 1973 are not shown), (B) composition of forest cover, expressed as a percent of region area, by region and time period (error bars represent standard error of estimate), and (C) percent net change in forest cover, expressed as a percent of region area, by time interval (error bars represent standard error). The regions are Marine West Coast Forests (MWCF), Eastern Temperate Forests (ETF), Mediterranean California (MC), Western Cordillera (WC), Great Plains (GP), North American Deserts (NAD) and the conterminous United States (CONUS).

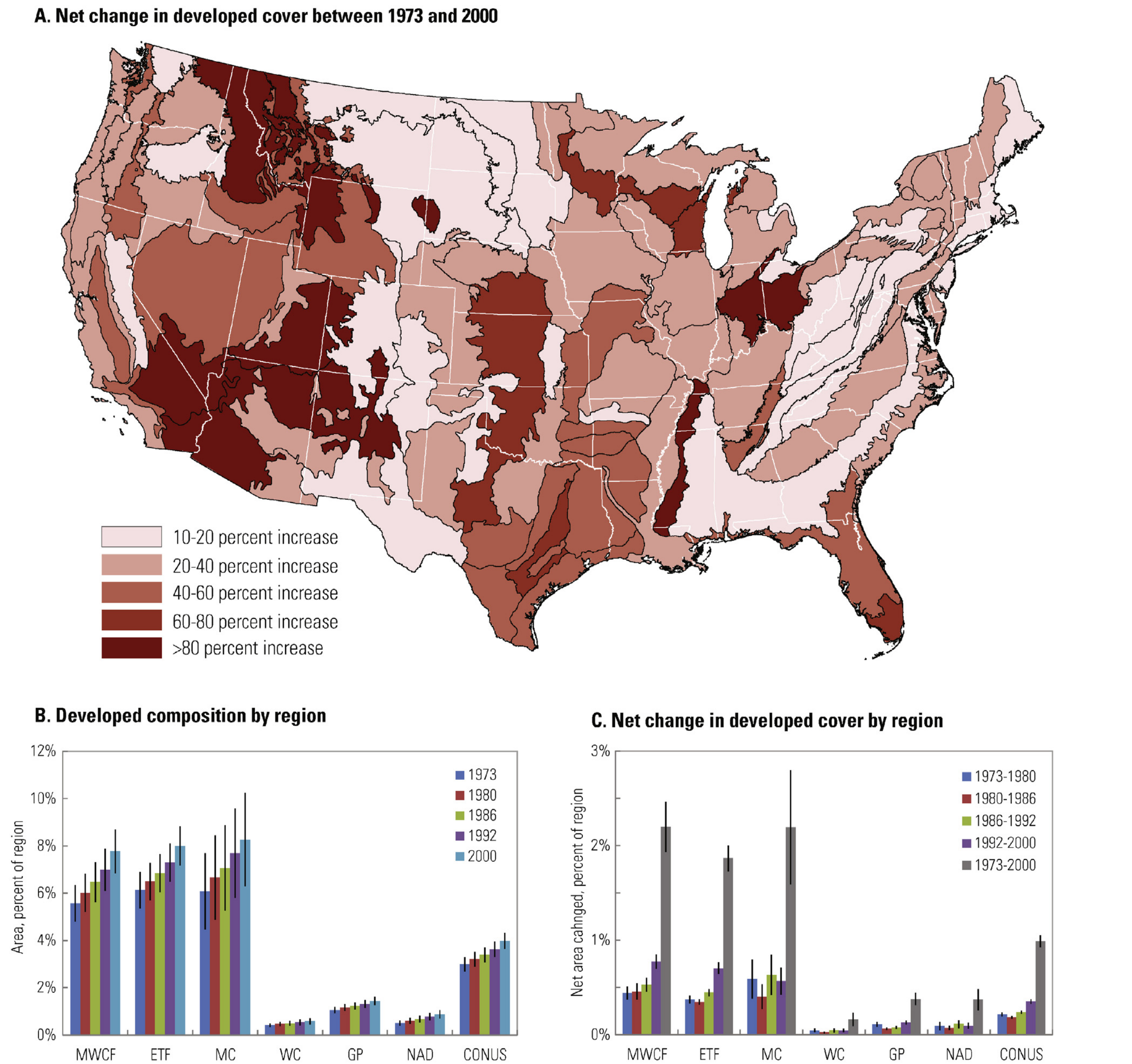

Fig. 8. Map of level III ecoregions showing net change in developed cover between 1973 and 2000, expressed as a percent change in the class area from 1973, (B) composition of developed cover, expressed as a percent of region area, by region and time period (error bars represent standard error of estimate), and (C) percent net change in developed cover, expressed as a percent of region area, by time interval (error bars represent standard error). The regions are Marine West Coast Forests (MWCF), Eastern Temperate Forests (ETF), Mediterranean California (MC), Western Cordillera (WC), Great Plains (GP), North American Deserts (NAD) and the conterminous United States (CONUS).

