Baseline Land-Use and Land-Cover Changes in the Western United States Between 1992 and 2005

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Chapter 2 of

Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States

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Chapter 2. Baseline Land-Use and Land-Cover Changes in the Western United States Between 1992 and 2005

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2.1. Highlights

- Annual, 250-m resolution land-use and land-cover (LULC) maps were produced for the baseline period of 1992 to 2005.
- Observed data derived from remotely sensed sources were used when possible for the baseline map products.
- When annual, observed data were not available, a spatial LULC model based on input data derived from LULC studies was used to produce the annual LULC maps.
- The baseline LULC change was relatively low but variable between ecoregions; some ecoregions experienced significant amounts of change and some ecoregions experienced very little change.
- LULC change associated with forestry was the most common form of LULC change, followed by urban development.

2.2. Introduction

As indicated in figure 1.2 (a graphic representation of the overall methodology for this assessment) of chapter 1 of this report, the mapping and modeling of LULC described in this chapter are some of the spatial foundations of this regional assessment and help define the boundaries and compositions of the assessed ecosystems. The results of the LULC mapping and modeling component feed into other components of the assessment, particularly chapter 5 (baseline terrestrial carbon storage and greenhouse-gas fluxes) and chapter 6 (development of future LULC scenarios).

The LULC in the Western United States is diverse; vast forests, shrublands, and grasslands are interspersed with human agricultural activities, mining, and some of the largest urban areas in the United States. Topography, soils, climate, and water availability interact to determine the landscape potential and anthropogenic land use, producing a mosaic of different LULC types across the West. Silviculture, agriculture, urban development, mining, and natural disturbances such as wildland fires have dramatically altered portions of the Western United States, but the LULC change is fragmented; some areas have experienced little change over the last century and others have experienced rapid and frequent changes.

The annual LULC maps for the Western United States serve as the spatial and temporal foundation for assessing the baseline carbon storage and fluxes for terrestrial ecosystems (chapter 5). The classification scheme (as discussed below) is a combination of land-use and land-cover classes that closely follows the classes used by the 1992 National Land Cover Database (NLCD) (Vogelmann and others, 2001). The disturbance of ecosystems by wildland fires is discussed separately (chapter 3). Land-management activities (for example, crop tillage, crop rotation, and fertilization) are also discussed separately (chapter 4). In order to provide a partitioned spatial framework for the Western United States, the region was divided into five level II ecoregions (modified from U.S. Department of Environmental Protection (EPA), 1999): Western Cordillera, Marine West Coast Forest, Cold Deserts, Warm Deserts, and Mediterranean California. The five ecoregions were mapped and modeled to create annual LULC maps for the baseline period of 1992 to 2005. The following sections discuss the data sources and methodologies used to map and model annual LULC change and the baseline LULC results.

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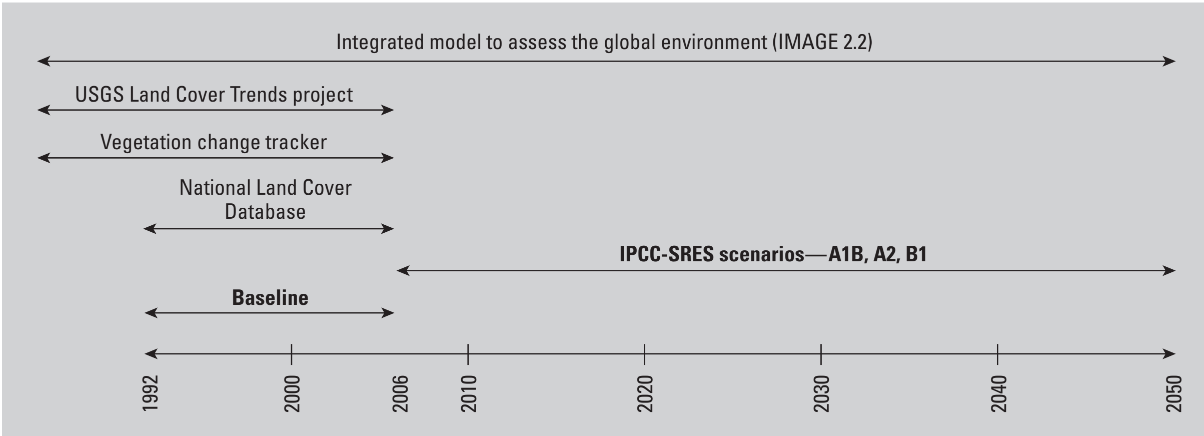


Figure 2.1. Timeline for LULC change mapping and modeling for both the baseline and scenario-based projections. The baseline period runs from 1992 to 2005; the modeled scenarios (from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (IPCC–SRES; Nakicenovic and others, 2000) were run from 2006 to 2050. The data sources at the top of the graphic were used to support the analysis of baseline, scenarios, or both. USGS, U.S. Geological Survey.

2.3. Input Data and Methods

The baseline period for this assessment was defined as the period from 1992 to 2005. The baseline period allowed for an examination of recent LULC change and for the calibration of both the LULC and biogeochemical modeling frameworks before beginning the simulations of future LULC. The year 1992 was chosen as the start of the baseline period because it marked the earliest year for which consistent, nationwide, high-spatial-resolution LULC data were available. A modified version of the 1992 National Land Cover Dataset (NLCD) (Vogelmann and others, 2001) served as the initial LULC data for this work; the NLCD data had been extensively assessed for accuracy (Stehman and others, 2003; Wickham and others, 2004). The year 2005 was chosen as the endpoint for the baseline period. The choice of the baseline years 1992 to 2005 thus maximized the use of consistent, spatially explicit, nationwide, observed LULC data available when work on the assessment began. Scenario-based projections of potential future land-cover change were created to cover 2006 through 2050 (see chapter 6 of this report) (fig. 2.1).

The NLCD thematic classification system provides a level of thematic detail that allows for an examination of the effects of LULC change on fluxes of carbon and greenhouse gases, but the classification system can also be directly collapsed to the primary ecosystem types that were analyzed for this assessment (table 2.1). The original resolution of the 1992 NLCD was 30 meters, but the data were resampled to 250 meters for this assessment to reduce the volume of data and hold the modeling requirements to a more manageable level. Several adjustments were made to the thematic classes in order to facilitate this assessment, including the collapsing of the four urban classes from the 1992 NLCD into one "urban/developed" class. Similarly, three agricultural classes from the 1992 NLCD (row crop, small grains, and fallow) were collapsed into one "agriculture" class that represented cultivated crops.

