Projected Land-Use and Land-Cover Change in the Western United States

By Benjamin M. Sleeter, Terry L. Sohl, Tamara S. Wilson, Rachel R. Sleeter, Christopher E. Soulard, Michelle A. Bouchard, Kristi L. Sayler, Ryan R. Reker, and Glenn E. Griffith

Chapter 6 of

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Contents

Figures

Figures

Tables

Chapter 6. Projected Land-Use and Land-Cover Change in the Western United States

By Benjamin M. Sleeter[1], Terry L. Sohl[1], Tamara S. Wilson[1], Rachel R. Sleeter[1], Christopher E. Soulard[1], Michelle A. Bouchard[1], Kristi L. Sayler[2], Ryan R. Reker[3], and Glenn E. Griffith[1]

6.1. Highlights

- The projected changes in land use and land cover are highly variable across ecoregions and scenarios. The overall rates of projected change varied from 1.3 percent in the Warm Deserts ecoregion under the A2 scenario to 44.9 percent in the Marine West Coast Forest ecoregion under the A1B scenario.
- Land-use and land-cover change was generally projected to be greatest under the economically oriented scenarios and smaller in the environment-oriented scenarios.
- Forest harvesting and regrowth accounted for the greatest amount of projected land-use and land-cover change under all of the scenarios; however, the projected rates of change were highly variable across the level III ecoregions and were driven by the regions' enabling environmental characteristics and resource potential.
- Urbanization was a key component of projected land-use and land-cover change in all of the scenarios and was most pronounced in the Mediterranean California and Marine West Coast Forest ecoregions.
- Forests were projected to decline in the economically oriented scenarios, resulting primarily from the projected high demand for urban land uses and, to a lesser extent, the expansion of agricultural land.

6.2. Introduction and Review of Methods

The current and projected changes in land use and land cover (LULC) are key components for this assessment of carbon and greenhouse-gas (GHG) stocks and fluxes (Zhu and others, 2010). As noted in chapter 1 of this report, mapping of the baseline (1992–2005) LULC conditions, discussed in detail in chapter 2 of this report, provided a spatial foundation for the wall-to-wall assessment of carbon stocks and GHG fluxes in various ecosystems. The development of a range of future potential LULC projections, together with corresponding climate-change projections, allowed for an evaluation of future potential carbon sequestration capacities and vulnerabilities as influenced by these projected drivers. This chapter provides an overview of the methods used to develop alternative future scenarios of LULC and presents the spatially explicit LULC modeling results for each level II ecoregion in the Western United States. The relation between the future LULC scenarios described in this chapter and other components of the assessment is depicted in figure 1.2 of chapter 1. The level II and level III ecoregion names and boundaries are modified from the Commission for Environmental Cooperation (2006) and U.S Environmental Protection Agency (EPA, 1999).

[1]U.S. Geological Survey, Menlo Park, Calif.

[2]U.S. Geological Survey, Sioux Falls, S.D.

[3]Arctic Slope Regional Corporation Research and Technology Solutions, Sioux Falls, S.D.

6.2.1. Scenario Framework

In 2001, the Intergovernmental Panel on Climate Change (IPCC) published the Special Report on Emission Scenarios (SRES) (Nakicenovic and others, 2000). The IPCC–SRES documented the development of a global set of greenhouse-gas-emissions scenarios, which were based on an underlying set of socioeconomic conditions that were consistent with the current (at the time) scenario literature. The IPCC–SRES scenarios were designed to assess the impacts of alternative GHG-emission pathways on coupled human and environmental systems and evaluate future vulnerabilities on those systems under various combinations of projected change. The IPCC–SRES scenarios consist of four basic narrative storylines, each of which describe alternative developments in the major drivers of GHG emissions, such as population growth, economic growth, technological change, energy use, globalization, and environmental protection. The four storylines are oriented along two axes with either economic growth (A) or environmental protection (B) aligned along one axis and either global development (1) or regional development (2) aligned along the other; for example, the B1 scenario assumes strong environmental protection and global cooperation.

In order to explore sensitivities in the energy sector, the A1 storyline was subdivided into three subscenarios that focused on fossil-fuel use (A1FI), renewable technologies (A1T), and a balanced energy sector that did not rely on any particular energy source (A1B). Six modeling teams characterized the various storylines, ultimately producing 40 quantified scenarios. No probability of occurrence was assigned to any one of the IPCC–SRES scenarios and all should be considered equally plausible with none considered more or less preferable. Furthermore, no integrated climate-change policies, such as the emissions targets of the Kyoto Protocol (United Nations Framework Convention on Climate Change, 1997), are incorporated into any of the scenarios; therefore, the scenarios serve as reference conditions to evaluate the effects of potential mitigation actions and strategies. Since the inception of the IPCC–SRES scenarios, a suite of future climate-change projections (known as the general circulation model (GCM) data) have also become available and correspond to the major storylines. At the early stage of this assessment, GCM data corresponding to the B2 storyline were not available. Because this assessment required the use of both the LULC scenarios and climate-change projection scenarios, only the A1B, A2, and B1 scenarios were used in the assessment. See table 6.1 for assumptions about the major driving forces associated with each scenario.

Table 6.1. Assumptions about the primary driving forces affecting land-use and land-cover change.

[These assumptions were used to downscale the A1B, A2, and B1 scenarios of the Intergovernmental Panel for Climate Change's Special Report on Emission Scenarios (Nakicenovic and others, 2000). Population and per-capita income projections are from Strengers and others (2004)]

Driving forces	A1B	A2	B1
Population growth (global and United States)	Medium. Globally, 8.7 billion by 2050, then declining; in the United States, 385 million by 2050	High. Globally, 15.1 billion by 2100; in the United States, 417 million by 2050	Medium. Globally, 8.7 billion by 2050, then declining; in the United States, 385 million by 2050.
Economic growth	Very high. U.S. per-capita income $72,531 by 2050	Medium. U.S. per-capita income $47,766 by 2050	High. U.S. per-capita income $59,880 by 2050.
Regional or global orientation	Global	Regional	Global.
Technological innovation	Rapid	Slow	Rapid.
Energy sector	Balanced use	Adaptation to local resources	Smooth transition to renewable.
Environmental protection	Active management	Local and regional focus	Protection of biodiversity.