passage of the Northwest Forest Plan in response to concerns over loss of habitat for endangered species (USDA, 1994), and increased softwood imports from Canada (Daniels, 2005). Unlike the Western Cordillera, urbanization was an important driver of forest cover loss in two of the three ecoregions comprising the Marine West Coast Forests. An estimated 1100 km^2 of forests were converted to development, with approximately 950 km^2 located in the Puget Lowland ecoregion.

3.2.2. Developed land cover

Development includes residential, industrial, commercial, transportation, and areas such as parks or other open spaces surrounded or otherwise dominated by an urban landscape (Anderson et al., 1976). In 1973, development accounted for approximately 235,000 km^2 and 3% of the U.S. land area. By 2000, development had increased by 33% to 313,000 km^2 and accounted for 4% of the U.S. land area (Fig. 8, Table 2). Increases in developed area tracked closely with U.S. population growth, which increased approximately 38% between 1970 and 2000 (Hobbs and Stoops, 2002).

The Eastern Temperate Forests accounted for the vast majority of developed area in the U.S. (approximately 78%). The establishment of new developed areas accelerated over time, from 1600 $km^2\ yr^{-1}$between 1973 and 1980 to 2700 $km^2\ yr^{-1}$ between 1992 and 2000. In total, 244,000 km^2, or 8% of the region, was classified as developed in the year 2000, including 24,000 km^2 converted from forest and 25,000 km^2 converted from agriculture since 1973. Four ecoregions (Atlantic Coastal Pine Barrens, Northern Piedmont, Northeastern Coastal Zone, and the Southern Coastal Plains) have greater than 20% of their area classified as developed and all four are within the Eastern Temperate Forests region.