The 1992 NLCD dataset was also augmented by incorporating information from LANDFIRE's vegetation change tracker (VCT) data (Chengquan Huang and others, 2010) (fig. 2.2). The VCT data mapped natural and anthropogenic disturbances by analyzing historical layers of Landsat Thematic Mapper (TM) data. Polygons of clearcut forest derived from VCT data were used to populate "mechanically disturbed" classes 3, 4, and 5 (table 2.1) for 1992. The three mechanically disturbed classes represented clearcuts that occurred on land owned by three different entities: (1) national forest, (2) other public land, and (3) private land. Given that each of these ownership types have varying management strategies, the Protected Area Database of the United States (PAD–US Partnership, 2009) was used to spatially distinguish ownership for the three disturbance classes. The PAD–US database includes Federal, State, and local protected lands, as well as information from national nonprofit organizations. The database does not cover all protected lands (such as conservation easements), but it is the most comprehensive and accurate protected lands database available for the United States. Thematically distinguishing clearcutting by these three different classes of ownership resulted in an improved ability to map and model LULC change related to forestry and thus improved the ability to examine the effects of forestry on carbon and greenhouse-gas fluxes.

Table 2.1. Thematic land-use and land-cover classes used in this assessment, the corresponding ecosystems defined for this assessment, percent area (from 1992) of the Western United States, and the source of the input data.

[LANDFIRE, Landscape Fire and Resource Management Planning Tools Project (Rollins, 2009); NLCD, National Land Cover Dataset (Vogelmann and others (2001); VCT, vegetation change tracker (a product of LANDFIRE; Chengquan Huang and others, 2010)]

Land-use and land-cover (LULC) class	Ecosystem	Area (percent)	Source
Open water	Aquatic ecosystems	1.5	NLCD—Open water.
Urban/developed	Other lands	1.0	NLCD—Low-intensity residential. NLCD—High-intensity residential. NLCD—Commercial/industry/transportation. NLCD—Urban/recreational grasses.
Mechanically disturbed—National forest	Forests	0.4	LANDFIRE VCT.
Mechanically disturbed—Other public land	Forests	0.1	LANDFIRE VCT.
Mechanically disturbed—Private land	Forests	0.1	LANDFIRE VCT.
Mining	Other lands	0.1	NLCD—Quarries/strip mines/gravel pits.
Barren	Other lands	3.8	NLCD—Bare rock/sand/clay.
Deciduous forest	Forests	2.0	NLCD—Deciduous forest.
Evergreen forest	Forests	23.9	NLCD—Evergreen forest.
Mixed forest	Forests	1.4	NLCD—Mixed forest.
Grassland	Grasslands/shrublands	13.9	NLCD—Grassland/herbaceous.
Shrubland	Grasslands/shrublands	45.1	NLCD—Shrubland.
Cultivated crop	Agricultural lands	3.6	NLCD—Row crops. NLCD—Small grains. NLCD—Fallow.
Hay/pasture	Agricultural lands	2.5	NLCD—Pasture/hay.
Herbaceous wetland	Wetlands	0.1	NLCD—Emergent herbaceous wetlands.
Woody wetland	Wetlands	0.3	NLCD—Woody wetlands.
Ice/snow	Other lands	0.1	NLCD—Perennial ice/snow.

The modified 1992 NLCD data served as the initial land cover dataset for the assessment. Annual LULC maps for the baseline period were required to adequately portray gross changes between LULC classes that could be missed by a wider temporal interval and thus could affect carbon and GHG calculations; however, there were no annual, nationally consistent, spatially explicit LULC data available for the entire baseline period of 1992 to 2005. NLCD data were available for 1992, 2001, and 2006 (Vogelmann and others, 2001; Homer and others, 2007; Xian and others, 2009), but different classification systems and different mapping methodologies between NLCD versions precluded the use of NLCD alone for providing LULC data for the 1992 to 2005 period. The VCT data were available on an annual basis, but only provided information on areas of disturbance such as forest clearcuts and fires (Chengquan Huang and others, 2010). The USGS Land Cover Trends project (Loveland and others, 2002) provided historical LULC data, but only sample-based data were available for 1992 and 2000. Even though the individual datasets could not provide the consistent, annual, wall-to-wall LULC maps needed for the assessment, they could be used to directly inform a spatial modeling framework to produce annual LULC maps from 1992 to 2005.

The spatial modeling framework, “forecasting scenarios of land-cover change” (FORE–SCE), was used to produce annual LULC maps from 1992 to 2005. FORE–SCE was successfully used to model annual LULC maps for large geographic regions (Sohl and Sayler, 2008; Sohl, Sleeter, Zhu, and others, 2012; Sohl, Sleeter, Sayler, and others, 2012). The FORE–SCE model used separate but linked “Demand” and “Spatial Allocation” components to produce spatially explicit, annual LULC maps. The “Demand” component provided aggregate-level quantities of LULC change for a region, or a “prescription” for the overall regional LULC proportions. The “Spatial Allocation” component ingested “Demand” and produced spatially explicit LULC maps using a patch-based allocation procedure.