6.2.2. Scenario Downscaling

In order to use the global scenarios, a scenario downscaling process was needed to translate the coarse-scale scenario data to finer geographic scales while maintaining consistency with the original dataset and local data (van Vuuren and others, 2007, 2010). Land-change scenarios were developed using a modular modeling approach. A global integrated assessment model (IAM) was used to supply future projections of land use at the national scale. An accounting model was developed to refine the national-scale IAM projections and to downscale to hierarchically nested ecoregions. The ecoregion-based projections were then converted into annual maps of LULC using a spatially explicit LULC change model. The approach used for this assessment follows the methods described in Zhu and others (2010) and more recently in Sohl, Sleeter, Zhu, and others (2012) and Sleeter, Sohl, Bouchard, and others (2012). A brief review of each of the major components is found below.

Initial quantities of projected LULC changes (scenario “demand”) were formulated by implementing a land-use-scenario downscaling accounting model (described in detail in Sleeter, Sohl, Bouchard, and others, 2012). National-scale LULC projections were based on national-scale projections from the Integrated Model to Assess the Global Environment (IMAGE, version 2.2), land-use histories, and expert knowledge. IMAGE was used to simulate future environmental change, including GHG emissions and land-use changes, for the three SRES marker scenarios (A1B, A2, B1) (Strengers and others, 2004). IMAGE used a series of linked modules to project environmental consequences resulting from anthropogenic activity (Alcamo and others, 1998; IMAGE Team, 2001). Environmental changes were projected for 17 world regions (the United States was treated as a single region) with some data (land use and land cover) available in a 30′ × 30′ grid. IMAGE produced projections of demand for agriculture and forest harvest, which were incorporated directly into the scenario downscaling model described in Sleeter, Sohl, Bouchard, and others (2012). Future projections of development and mining were developed through the use of proxy data (population and coal usage, respectively) from the IMAGE. Land-use histories were then used to expand the scenario projections of net change in major land-use classes into comprehensive projections of gross changes between all major LULC types.

Land-use histories described the recent historical LULC changes occurring in ecoregions of the United States. These data came primarily from the USGS Land Cover Trends project, which provided ecoregion-based estimates on the rates, extent, and types of LULC change for multiple dates between 1973 and 2000 (Loveland and others, 2002; Sleeter, Wilson, and Acevedo, 2012). USGS Land Cover Trends data were incorporated into the scenarios’ construction and downscaling in two primary ways. First, the data were used to expand projections of net change in development, mining, and agriculture into gross conversions between all primary LULC classes at the national scale. Second, the data were used to proportionally downscale these LULC conversions to ecoregions of the conterminous United States. Throughout the downscaling process, regional and sectoral experts were consulted in a series of workshops and ad-hoc consultations. The data served as a default parameter for downscaling, and experts were able to modify certain variables in order to produce regionally specific scenarios that retained consistency with the IPCC–SRES storylines. A complete description of the downscaling process can be found in Sleeter, Sohl, Bouchard, and others (2012).

Regional LULC scenarios, developed in the process as described above, were used as input to the “forecasting scenarios of land-use change” (FORE–SCE) model (Sohl and Sayler, 2008; Sohl, Sleeter, Sayler, and others, 2012). The FORE–SCE model produced annual, spatially explicit LULC maps from 2006 to 2050 that were consistent with the scenario assumptions and LULC proportions from the scenario downscaling process. The initial LULC map for the start of the simulation period was the 2005 LULC map produced from the baseline LULC modeling described in chapter 2 of this report. The suitability-of-occurrence surfaces that were used for the modeling of the baseline LULC change guided the placement of patches of change for the 2006 to 2050 scenarios. The Protected Area Database (PAD–US) used in the modeling of baseline LULC was also used for the scenario modeling. Different decision rules were used for each scenario, with more land protected from significant LULC change in the environment-oriented B1 scenario and more lands available for development in the economically oriented A1 and A2 scenarios. Each level III ecoregion was individually parameterized and modeled by applying the FORE–SCE model for each of the three IPCC–SRES scenarios. The 2006 to 2050 models of LULC provide spatial representations of plausible outcomes that are based on the IPCC–SRES scenarios. When combined with the mapped and modeled baseline (1992 to 2005) LULC maps described in chapter 2, the baseline and modeled scenarios resulted in a continuous, consistent LULC map database from 1992 to 2050.

6.3. Results

6.3.1. Scenario Downscaling Results for the Western United States

The projected changes in LULC were variable across ecoregions and scenarios. The LULC-change footprint was the area of the Western United States that changed at least once over the projection period. Under the three scenarios used for this assessment, the projected LULC change ranged from a low of 5.8 percent in the B1 scenario to a high of 7.8 percent in the A1B scenario; in the A2 scenario, the LULC change was 6.4 percent. The scenarios that indicated the greatest (A1B) and smallest (B1) amounts of projected LULC change shared the same assumptions about population growth; however, the greatest change indicated by the A1B scenario resulted from high demand for forest products, agricultural intensification, and high rates of urbanization. The B1 scenario was characterized by strengthening environmental protections, which limited the anthropogenic conversion of natural land covers to either agricultural land or urbanized land. The demand for forest products and agricultural commodities was reduced in scenario B1 compared to A1B, and the environmental emphasis associated with scenario B1 resulted in a more compact pattern of urbanization. The variability was even greater between the level II ecoregions in the Western United States (table 6.2). The greatest projected LULC change of any of the ecoregion regions was in the Marine West Coast Forest, followed by the Western Cordillera and Mediterranean California. The projected LULC change of the Cold Deserts and Warm Deserts ecoregions was below 3 percent (table 6.2 and fig. 6.1).

Forest ecosystems accounted for 746,370 km^2 of the Western United States in 2005 and were projected to decline by 5,630 km^2 in the A1B scenario and by 5,350 km^2 in the A2 scenario by 2050 (fig. 6.2) with the harvesting of evergreen forests accounting for more than 80 percent of the loss. In the B1 scenario, forests were projected to remain relatively stable, declining by 630 km^2 by 2050 (fig. 6.3). The projected net forest loss was driven primarily by the demand for urbanization and new agricultural lands. New developed areas were projected to increase by 62 percent in the B1 scenario, 69 percent in the A2 scenario, and 90 percent in the A1B scenario, whereas agriculture was projected to increase by 12 percent in the A1B scenario and 4 percent in the A2 scenario, and decline by 1 percent in the B1 scenario (fig. 6.2).