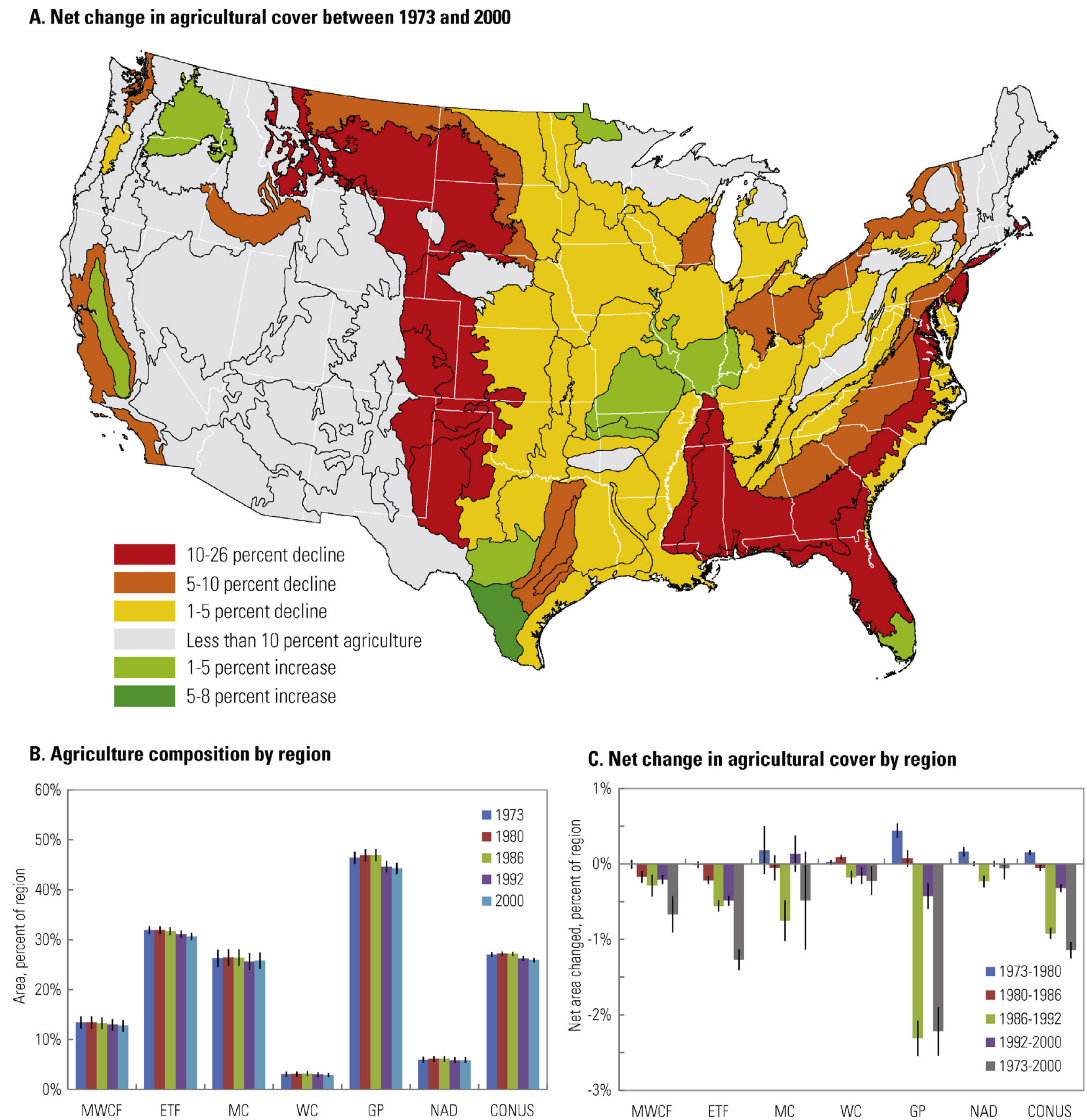

Fig. 9. (A) Map of level III ecoregions showing net change in agriculture cover between 1973 and 2000, expressed as a percent change in the class from 1973 (ecoregions with less than 10 percent agriculture cover in 1973 are not shown), (B) composition of forest cover, expressed as a percent of region area, by region and time period (error bars represent standard error of estimate), and (C) percent net change in agricultural cover, expressed as a percent of region area, by time interval (error bars represent standard error). The regions are Marine West Coast Forests (MWCF), Eastern Temperate Forests (ETF), Mediterranean California (MC), Western Cordillera (WC), Great Plains (GP), North American Deserts (NAD) and the conterminous United States (CONUS).

The Great Plains region accounted for nearly 10% of the U.S. developed land area in 2000. From 1973 to 2000, the area of developed land increased by 36% (Drummond et al., 2012). An estimated 91% of new developed area came from agriculture (5000 km^2) and grassland/shrubland (3000 km^2). The pattern was similar in Mediterranean California. Development increased by 35%, expanding from 6.1% of the region in 1973–8.2% in 2000, an increase of 3500 km^2. As in the Great Plains, the vast majority of new development originated from agriculture (2100 km^2) and grassland/shrubland (1100 km^2).

The Marine West Coast Forests region experienced the second highest rate of growth in new developed areas. Development expanded from 5.6% of the region in 1973–7.8% in 2000, a 40% increase. Forest cover was the primary source of new development with 1200 km^2 converting over the 27-year period; conversion from agriculture contributed an additional 500 km^2. The largest percentage change in developed area occurred in the North American Deserts where there was a 74% increase in new development from an estimated 7700 km^2 in 1973 to 13,300 km^2 in 2000. An estimated 68% of this new development originated from grassland/shrubland and 25% originated from agriculture. Large and fast growing metropolitan cities, such as Las Vegas, NV in the Mojave Basin and Range Ecoregion, Phoenix, AZ in the Sonoran Basin and Range Ecoregion, and Salt Lake City, UT in the Central Basin and Range Ecoregion were major contributors to increased urbanization (Knowles-Yanez et al., 1999; Acevedo et al., 2006).