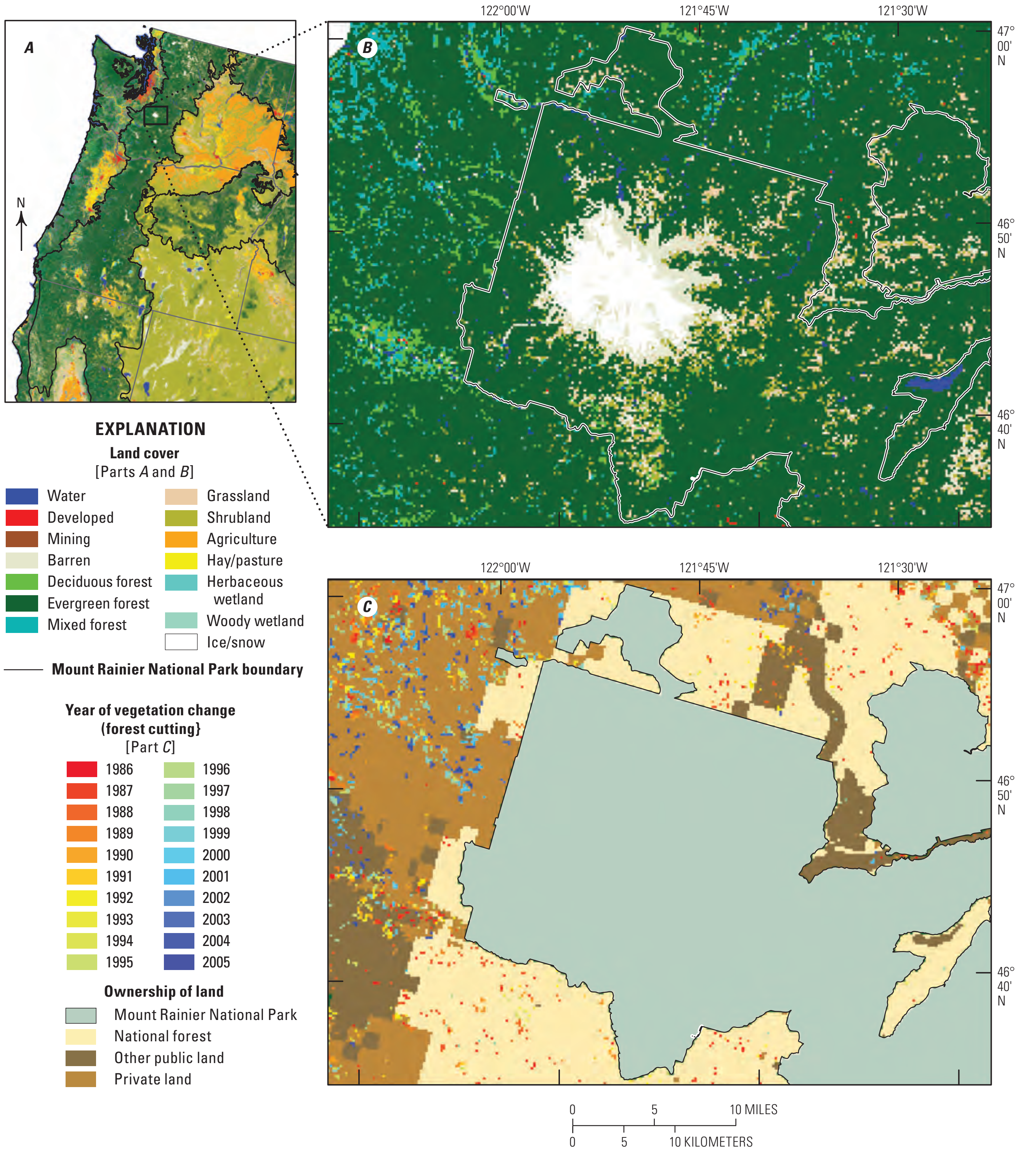


Figure 2.2. Map showing how data from LANDFIRE's vegetation change tracker (VCT) provided information on ecosystem disturbances. In this assessment, the VCT data were used to identify polygons that represented forest clearcuts for the baseline period (1992–2005). *A,* Land-use and land-cover map of a portion of the Western United States. *B,* Inset map showing land use and land cover of Mount Ranier National Park and the surrounding national forest, other public land, and private land. *C,* Inset map showing vegetation changes in the same area as part *B*. The small colored polygons outside of the national park boundary (national forest, other public land, and private land) represent forest clearcuts, color-coded by the year in which the clearcutting occurred. LANDFIRE, Landscape Fire and Resource Management Planning Tools Project.

The “Demand” for the baseline LULC change was split into two time periods to take advantage of temporally specific historical data. Demand from 1992 to 2000 was provided by USGS Land Cover Trends data (U.S. Geological Survey, 2012a). The USGS Land Cover Trends project used a sampling approach and the historical archive of Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) data to produce estimates of LULC change for each of the 84 level III ecoregions (modified from EPA, 1999) in the conterminous United States (Loveland and others, 2002). Although the coarser-scale level II ecoregion framework was used for the overall assessment in the Western United States, the finer-scale level III ecoregion framework served as the primary framework for all FORE–SCE-based LULC modeling, thus improving the representation of spatial LULC change patterns in the very heterogeneous Western United States. As a result, the “Demand” information from the USGS Land Cover Trends project was provided separately for each level III ecoregion, and the “Spatial Allocation” component of FORE–SCE was parameterized individually for each level III ecoregion. For the 1992 to 2000 period, USGS Land Cover Trends data provided baseline regional proportions of LULC change (“Demand”) for each level III ecoregion; however, these data were thematically less detailed than the LULC classes used for this assessment (table 2.1). For example, USGS Land Cover Trends only estimated one aggregate “forest” class, while this assessment differentiated between deciduous, evergreen, and mixed forest types. To obtain the three forest types and their transitions from the USGS Land Cover Trends data for 1992 to 2000, proportions of the three forest types from the 1992 NLCD were used to disaggregate the USGS Land Cover Trends single forest class for each level III ecoregion. A similar disaggregation of USGS Land Cover Trends classes using the 1992 NLCD was performed to split the class “grass/shrub” into the “grassland” and “shrubland” classes, split “wetland” into the “herbaceous wetland” and “woody wetland” classes, and split “agriculture” into “hay/pasture” and “cultivated crop.” Finally, the 1992 to 2000 estimates by ecoregion were annualized to produce annual rates of change that served as annual “Demand” for the FORE–SCE model.

A similar methodology was used to populate the “Demand” component of the model for 2001 to 2005. The “Demand” for this period was provided by the 2001 to 2006 NLCD change-product data (Xian and others, 2009). The 2001 and 2006 NLCD data provided a LULC change product that provided consistent, wall-to-wall LULC data for the United States. The level of thematic detail was compatible with this assessment, and, unlike the USGS Land Cover Trends data for 1992 to 2000, no disaggregation to a finer thematic scale was necessary. The 2001 to 2006 NLCD change data were annualized to produce rates of change that served as yearly “Demand” for 2001 to 2005 for the FORE–SCE model.

The 1992 to 2005 annual “Demand” for LULC served as input to the spatial modeling component of FORE–SCE. FORE–SCE used logistic regression to quantify empirical relationships between LULC and spatially explicit biophysical and socioeconomic variables. Suitability surfaces were produced for each unique LULC class that was modeled (table 2.1) for each level III ecoregion. The suitability surfaces were used to guide the placement of individual patches of LULC change; the characteristics of the patches were parameterized using historical LULC data from the USGS Land Cover Trends project. The US–PAD data were used to restrict the placement of specific forms of LULC change on certain types of protected lands (for example, restricting urban development in national park lands). Individual patches of LULC were placed on the landscape for a given annual model run until “Demand” was met for that year. The processing then continued to the next year until the baseline period of 1992 to 2005 was complete. Additional details on the FORE–SCE model structure may be found in Sohl and Sayler (2008); Sohl, Sleeter, Zhu, and others (2012); and Sohl, Sleeter, Sayler, and others (2012).