The projected changes in urban and built-up areas for each ecoregion and scenario can be found in figure 6.4. Forest harvesting was also a major driver of forest change in the west. The rate of forest harvesting was projected to increase in both the A1B and A2 scenarios but decline in the B1 scenario. By 2050, clearcut logging was projected to affect 21 percent of Western United States' forests in the A1B scenario, 19 percent in the A2 scenario, and 17 percent in the B1 scenario. The grasslands/shrublands ecosystem was projected to experience the greatest areal changes of any ecosystem in the Western United States, declining in all scenarios. Figure 6.2 shows the projected net change in major ecosystem types between 2005 and 2050 for each of the three scenarios, and figure 6.3 shows the projected trends in ecosystem composition over time. Below is a brief overview of the major projected LULC changes in each of the five level II ecoregions in the Western United States for each of the three IPCC–SRES scenarios.

Table 6.2. The projected land-use- and land-cover-change footprint in the level II ecoregions of the Western United States.

[Values given in the A1B, A2, and B1 column are the percent of each level II ecoregion that experienced a change in land use or land cover at least once between 2005 and 2050]

Ecoregion	Area (square kilometers)	A1B (percent change)	A2 (percent change)	B1 (percent change)
Western Cordillera	872,023	12.7	11.1	9.6
Marine West Coast Forest	85,324	44.9	41.6	34.9
Cold Deserts	1,056,072	2.7	1.8	1.8
Warm Deserts	464,312	2.0	1.3	1.5
Mediterranean California	164,481	12.1	7.9	8.5
Western United States (total)	2,642,212	7.8	6.4	5.8

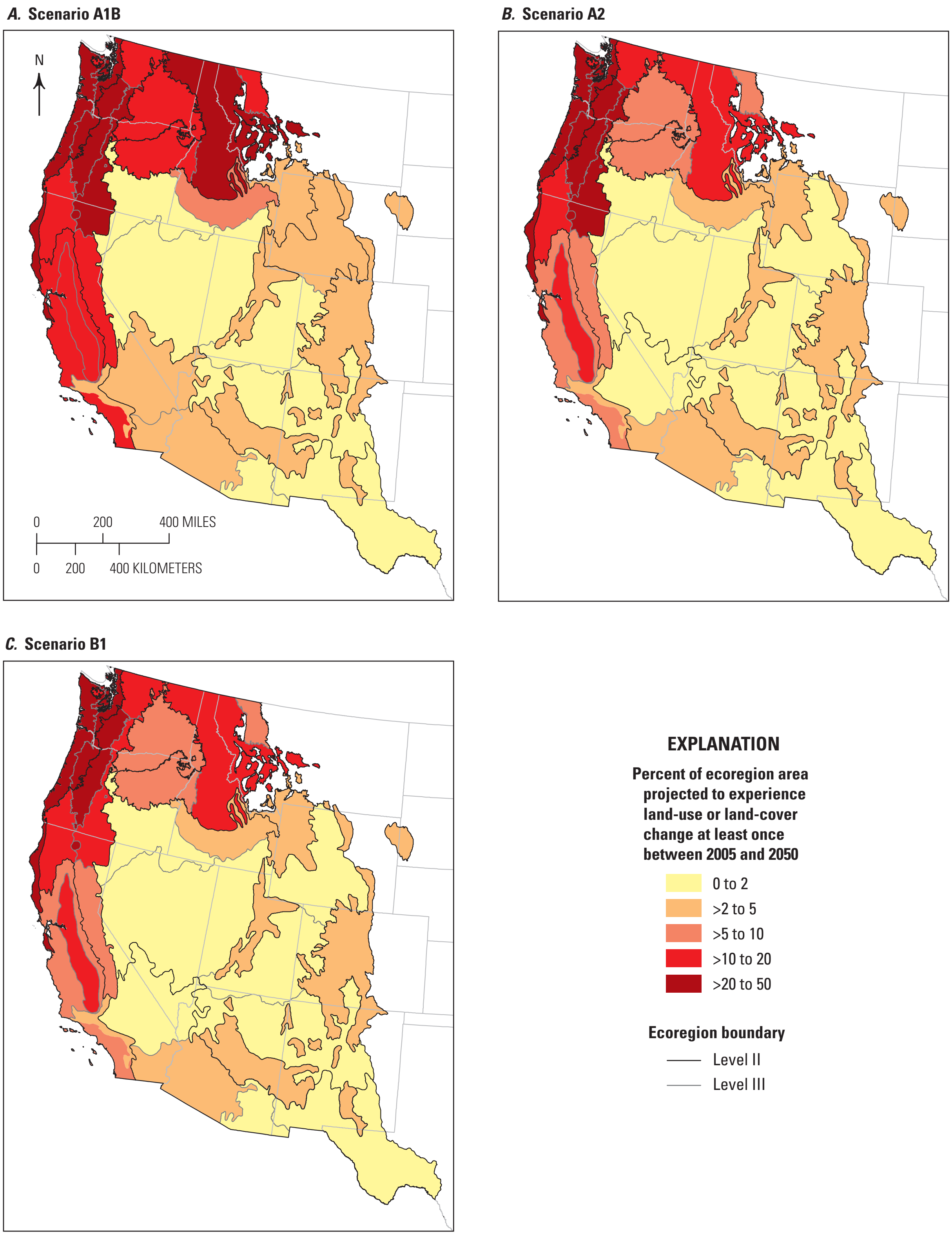

Figure 6.1. Maps showing the projected land-use- and land-cover-change footprint for each of the level III ecoregions in the Western United States. The footprint represents the percent of the ecoregion that changed at least once between 2005 and 2050. *A*, Scenario A1B. *B*, Scenario A2. *C*, Scenario B1.