3.2.3. Agricultural land cover

Agricultural lands are characterized as any area used for the production of food and fiber, including cultivated cropland, pasture, orchards and vineyards, nurseries and ornamental horticulture areas, and confined livestock feeding operations. In 1973, agriculture accounted for 2,125,000 km^2 (27%) of the U.S. land area (Fig. 9). From 1973 to 1980, agriculture expanded at a net rate of 1700 km^2 yr^{-1}, with nearly all of the net change occurring in the Great Plains region. Between 1980 and 1986, agriculture continued to expand in the Great Plains at a rate of 300 km^2 yr^{-1}; however, net decline in agriculture in the Eastern Temperate Forests (1100 km^2 yr^{-1}) resulted in an overall loss nationally of approximately 4200 km^2. Between 1986 and 1992 we estimate a total net decline of 72,000 km^2 of agricultural land. The highest annual rate of decline was in the Great Plains at 8100 km^2 yr^{-1}, followed by the Eastern Temperate Forests at 2800 km^2 yr^{-1}. Between 1992 and 2000, the rate of loss slowed to 1100 km^2 $yr^{-1}$for the Great Plains and 1900 km^2 $yr^{-1}$for the Eastern Temperate Forests. From 1973 to 2000, agriculture had declined by approximately 90,000 km^2 nationally, with 43% of the area of net loss occurring in the Eastern Temperate Forests and 52% in the Great Plains (Fig. 9). Nationally, 34,400 km^2 of agriculture was converted to developed land. Gains in agriculture came primarily from grassland/shrubland (83,200 km^2) and forest (25,300 km^2).

Prior to 1973, U.S. agricultural production outpaced domestic demand (Cochrane, 1993). A spike in grain exports during the 1970s, coupled with inflation, increased the value of cropland and acreage in production (Cochrane, 1993; Hargreaves, 1993). By 1985, a depressed agricultural economy and growing environmental concerns led to changes in federal farm policy. The Conservation Reserve Program (CRP) was first established in the Food Security Act of 1985 and was authorized to idle nearly 160,000 km^2 of cropland by 2002, mostly in grasslands in the Great Plains, but also in forested areas in the South and elsewhere (Sullivan et al., 2004). Nationally, the gross loss of agriculture to grassland/shrubland was estimated to be 132,400 km^2 and the gross loss to forest was 26,000 km^2.

3.2.4. Discussion of results

LULC change is recognized as a major driver of global environmental change with systemic and cumulative consequences (Turner et al., 1990). Systemic effects are the physical impacts of human activities such as changes to atmospheric CO_2 and other greenhouse gasses, hydrology, and climate and weather. The accumulation of many smaller scale changes causes cumulative consequences including deforestation, biodiversity loss, and degradation of other ecosystem services. Land use trends in the US have various implications.

The stability of carbon stocks is a key concern. Land use change between 1973 and 2000 affected the extent of forest cover, tilled soil, grassland, wetland, and other land covers that contribute to carbon and other biogeochemical fluctuation. The 4.2% decline in forest cover has implications for loss of standing carbon to urbanization and timber harvest, though some carbon remains as woody debris after harvest and accumulates in secondary growth. However, there is regional variation in biomass, growth rate, and soil carbon storage between Northern, Eastern Temperate, and Western forests (Liu et al., 2007). As well, the causes and extent of forest changes are regionally and temporally variable.

Carbon sequestration in soils is affected when grassland cover is replaced with a cropping regime. The substantial increase of grassland/shrubland in agricultural regions since 1986, driven in large part by the CRP, is important to carbon dynamics. Lands converted to CRP are small but reliable carbon sinks (Gebhart et al., 1994). Over the long term, CRP lands have a much larger impact due to prevention of further carbon loss and biodiversity and water quality benefits (Gelfand et al., 2011).

Climate and land cover interact through biogeophysical processes that effectively make cropland, forests and cities a component of climate and weather systems (Pielke et al., 2007). Land use also has important but under-studied consequences for hydrology, including shifting water demands and changes in water supply caused by human-altered hydrologic processes (Defries et al., 2004). Natural disturbance, forest clearing, and land conversion to agriculture and urbanization affect surface albedo and hydrology, which ultimately affect regional weather and climate (Barnes and Roy, 2008; Lawrence and Chase, 2010). Our research suggests that there is often a mix of expanding, contracting, and stable land use and land cover types across regions that need to be considered in a comprehensive manner in order to better understand forcings and feedbacks.