The age of forest stands was also tracked spatially and temporally and was estimated in the modeling environment. Data about forest-stand ages were used to ensure realistic clearcutting cycles (based on the typical age when a forest stand is ready for harvesting) for a given geographic area, and provided information on forest structure that could be used for biogeochemical or climate modeling. An initial map of forest-stand ages was generated for the region using a combination of data from LANDFIRE’s VCT and the U.S. Forest Service’s (USFS’s) Forest Inventory and Analysis (FIA; USDA Forest Service, 2012b). Where the LANDFIRE VCT measured a disturbance, the forest-stand age was directly calculated for the initial year of 1992. In areas where no disturbance was measured by the LANDFIRE VCT, the FIA data points were used to create an interpolated, continuous surface of forest-stand age. The FORE–SCE model tracked forest-stand age for each yearly model iteration and reset the stand age to “0” whenever a new forest area was generated or whenever a forest was clearcut; however, to ensure the use of as much observed spatial data as possible for the baseline period, the clearcutting of forests (classes 3, 4, and 5) in table 2.1 was not modeled using the procedures outlined above; instead, the models were extracted from the LANDFIRE VCT data. All areas of forest that the VCT had identified as clearcut between 1992 and 2005 were “burned in” to the appropriately dated LULC maps produced from the FORE–SCE model (for example, all 1994 clearcut areas identified by the VCT were burned in to the 1994 LULC map produced from the FORE–SCE model). The forest-stand age was appropriately updated throughout the baseline period, mimicking measured dates of forest clearcuts from the VCT.

The result of the mapping and modeling efforts for 1992 to 2005 LULC were annual, 250-meter-resolution LULC maps depicting the LULC classes (shown in table 2.1) and annual, 250-meter-resolution data on forest-stand age. Given the limitations of available, spatially and thematically consistent LULC data for 1992 to 2005, the combined mapping and modeling technique ensured that the overall proportions of the 1992 to 2005 LULC maps were as representative as possible of the real, measured LULC change distributions that were provided by the USGS Land Cover Trends, NLCD, and LANDFIRE VCT projects. The location of LULC change after the initial 1992 year was a mix of actual mapped change and modeled change. The VCT provided the actual locations of clearcut forest patches between 1992 and 2005, a welcome dataset given that forest clearcutting represented the largest LULC change in the Western United States per unit of area (Benjamin M. Sleeter, USGS, unpub. data, 2012). For other LULC types, the “Spatial Allocation” component for LULC change was modeled using the FORE–SCE model.

The validation of the baseline 1992 to 2005 LULC maps was accomplished through a combination of qualitative and quantitative assessment. A quantitative assessment of the model’s performance was obviously preferred. The quantitative validation of LULC model output could be performed by examining measures of quantity disagreement and allocation disagreement that reflected the model’s capability to map the correct quantity and location of LULC change, respectively (Pontius and Millones, 2012). An examination of quantity disagreement was unnecessary for this assessment, however. The quantity of LULC change was dictated by the USGS Land Cover Trends project for 1992 to 2000 and by the NLCD 2001 to 2006 change product for 2001 to 2005. The FORE–SCE model was designed to precisely match prescribed proportions of LULC change as dictated by the “Demand” component of the model. Given the design of the FORE–SCE model, quantity disagreement was, therefore, not an issue because the model matched the annual, prescribed LULC “Demand” for 1992 to 2005 on a regional basis.

Given that all level III ecoregions were parameterized and modeled independently, the allocation disagreement was already partially mitigated because the proportions of change were spatially distributed to the ecoregion level. The allocation disagreement was only an issue within a level III ecoregion. The allocation disagreement (where LULC change was mapped) was not an issue for the clearcutting of forests (the most prevalent form of LULC change in the Western United States) because the 1992 to 2005 polygons of forest change were mapped by the LANDFIRE VCT, not modeled by FORE–SCE. All of the other types of LULC change, however, were modeled by FORE–SCE and were thus subject to allocation disagreement. There were difficulties in performing an assessment of allocation disagreement, however, given the inability to directly compare USGS Land Cover Trends, the 1992 NLCD, and the 2001 and 2006 NLCD data. The 2001 and 2006 NLCD data were produced using a consistent methodology and could theoretically be used to evaluate the allocation disagreement of the modeled LULC change for that period; however, outside of the dominant LULC change in the Western United States (forest clearcutting and associated forest regeneration, mapped by VCT and not modeled), other LULC change was very minor as only 0.76 percent of the region changed between 2001 and 2006. An assessment of the model’s performance by examining small amounts of LULC change over very short temporal intervals is of questionable value (Sohl, Sleeter, Zhu, and others, 2012). Allocation disagreement for classes other than forest clearcutting was thus evaluated through qualitative assessment. During the modeling process, the performance of the model from 1992 to 2005 was evaluated independently for each level III ecoregion using a visual assessment of the LULC-change distribution. An unacceptable distribution of LULC change resulted in a re-parameterization of the FORE–SCE model and a subsequent new model was run until the model performance was deemed acceptable.

2.4. Results and Discussion

2.4.1. Baseline LULC Mapping and Modeling—Results for the Western United States

At the beginning of the simulation period in 1992, the Western United States as a whole was dominated by shrubland (45.1 percent), evergreen forest (23.9 percent), and grassland (13.9 percent)—three LULC classes that covered nearly 83 percent of the Western United States. The less common but significant LULC classes included cultivated crop (3.8 percent), barren (3.8 percent), hay/pasture (2.5 percent), and developed (1.0 percent). The three mechanically disturbed classes, derived from the LANDFIRE VCT data and representing clearcut forest, covered nearly 1.0 percent of the region.

Between 1992 and 2005, 2.9 percent of the land area in the Western United States changed its LULC class at least once. Most LULC classes experienced relatively small net changes during the study period (table 2.2). The three largest LULC classes—shrubland, evergreen forest, and grassland—changed by −2,854 km^2, +5,201 km^2, and −1,426 km^2, respectively. Although the areal change may seem large for the three major classes, the amount of net change was less than 1 percent of the total area for each LULC class during the time period.

The most dynamic changes to LULC classes in the Western United States, both in terms of absolute net change and in terms of relative change for a given LULC class, were changes related to (1) forest clearcutting and (2) urban development. The area covered by the three mechanically

Table 2.2. Mapped and modeled land-use and land-cover (LULC) change (in square kilometers) indicating trends in mapped and modeled LULC classes for the Western United States for the baseline period (1992–2005).

[km^2, square kilometers; LULC, land use and land cover]

LULC class	1992 (km^2)	2005 (km^2)	Change (km^2)	Percent change
Water	39,289	39,744	455	1.2
Urban/developed	27,430	32,486	5,056	18.4
Mechanically disturbed—National forest	9,227	3,888	−5,339	−57.9
Mechanically disturbed—Other public	2,544	1,909	−635	−25.0
Mechanically disturbed—Private	11,580	8,103	−3,476	−30.0
Mining	1,329	2,032	703	52.9
Barren	100,658	100,783	125	0.1
Deciduous forest	52,088	53,791	1,704	3.3
Evergreen forest	636,190	641,391	5,201	0.8
Mixed forest	36,286	37,289	1,003	2.8
Grassland	369,279	367,853	−1,426	−0.4
Shrubland	1,199,764	1,196,910	−2,854	−0.2
Cropland	95,943	95,893	−50	−0.1
Hay/pasture	65,573	64,820	−753	−1.2
Herbaceous wetland	6,913	6,890	−22	−0.3
Woody wetland	2,913	3,223	310	10.7
Ice/snow	1,521	1,521	0	0

disturbed classes of forest clearcutting experienced a total net decline of nearly 9,500 km^2 by 2005, which was a reduction of over 40 percent in areal extent since 1992 (fig. 2.3). The 5,201 km^2 increase in evergreen forest during the same time period was strongly tied to the reduction in overall clearcutting rates. Although clearcutting declined in all classes of mechanically disturbed lands, the sharpest decline in clearcutting was on national forest lands, which declined by 58 percent between 1992 and 2005. Clearcutting on privately held forested land also declined sharply (by 30 percent), but at a much lower rate than the clearcutting on National Forest land.