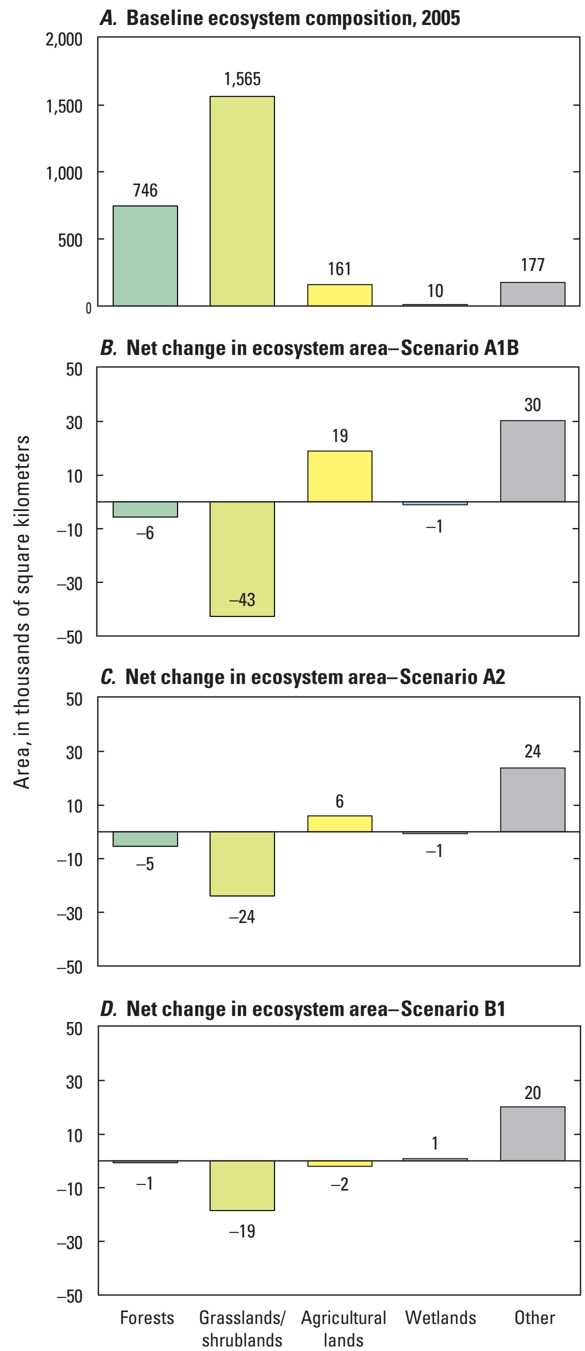

Figure 6.2. Chart showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Western United States, for the end of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The "other" ecosystem includes developed land, mined land, barren land, and water.

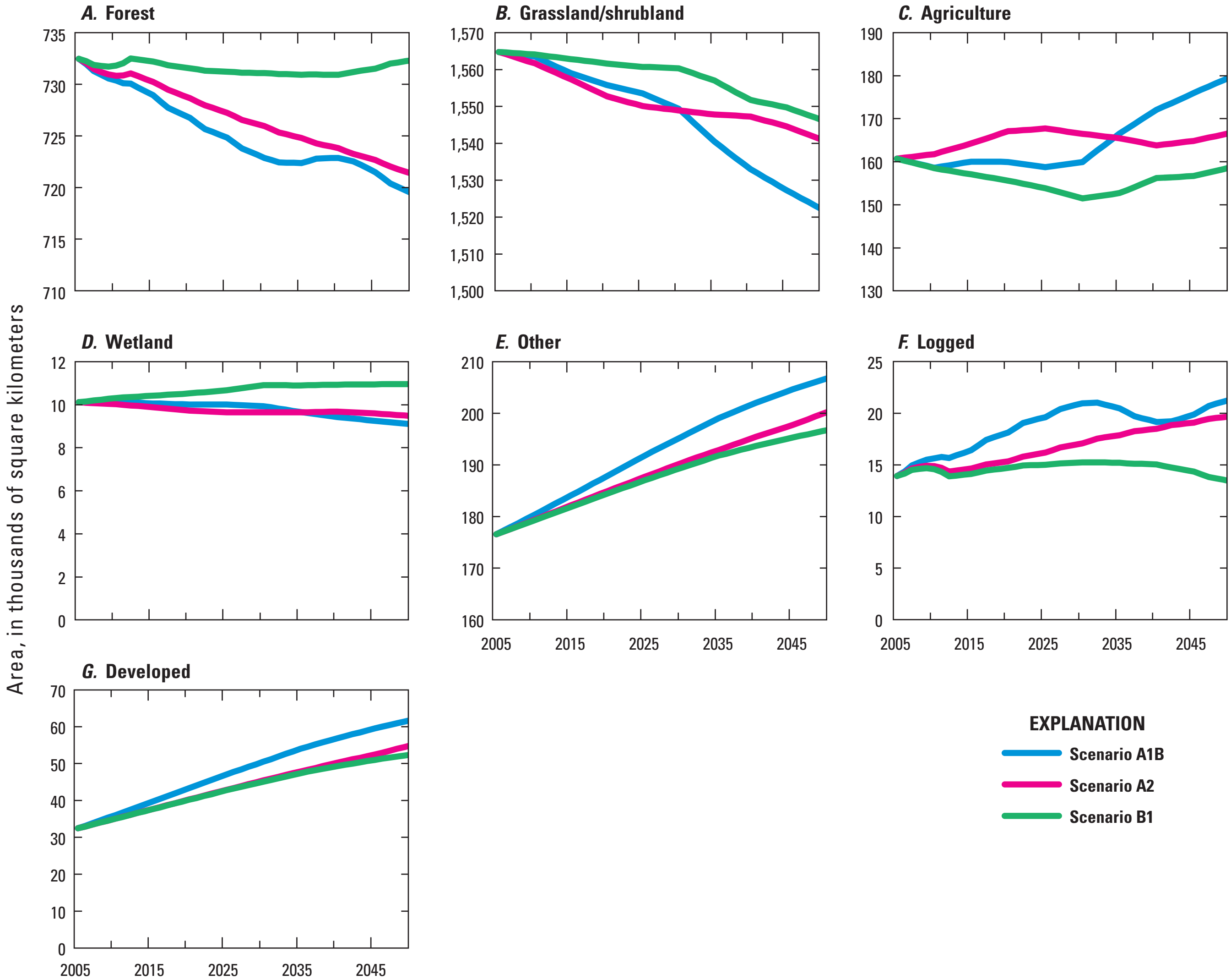

Figure 6.3. Graphs showing trends in the projected composition of the major land-use and land-cover classes over the projection period (2005 to 2050) for the Western United States, by scenario. *A*, Forest. *B*, Grassland/shrubland. *C*, Agriculture. *D*, Wetland. *E*, Other (includes developed land, mined land, barren land, and snow/ice). *F*, Logged (shown separately from other forests because it is a major driver of forest change). *G*, Developed.