Local changes in forest, urban, and agricultural land uses have a cumulative effect on regional and national land cover extent, pattern, and composition that affect habitat, biota, and other environmental and socioeconomic conditions. The loss of forest cover identified here is counter to assumptions that the US and the eastern forests in particular are still undergoing a forest transition from historical deforestation to a period of expanding forest cover (Mather, 1992). The net decline in forest that occurred throughout the study period affects habitat and the types of species that occur across a range of ecological systems. Large and unfragmented core forested areas are required by some birds and other species (Robinson et al., 1995). Conversely, the increases in grassland/shrubland in the Great Plains since 1986 are beneficial to many wildlife species (McLachlan et al., 2007). The acceleration of urban growth and other land use changes have transformed a substantial fraction of the US and contributed to human well-being but also to detrimental changes to ecosystem services that may be exacerbated by a changing climate (Millennium Ecosystem Assessment, 2005).

4. Conclusion

Previous land cover monitoring efforts in the U.S. lacked the spatial, temporal, and thematic consistency required to characterize the rates and types of land-cover change at a spatial and temporal scale useful for environmental management (Loveland and Merchant, 2004). Quantifying land change via a nationally and temporally consistent methodology enabled the direct comparison of estimates of gross and net changes in land cover across time periods and ecoregions of the conterminous U. S. The national story of U.S. land-cover change during 1973–2000 is that change is a pervasive and variable phenomenon. There is significant geographic and temporal variability in land-cover change. Some regions (e.g., southeast and northwest) are undergoing almost continuous change while others are relatively stable (e.g., southwest deserts). The resource potential, controlled by regional environmental variables including climate, topography, and soils determine the dominant land uses, the probable transformations, and intensity of land management. The most dynamic regions are those in which environmental conditions such as climate, soils, and topography are suitable for productive and relatively intensive resource-based land uses.

An estimated 8.6% of the U.S. landscape (an area roughly the size of Texas) underwent at least one land-cover change between 1973 and 2000. Forest change was a major contributor to the dynamic landscape with forest management (harvest and regeneration) responsible for a large area of change. As a result of cyclic harvesting and regeneration, at any given time, a significant amount of land is in transition from forest cover to disturbed bare ground to grasses and shrubs. These transitions, especially the bare soil disturbed phase, may have important but temporary environment impacts. Although a large proportion of the estimated 97,000 km^2 of net forest loss may be land temporarily in a disturbed or transitional grassland/shrubland state, 25,000 km^2 of forest was converted to development and agriculture.

The addition of an estimated 77,000 km^2 of development (an area slightly less than South Carolina) will surely have substantial consequences on ecosystem services. The net loss of agricultural land is another significant story of U.S. land-cover change. Not surprisingly, a substantial amount of the agricultural area lost was to developed, but agriculture conversion to grassland/shrubland was also common.

Numerous different, and often complex, interactions between socioeconomic drivers and biophysical characteristics have produced widespread ecoregional and temporal variability in the rates, total extent, and types of U.S. land change. Regional changes are the cumulative result of individual land owner and land manager decisions on how to optimize the generation of desired benefits. Decisions are shaped by a complex set of factors including resource potential, economics, technology, government policy, and land use history.

Key regional trends and causes emerged, as well as singular events and actions that led to punctuated episodes of change. The characterization and quantification of regional trends in LULC over large areas provides an important foundation for a wide range of environmental and ecological research activities, including modeling the linkages and feedbacks between land change and biogeochemical cycling (Liu et al., 2006), the exchange of energy between the land and atmosphere (Barnes and Roy, 2008), and the development and downscaling of global scenarios (Sleeter et al., 2012a, b). The results presented here are an important contribution to a long-term land change-monitoring program capable of meeting the needs of the global change research community.

This study was designed based on constraints (e.g., Landsat data costs) that are no longer an issue. The 2008 decision to make all Landsat data available at no cost means that future studies can make greater use of the temporal richness of the Landsat archive (Wulder et al., 2012). Recent research is showing that by using the Landsat time series, change can be mapped with greater accuracy using automated methods and that by using the full Landsat history for a given place, change may soon be detectable shortly after it occurs (Zhu et al., 2012). Based on this study, we have demonstrated that change is an uncommon event (the annual average rate of change ranged from 0.3 to 0.6 percent over time) at the national level, but very high change rates occur in some regions. Because change rates are so variable in time and space, change will be better understood when we evolve into the continuous, wall-to-wall mapping and monitoring of land change. However, wall-to-wall maps of change have limitations associated with the accuracy and precision of change statistics. In the future, sampling, combined with wall-to-wall mapping (see Hansen et al., 2008), can provide both the geospatial results needed for modeling and assessing the consequences of change and the definitive statistics that allow us to clearly and accurately understand the complex geographic, temporal, and thematic dimensions of change.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2013.03.006.

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