A number of factors drove the lower rates of forest clearcutting in the Western United States during the baseline time period of 1992 to 2005. Federal environmental policy strongly affected clearcutting practices in the Pacific Northwest. On June 23, 1990, the Northern Spotted Owl (*Strix occidentalis caurina*) was listed as “threatened” under the Endangered Species Act. On May 21, 1991, a U.S. District Court blocked further clearcutting on national forest lands in the region. Those restrictions held until the passing of the Northwest Forest Plan in 1993, an agreement which limited the clearcutting of forested public lands to 1 billion board feet annually, which was roughly one-fourth of the clearcutting rates during the 1980s. Those timber harvesting constraints rippled through the global timber export markets; the higher prices lead Asian importers to look for cheaper timber from New Zealand, Chile, Russia, and elsewhere (Daniels, 2005).

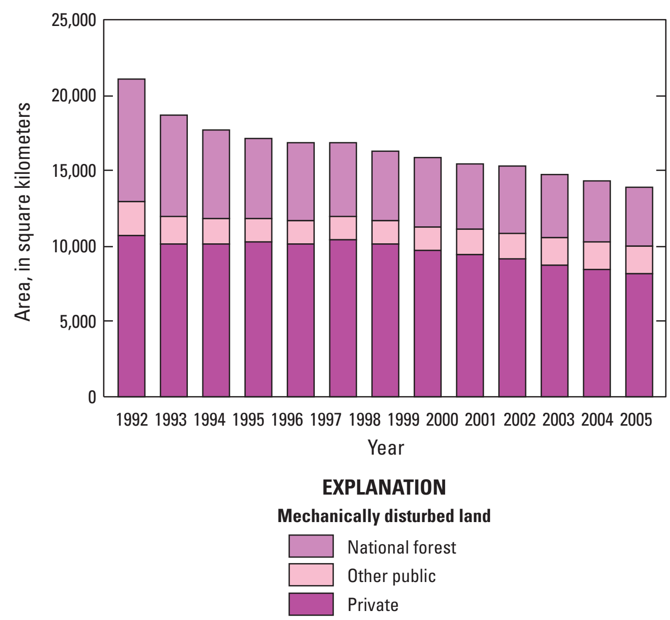


Figure 2.3. Chart showing the declining trend of forest clearcutting in the Western United States between 1992 and 2005. The areal extent of mechanically disturbed (clearcut) land declined significantly over the baseline study period of 1992 to 2005. The strongest declines were noted on national forest lands.

The Asian demand for timber products from the Western United States declined even further in response to the Asian economic crisis in 1997 (Daniels, 2005). Predictions of the decline in forest clearcutting rates in the Western United States, however, had been made far in advance of the passage of the Northwest Forest Plan or the Asian economic crisis in the 1990s, as studies noted that the rates of forest clearcutting in parts of the Western United States before the 1990s were unsustainable (Beuter and others, 1976). The decline in clearcutting noted in this assessment was preceded by additional declines before 1992. Timber harvests in the Pacific Northwest declined by 87 percent from 1988 to 1996 (Warren, 1999; Daniels, 2005).

Urban development was the other most active LULC class in terms of absolute net change relative to initial 1992 LULC conditions. Urban development in the Western United States increased by over 5,000 km^2 from 1992 to 2005, which was an 18.4 percent increase in area (fig. 2.4). Although the rate of increase in development was realistic, the initial extent of urban development in the 1992 LULC data was likely an underestimation of the actual urban extent because it was difficult to identify and map low-density residential areas using Landsat data (Claggett and others, 2004; McCauley and Goetz, 2004). In addition, the 2001 NLCD data had significantly more urban land mapped than the 1992 NLCD, which was likely due to improved source data and methodologies just as much as actual urban expansion. Although urban development was likely underestimated in the initial 1992 map, urban lands still represented only a small portion of the Western United States landscape, and the "story" of urban growth was represented through the measured rates of urban development between 1992 and 2005.

The net change of other LULC types in table 2.2 was relatively minor. The evergreen forest class increased by over 5,200 km^2 (0.8 percent) from 1992 to 2005, as did deciduous forest (+1,704 km^2, or 3.3 percent) and mixed forest (+1,003 km^2, or 2.8 percent). As noted above, the increase in area of the three forest classes was primarily related to the reduction in the rates of forest clearcutting, which resulted in more area categorized as forest in 2005 because of the regeneration of forest in formerly clearcut areas. Other notable LULC changes included an increase of 700 km^2 of mining by 2005, which was a 60 percent increase from 1992. The two agricultural classes, cultivated crop and hay/pasture, each declined with a negligible decline for cultivated crop and a decrease of 1.1 percent in hay/pasture from 1992 to 2005. Grassland and shrubland both declined, with grassland losing 1,426 km^2 and shrubland losing 2,854 km^2. Given the vast expanses of grassland and shrubland in the Western United States, however, this only represented a net loss of −0.39 percent and −0.24 percent, respectively, from the initial 1992 extents of grassland and shrubland.