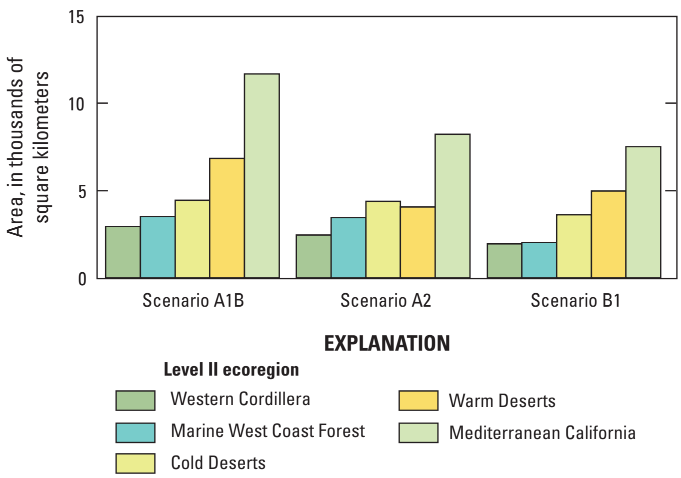

Figure 6.4. Chart showing projected change in area of developed land by level II ecoregion for the A1B, A2, and B1 scenarios for the period 2005 to 2050.

6.3.2. Regional Results

6.3.2.1. Western Cordillera

The Western Cordillera level II ecoregion includes 12 level III ecoregions: Cascades, North Cascades, Eastern Cascades—Slopes and Foothills, Klamath Mountains, Blue Mountains, Sierra Nevada Mountains, Northern Rockies, Canadian Rockies, Wasatch-Uinta Mountains, Middle Rockies, Southern Rockies, and Arizona-New Mexico Mountains. The ecoregion includes the high mountains of the interior Western United States and highly variable climate, vegetation, and land use because of its rugged topography and extensive ranges in elevation. A large proportion of this ecoregion is publicly owned, which affects land-use and land-management practices. Landscapes range from grass- and shrub-covered lowlands, forested middle elevations, and alpine areas of rock, snow, and ice. Livestock grazing is common in valleys and the lower to middle elevations, and logging is typical in forested areas. Recreation, wildlife, and land-management issues related to watersheds or water supply also influence the LULC. Forestry activity over recent historical times has accounted for as much as two-thirds of all of the regional LULC change; however, forestry activities were highly variable across the level III ecoregions. Data from the USGS Land Cover Trends project (Sleeter, Soulard, and others, 2012) indicated that 74 percent of all logging activity in the past three decades occurred in four level III ecoregions: Cascades, Northern Rockies, Eastern Cascades—Slopes and Foothills, and Klamath Mountains. Furthermore, the overall amount of LULC change was geographically highly variable and ranged from 1 percent in the Southern Rockies to 25 percent in the Cascades. Approximately three-fourths of the Western Cordillera is Federally managed public land, and within it, 22 percent is designated as either highly protected wilderness or a national park, which spatially limits timber harvesting and other anthropogenic activities. Population growth is sparse and scattered in this ecoregion due to the rugged terrain, lack of infrastructure, and proximity to goods and services, which limits the growth of urban and developed land. Agriculture is also limited and is generally confined to lower elevations, where livestock grazing is common.

In all of the scenarios, the projected LULC change in the Western Cordillera ecoregion centered on forestry activities. Approximately three-fourths of all logging was projected to occur in the Cascades, Eastern Cascades—Slopes and Foothills, Northern Rockies, and Klamath Mountains level III ecoregions.

In the A1B scenario, 92,990 km^2 of forested land was projected to be harvested between 2005 and 2050. Most of the projected harvest was conifer forest, with 58 percent occurring in national forests and 32 percent in privately owned forests (table 6.3). The overall extent of forested land was projected to decline from 546,560 km^2 in 2005 to 545,010 km^2 by 2050 (fig. 6.5). Agricultural lands were projected to expand by 3,500 km^2 (from 16,720 km^2 in 2005); the Blue Mountains ecoregion was projected to have the largest increase in agricultural land (1,220 km^2), with most of the increase due to the conversion of grasslands/shrublands (880 km^2). The primary type of agricultural land was hay/pasture land. Between 2005 and 2050, developed land was projected to more than double, expanding by 2,940 km^2 (from 2,630 km^2 in 2005); 44 percent of this growth was projected to occur near Spokane, Washington, and Coeur d’Alene, Idaho, within the Northern Rockies ecoregion.

In the A2 scenario, 82,730 km^2 of forested land was projected to be harvested between 2005 and 2050 (table 6.3). As in the A1B scenario, national forests were projected to account for the majority of forest harvesting. The overall forested area was projected to decline from 546,560 km^2 in 2005 to 545,170 km^2 in 2050, while agricultural land was projected to increase by 1,400 km^2 (from 16,720 km^2 in 2005) (fig. 6.5). Most of the agricultural expansion was projected to occur because of the conversion of grasslands/shrublands to hay/pasture lands to support livestock. Developed land was projected to double in area, increasing from 2,630 km^2 in 2005 to 5,090 km^2 in 2050 (fig. 6.4). The projected expansion of agricultural and developed land resulted in a projected decline in the grasslands/shrublands ecosystem of 1 percent, from 277,880 km^2 in 2005 to 275,110 km^2 in 2050 (fig. 6.5).

Table 6.3. Projected extent of forest logging (driven by demand for forest products) in national, other publicly owned, and privately owned forests in the Western United States and two ecoregions, by ecoregion and ownership category, for the A1B, A2, and B1 scenarios.