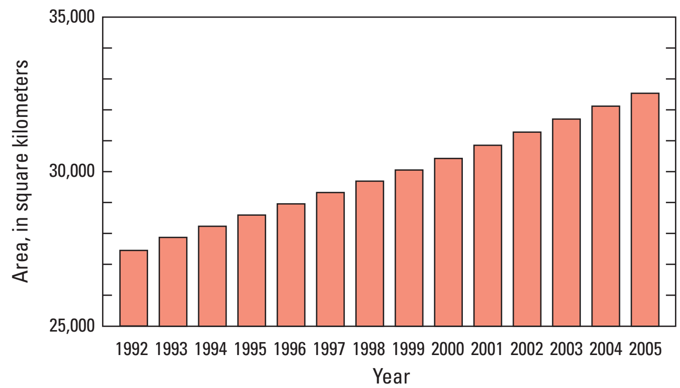
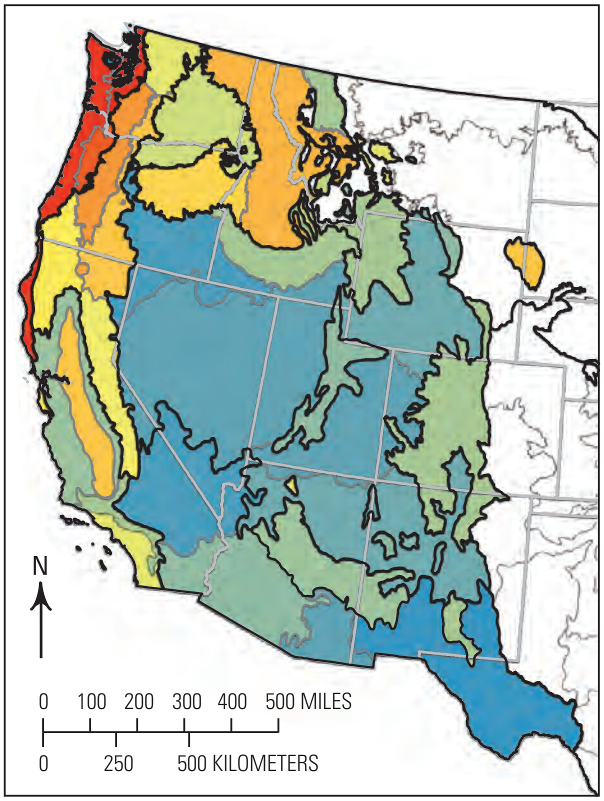


Figure 2.4. Chart showing the increasing trend in the areal extent of urban development in the Western United States between 1992 and 2005. The data were derived from the USGS Land Cover Trends project for the 1992 to 2000 period and from the National Land Cover Dataset (NLCD) 2001 to 2006 change product for the 2001 to 2005 period. A consistent annual rate of change was modeled between 1992 and 2000, and again for 2001 to 2005, on the basis of the USGS Land Cover Trends and NLCD data, respectively. The measured rate of urban development for those two periods was nearly constant.

2.4.2. Regional Results

Although table 2.2 indicates overall net changes in the primary LULC types for the Western United States from 1992 to 2005, regional variability resulted in a heterogeneous pattern of LULC change during the study period. Within the level III ecoregions where significant amounts of forest clearcutting had occurred, 20 percent or more of the land area changed its LULC class at some point between 1992 and 2005, whereas within the ecoregions covered primarily by desert, 1 percent or less of the area changed its LULC class (fig. 2.5). The total spatial change closely mimicked the spatial variability of forest clearcutting, which was the most prevalent form of LULC conversion in the Western United States (fig. 2.6). Forest clearcutting was only one part of the story, however. Each ecoregion had greater internal homogeneity than the Western United States' landscape as a whole, and each had a unique "story" about its baseline land-cover change from 1992 to 2005. The following sections describe the basic characteristics of each level II ecoregion and discuss the primary LULC changes from 1992 to 2005, including a brief discussion of the major driving forces of the changes.



EXPLANATION

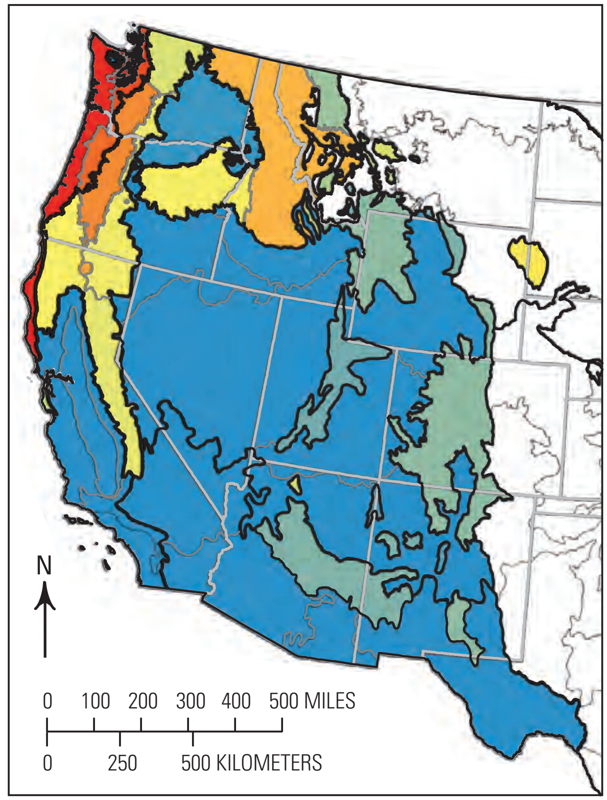
Spatial variability of land-use and land-cover change in the Western United States, by level III ecoregion, in percent

0 5 10 15 20

Level II ecoregion

Level III ecoregion

Figure 2.5. Map showing the spatial variability of land-use and land-cover change in the Western United States between 1992 and 2005. The spatial change (the percent of area that changed at least once from 1992 to 2005) varied greatly between the ecoregions. See figure 1.1 in chapter 1 for ecoregion names.



EXPLANATION

Spatial variability of forest clearcutting in the Western United States, by level III ecoregion, in percent

0 5 10 15 20

Level II ecoregion

Level III ecoregion

Figure 2.6. Map showing the spatial variability of forest clearcutting in the Western United States from 1992 to 2005. Given that forestry activity was the primary driver of measured land-use and land-cover (LULC) change in the region, the distribution of clearcutting by ecoregion was very similar to the overall pattern of LULC change of Western United States. See figure 1.1 in chapter 1 for ecoregion names.

2.4.2.1. Western Cordillera

The Western Cordillera ecoregion covers most of the forested lands in the interior of the Western United States and consists of a number of geographically disparate regions stretching from the Canadian border in Washington to the "sky islands" of New Mexico and Arizona. The Western Cordillera is characterized by generally rugged topography (including mountain ranges that have the highest elevations in the Western United States) and predominantly natural landscapes. In 1992, forest cover (evergreen, mixed, and deciduous forest) alone covered 60.8 percent of the ecoregion. The "natural" land-cover classes (forested classes, grassland, shrubland, wetland classes, and water) covered over 95.9 percent of the ecoregion whereas anthropogenic land uses (urban development, forest cutting, mining, and agriculture) covered only 4.1 percent of the ecoregion (fig. 2.7).

Approximately 4.4 percent (38,447 km^2) of the ecoregion experienced LULC change at least once during the baseline period (1992–2005). Although a relatively small proportion of the ecoregion changed, this was the second most active level II ecoregion in the Western United States for this period. Between 1992 and 2005, the vast majority of LULC change was associated with forestry activity; 87.8 percent (33,739 km^2) of the changed pixels were associated with either clearcutting for timber or the regeneration of the clearcut areas. As with the Western United States as a whole, the net changes in LULC classes were small, and the largest changes by absolute area and by percentage loss or gain were associated with the timber industry (fig. 2.7). Between 1992 and 2005, clearcutting activity declined sharply in all three mechanically disturbed classes (national forests, other public forests, and private forests). The cutting rates on national forest land experienced both the largest absolute change (−5,130 km^2) and relative change (−57.7 percent) from 1992 to 2005. Forested lands (evergreen, deciduous, and mixed forest) increased by 1.4 percent (7,335 km^2), which was primarily due to the declines in clearcutting rates. The developed lands experienced a modest increase of 367 km^2, or an increase of 16.2 percent, between 1992 and 2005.

2.4.2.2. Marine West Coast Forest

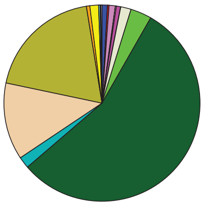
The Marine West Coast Forest ecoregion covers the maritime forests along the West Coast of the United States. This ecoregion was the most heavily forested of the five level II ecoregions in the Western United States with approximately 70 percent of the land area covered by one of the three forest classes in 1992. This ecoregion was similar to the Western Cordillera ecoregion in that the "natural" land-cover classes covered the majority of the ecoregion, and a smaller percentage (24.8 percent) of the land area of this ecoregion was categorized by anthropogenic land uses in 1992. In 1992, the terrestrial portion of the Marine West Coast Forest had higher proportions of clearcut land (7.9 percent), a higher proportion of developed lands (4.5 percent, mostly around the Puget Sound and around the Willamette Valley), and significantly more agricultural land (12.4 percent, the majority of which was hay/pasture) than the Western Cordillera (fig. 2.7).

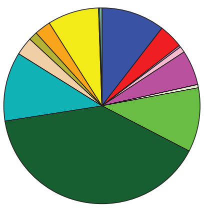
The spatial footprint of LULC change between 1992 and 2005 was much higher in this ecoregion than in any other level II ecoregion in the Western United States. Approximately 19.7 percent (16,850 km^2) of the landscape changed LULC classes at least once between 1992 and 2005 with the vast majority of the change related to forestry activity (a spatial footprint of 15,061 km^2). As with the Western Cordillera ecoregion, forest clearcutting declined from 1992 to 2005, although not as sharply with a total decline of 24.9 percent (1,671 km^2). Forest clearcutting on National Forest land dropped by nearly 70 percent; however, most of the forested land in this ecoregion was privately held, and the more modest declines in clearcutting rates on private land mitigated the decline in the ecoregion's overall rate of clearcutting. Despite the overall decline in clearcutting rates, the amount of land in the three forest classes only increased slightly—by 0.5 percent (520 km^2)—between 1992 and 2005. The increase in forested land was less than that in the Western Cordillera largely because the decreases in forest clearcutting were partially offset by clearing forested land for urban development. Even though the Marine West Coast Forest ecoregion is smaller in area than the Western Cordillera ecoregion, it had 1,563 km^2 more developed land in 1992 and more new urban development between 1992 and 2005 (893 km^2 in the Marine West Coast Forest compared to 367 km^2 in the Western Cordillera). The net change within the other LULC classes was minor; no land area categorized by those classes changed by more than 200 km^2 between 1992 and 2005.

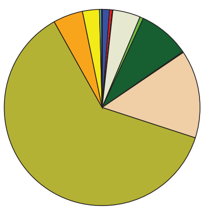
2.4.2.3. Cold Deserts

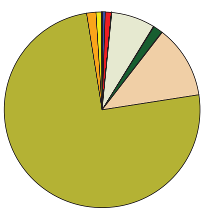
The Cold Deserts ecoregion encompasses the temperate and cooler arid lands of the interior Western United States. Grassland and shrubland were the most common land-cover types in the ecoregion; in 1992, they covered 61.9 percent and 14.5 percent of the ecoregion, respectively. In 1992, forests (evergreen, deciduous, and mixed) covered 9.2 percent of the ecoregion and were found throughout the ecoregion in scattered pockets of land with suitable soils, moisture, and climate. In 1992, agricultural lands (cultivated crop and hay/pasture) covered 7.7 percent of the ecoregion; the majority was irrigated agricultural land located in the Columbia Plateau and the Snake River Plain level III ecoregions. The Cold Deserts ecoregion had a low population density with only a few large urban areas, including Salt Lake City, Utah, and Albuquerque, New Mexico. Urban development covered 5,085 km^2 of the ecoregion at the beginning of the baseline period in 1992.

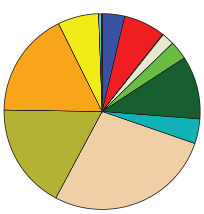
Land-use or land-cover class	Open water	Developed	Mechanically disturbed (national forest)	Mechanically disturbed (other public)	Mechanically disturbed (private)	Mining	Barren	Deciduous forest	Evergreen forest	Mixed forest	Grassland	Shrubland	Agriculture	Hay/pasture	Woody wetland	Herbaceous wetland	Ice/snow
Western Cordillera ecoregion																	
1992 (area, in km^2)	7,827	2,260	8,896	1,557	5,987	266	14,916	30,213	483,704	16,541	110,982	166,953	4,977	12,289	2,229	1,176	1,507
2005 (area, in km^2)	7,939	2,627	3,767	1,113	3,889	393	15,004	31,104	489,702	16,987	110,983	166,892	4,778	11,944	2,303	1,353	1,507
Net change in area (in km^2)	111	367	–5,130	–444	–2,099	127	88	891	5,998	446	1	–61	–200	–346	74	177	0
Change in area (in percent)	1.4	16.2	–57.7	–28.5	–35.1	48.0	0.6	2.9	1.2	2.7	0.0	0.0	–4.0	–2.8	3.3	15.0	0.0
Marine West Coast Forest ecoregion																	
1992 (area, in km^2)	9,964	3,823	290	953	5,471	32	505	10,082	38,077	10,880	2,846	1,367	2,561	8,042	182	347	0
2005 (area, in km^2)	10,004	4,715	89	783	4,170	52	499	10,888	37,345	11,326	3,037	1,507	2,516	7,902	223	364	0
Net change in area (in km^2)	40	892	–201	–170	–1,301	20	–6	806	–732	446	191	140	–45	–140	41	17	0
Change in area (in percent)	0.4	23.3	–69.3	–17.8	–23.8	62.5	–1.2	8.0	–1.9	4.1	6.7	10.2	–1.8	–1.7	22.5	4.9	0.0
Cold Deserts ecoregion																	
1992 (area, in km^2)	12,804	5,085	11	20	61	645	48,201	6,089	89,580	1,499	152,950	653,289	51,675	29,562	3,538	1,037	10
2005 (area, in km^2)	12,924	6,237	2	4	11	937	48,284	6,098	89,552	1,513	152,684	651,974	51,865	29,325	3,458	1,177	10
Net change in area (in km^2)	121	1,153	–9	–16	–50	291	84	9	–28	14	–267	–1,315	190	–237	–80	139	0
Change in area (in percent)	0.9	22.7	–80.0	–81.0	–81.8	45.2	0.2	0.2	0.0	1.0	–0.2	–0.2	0.4	–0.8	–2.3	13.4	0.0
Warm Deserts ecoregion																	
1992 (area, in km^2)	2,424	4,618	16	7	19	322	33,539	497	7,120	466	55,915	348,558	7,168	4,286	129	205	0
2005 (area, in km^2)	2,446	5,747	12	3	3	507	33,450	499	7,100	466	55,806	347,586	7,097	4,240	135	191	0
Net change in area (in km^2)	21	1,129	–3	–4	–16	185	–89	2	–20	0	–109	–972	–71	–46	6	–14	0
Change in area (in percent)	0.9	24.4	–21.9	–52.3	–83.4	57.6	–0.3	0.4	–0.3	0.0	–0.2	–0.3	–1.0	–1.1	4.8	–6.8	0.0
Mediterranean California ecoregion																	
1992 (area, in km^2)	6,270	11,645	14	7	42	64	3,498	5,207	17,709	6,901	46,586	29,598	29,562	11,393	835	149	3
2005 (area, in km^2)	6,431	13,160	18	6	31	144	3,547	5,202	17,692	6,997	45,343	28,951	29,638	11,409	772	139	3
Net change in area (in km^2)	162	1,515	4	–1	–11	80	49	–5	–17	96	–1,243	–646	76	16	–64	–10	–0
Change in area (in percent)	2.6	13.0	25.9	–16.5	–26.5	123.5	1.4	–0.1	–0.1	1.4	–2.7	–2.2	0.3	0.1	–7.6	–6.4	–4.0