[For each set of data, the area is the projected sum of all logged area between 2006 and 2050 and the percentages are the allocation of logged area across the three ownership categories. Data for other three ecoregions covered in this assessment were not included because timber harvesting is not a major economic activity in these regions]

		A1B	A2	B1
Western United States (includes all ecoregions)	Total cut area (km^2)	124,288	110,576	93,485
	National forests (percent)	43.9	44.0	43.2
	Other publicly owned forests (percent)	11.9	12.2	11.4
	Private forests (percent)	44.2	43.7	45.4
Western Cordillera ecoregion	Total cut area (km^2)	92,986	82,728	69,944
	National forests (percent)	57.9	57.6	57.3
	Other publicly owned forest (percent)	10.2	10.2	10.3
	Private forests (percent)	31.8	32.2	32.4
Marine West Coast Forest ecoregion	Total cut area (km^2)	30,991	27,576	23,307
	National forests (percent)	1.9	3.5	0.8
	Other publicly owned forests (percent)	17.0	18.2	14.7
	Private forests (percent)	81.1	78.2	84.5

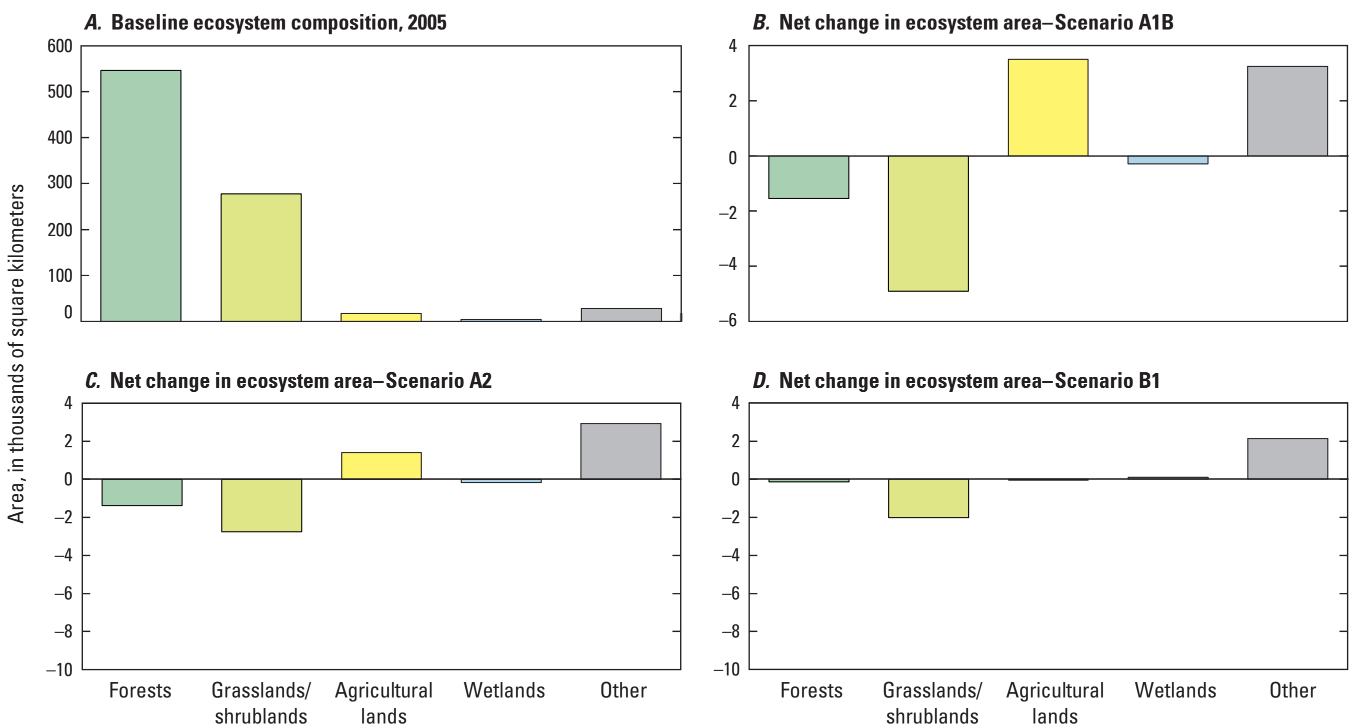

Figure 6.5. Charts showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Western Cordillera ecoregion, for the final year of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The "other" ecosystem includes developed land, mined land, barren land, and water. The large projected net changes in the "other" class were primarily attributed to the projected increases in developed land.

In the B1 scenario, the demand for wood products was projected to be lower than in the other scenarios, resulting from a large focus on conservation and protection of biodiversity. Forest harvesting was projected to affect 93,490 km^2 of forest cover. The Cascades was the only level III ecoregion where the overall change was projected to be greater than 20 percent (fig. 6.1); however, cutting was still projected to occur at relatively high rates in the East Cascades—Slopes and Foothills, Klamath Mountains, Northern Rockies, and North Cascades. In contrast to the economically oriented scenarios, the forested area in this scenario was projected to decrease by only 140 km^2 (from 546,560 km^2 in 2005), while agricultural lands were projected to decrease by 50 km^2 (from 16,700 km^2 in 2005) (fig. 6.5). Furthermore, the B1 scenario is the only one that indicated a projected increase in wetlands; in 2005, wetlands accounted for 3,660 km^2 and in 2050 they were projected to account for 3,750 km^2. Similar to the A2 scenario, developed areas were projected to increase by 1,940 km^2 and were concentrated around the city of Spokane, Washington, in the Northern Rockies. Figure 6.6 shows a comparison of projected LULC changes resulting from forest harvesting activities near Crater Lake, Oregon, in the Cascades and East Cascades—Slopes and Foothills.

6.3.2.2. Marine West Coast Forest

The Marine West Coast Forest level II ecoregion includes the Coast Range, Puget Lowland, and Willamette Valley level III ecoregions. The ecoregion consists of a highly dynamic, heterogeneous landscape with regionally unique LULC. The conifer-covered, rolling hills of the sparsely populated Coast Range give way to the low-lying, agriculture-dominated Willamette Valley to the east and the intensively developed Puget Lowland in the north. The three subregional economies are distinct from each other and contribute to marked differences in projected LULC change. Forestry and forest products are major drivers of the region's economy, along with agriculture, information technology, manufacturing, construction, and service industries (Sleeter, Soulard, and others, 2012). Although timber harvesting is common throughout the ecoregion, privately owned forests in the Coast Range and along the periphery of the Willamette Valley are the most heavily logged. Much less cutting has occurred on public lands since the Federal enactment of species protection through the Northwest Forest Plan (U.S. Department of Agriculture and U.S. Department of the Interior, 1994). According to the USGS Land Cover Trends data (Sleeter, Soulard, and others, 2012), forest cutting in the past three decades was the highest ranking LULC change and affected over 16 percent of the total land area. Urbanization was also an important LULC transition with large areas of forest and agriculture converted to urban land in the Puget Lowland and Willamette Valley, respectively. Overall, the Marine West Coast Forest ecoregion experienced the highest rates of late-20th-century LULC change in the Western United States. The drivers of LULC change included regional and global timber demand, market competition, population expansion, conversion of forested lands to agricultural lands, and environmental protection (Daniels, 2005).

The projected LULC change was greatest in the Marine West Coast Forest in comparison with the other four ecoregions in the Western United States; 20 percent or more of the ecoregion was projected to experience LULC change in all of the scenarios. Forest harvesting was projected to be greatest in each of the three scenarios with the majority of harvesting occurring in the Coast Range. The extent of developed lands was projected to increase in all of the scenarios, with most new development occurring in the Puget Lowland and successively smaller amounts occurring in the Willamette Valley and Coast Range. Agricultural land was projected to increase in the A1B and A2 scenarios and decline in the B1 scenario. Figure 6.7 shows the baseline ecosystem composition and the projected net change for each ecosystem in each scenario studied for this assessment.

In the A1B scenario, anthropogenic land-use demand was projected to increase almost a full percent of the land area (to 25.6 percent) while natural land covers were projected to decline (to 74.4 percent) from the baseline conditions. The projected forest-related LULC change was the greatest of any of the scenarios, with nearly 31,000 km^2 of the forested part of the ecoregion harvested between 2005 and 2050 (table 6.3) and over 2,500 km^2 cleared for development. More than 81 percent of all cutting was projected to occur on private lands, whereas the Coast Range included more than half of the modeled clearcut land. Overall, forests were projected to decline by 3,760 km^2 (from 64,600 km^2 in 2005). By 2050, developed lands were projected to increase by 79 percent (3,510 km^2) from 4,720 km^2 in 2005. The Puget Lowland was projected to grow the most (64 percent of all new developed lands) followed by the Willamette Valley (27 percent of all new developed lands). In the Puget Lowland, 67 percent of all new developed land was projected to be converted from forested land. Another notable change was the projected addition of 560 km^2 of new hay/pasture land (from 7,900 km^2 in 2005), mostly in the Coast Range as cleared forests were converted to agricultural land.

In the A2 scenario, more than 27,500 km^2 of forests was projected to be harvested by 2050. In this scenario, nearly 22 percent of all trees harvested came from public lands (both national forests and other public forests; table 6.3), which was the greatest percentage of any scenario. In the Coast Range, nearly 25 percent of all forest cutting was projected to occur in public forests, the highest percentage for any scenario.