EXPLANATION

[Pie charts represent data for 2005]

Land-use or land-cover class

- Open water
- Developed
- Mechanically disturbed (national forest)
- Mechanically disturbed (other public land)
- Mechanically disturbed (private land)
- Mining
- Barren
- Deciduous forest
- Evergreen forest
- Mixed forest
- Grassland
- Shrubland
- Agriculture
- Hay/pasture
- Woody wetland
- Herbaceous wetland
- Ice/snow

Figure 2.7. Charts showing the proportions of land use and land cover (LULC) at the end of the baseline period (pie charts for 2005) and the net change in the mapped and modeled LULC classes between 1992 and 2005, by level II ecoregion.

The spatial footprint of LULC change between 1992 and 2005 was only 1.1 percent of the ecoregion area. Commercial forestry activity and other forest clearcutting, which were major sources of LULC change in the Western Cordillera and Marine West Coast Forest ecoregions, were negligible in the Cold Deserts ecoregion because of the absence of suitable forest resources. Urban development was responsible for the largest net changes in LULC types, as shown in figure 2.7. An estimated 1,153 km^2 of new urban lands were developed by 2005, which was a net increase of 22.7 percent over the 1992 urban extent. The largest absolute net change by class was a 1,315 km^2 loss of shrubland, which was primarily due to the conversion of shrubland to urban development and irrigated agriculture; however, given the prevalence of shrubland in this ecoregion, the areal extent of shrubland declined by only 0.2 percent from 1992 to 2005. The absolute net changes in all other LULC classes were minor. No land area categorized by those classes changed by more than 300 km^2 from 1992 to 2005. Mining lands, however, increased by 291 km^2 from 1992 to 2005, an increase of 45.2 percent.

2.4.2.4. Warm Deserts

The Warm Deserts ecoregion covers the warmer deserts and arid regions of the interior Southwestern United States. Three LULC classes alone covered 94.1 percent of the ecoregion in 1992: shrubland, 74.9 percent; grassland, 12.0 percent; and barren land, 7.2 percent. Forests and agricultural lands were only found in a few scattered locations in the ecoregion. The forested lands (evergreen, deciduous, and mixed) were primarily found in a few areas of higher elevation and near water sources and together covered 1.7 percent of the ecoregion in 1992. The agricultural lands (cultivated crop and hay/pasture) were primarily found in areas where irrigation sources were available, such as near the Salton Sea in California and near Phoenix, Arizona; in 1992, they covered 2.5 percent of the ecoregion. Urban development only covered 1.0 percent of the ecoregion in 1992, yet several large urban centers are located in this ecoregion, including Phoenix and Tucson in Arizona, and Las Vegas, Nevada.

The spatial footprint of LULC change between 1992 and 2005 was only 0.8 percent of the Warm Deserts ecoregion, making it the ecoregion with the least amount of LULC change in the Western United States. Urban development increased by 1,129 km^2, a 24 percent increase from 1992. Shrubland declined by 972 km^2, a decline of 0.3 percent, with most of the loss attributed to the conversion of shrubland to urban development. Other LULC changes in the ecoregion were minor. Commercial forestry was negligible in the ecoregion. Mining lands expanded by 185 km^2, an increase of 57.6 percent from 1992.

2.4.2.5. Mediterranean California

The LULC of the Mediterranean California ecoregion is more heterogeneous than the other ecoregions in the Western United States. This ecoregion is the only one where forests (evergreen, mixed, and deciduous) or shrubland alone did not cover a majority (>50 percent) of the ecoregion area. Grassland (27.5 percent), agricultural classes (24.2 percent for the two classes), forest (17.6 percent for the three classes), shrubland (17.5 percent), and urban development (6.9 percent) each represented the dominant LULC class for specific portions of the ecoregion in 1992. Grassland was scattered throughout the ecoregion but there was a high concentration around the periphery of the Central California Valley level III ecoregion. Agricultural land was concentrated in the Central California Valley, although there were smaller, scattered patches in western and southern California. Forested lands were concentrated in the Southern California Mountains level III ecoregion and along the edges of the Southern and Central California Chaparral and Oak Woodlands level III ecoregion. The vast majority of shrubland was found in the far southern third of the ecoregion, and areas of dense urban development were found throughout the ecoregion.

The spatial footprint of LULC change between 1992 and 2005 was 3.5 percent of the ecoregion area. The greatest amount of change by area was associated with the gross change between the cultivated crop and hay/pasture classes. The net change in those two classes was very small, with cultivated crop increasing by 76 km^2 (0.3 percent) and hay/pasture increasing by 16 km^2 (0.1 percent). Underlying the small amount of net change, however, were large amounts of gross change with near balances of cultivated crop converting to hay/pasture and vice versa. The highest net changes in LULC classes were associated with urban development. Over 1,500 km^2 of new urban development occurred between 1992 and 2005, which was a 13.0 percent increase over the 1992 extent. Grassland declined by 1,243 km^2 (2.7 percent) and shrubland declined by 646 km^2 (2.2 percent), with the majority of the declines caused by conversion to urban development. Other LULC changes in the ecoregion were minor.