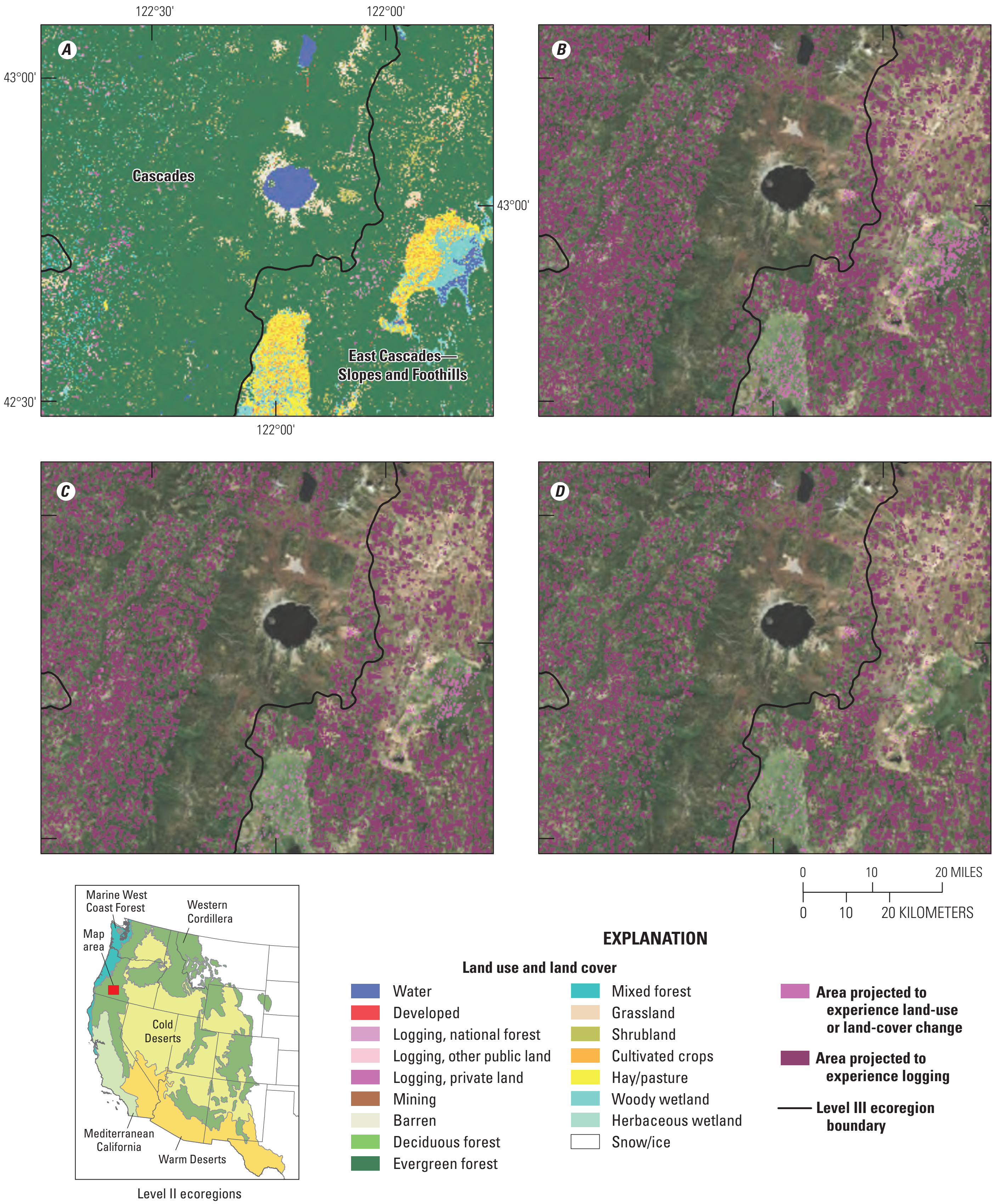

Figure 6.6. Maps showing land use and land cover (LULC) in 2005 and a comparison of the projected LULC changes in the A1B, A2, and B1 scenarios in 2050 for the area around Crater Lake, Oregon, in the Western Cordillera ecoregion. Changes were projected to be the result of either land-use change or forest clearcutting. *A*, LULC in 2005. *B*, Projected LULC change in the A1B scenario. *C*, Projected LULC change in the A2 scenario. *D*, Projected LULC change in the B1 scenario. Crater Lake is located in the center of the image.

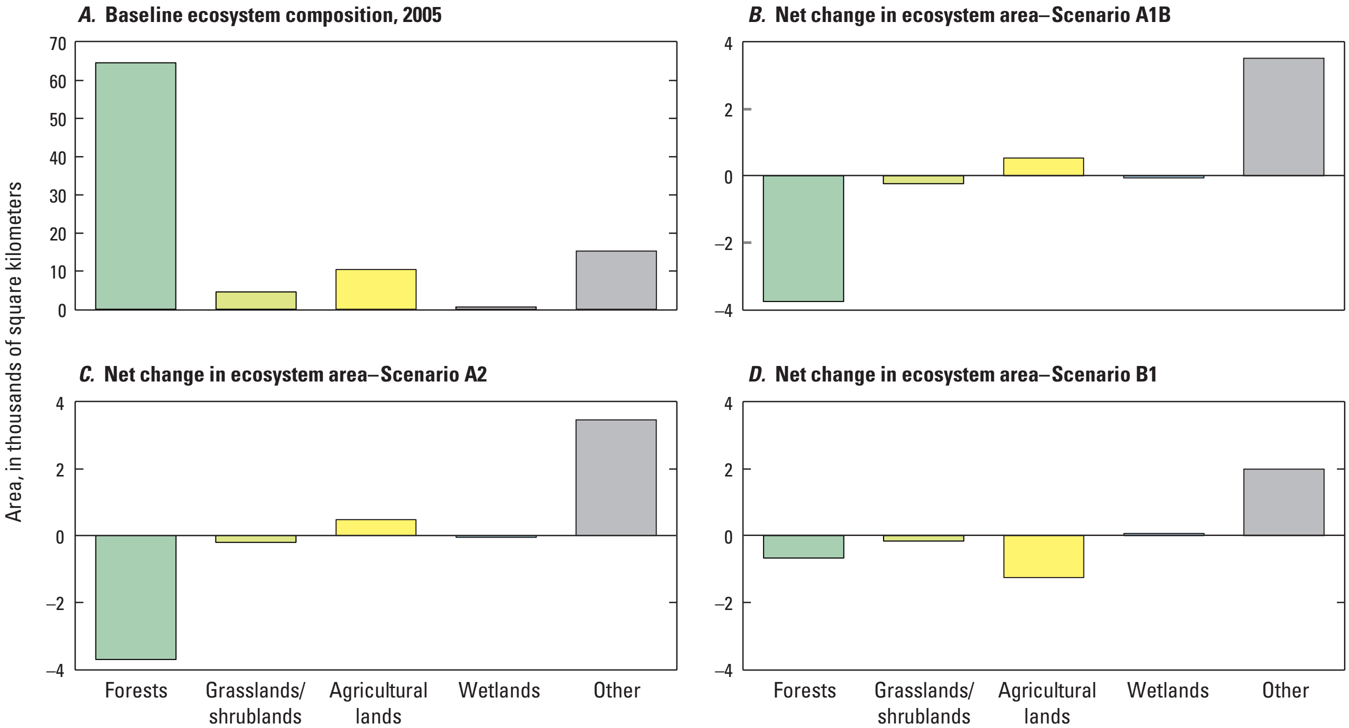

Figure 6.7. Charts showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Marine West Coast Forest ecoregion, for the final year of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The “other” ecosystem includes developed land, mined land, barren land, and water. The large projected net changes in the “other” class were primarily attributed to the projected increases in developed land.

New developed land was projected to expand by 3,450 km^2 to 8,160 km^2 by 2050, which was an increase of 77 percent over 2005 levels. More than 500 km^2 of natural land cover (forest, wetlands, and grasslands/shrublands) was projected to be converted to agricultural land. Agricultural land was projected to increase by 5 percent, from 10,400 km^2 in 2005 to 10,900 km^2 in 2050; cultivated cropland was projected to remain relatively stable at 2,500 km^2, whereas hay/pasture was projected to increase from 7,900 km^2 to 8,410 km^2. In the Willamette Valley, agricultural land was projected to remain relatively stable, whereas in the Coast Range ecoregion, a large resource base and low demand for urban land use was projected to result in both cultivated cropland and hay/pasture land increasing by 40 km^2 and 680 km^2, respectively. By 2050, natural land cover was projected to account for 74.9 percent of all land area, while anthropogenic LULC was projected to account for 25.1 percent.

The projected LULC change was lowest under the B1 scenario. Overall, the projected forest harvest levels were the lowest of the three scenarios with roughly 23,300 km^2 of forest cutting projected to occur between 2005 and 2050, which is 25 percent less than the area projected in scenario A1B. The strong environmental regulation of public land was projected to lead to a higher proportion of forest cutting occurring in privately owned forests compared to the A1B and A2 scenarios. By 2050, nearly 80 percent of all land in the Marine West Coast Forest was projected to be natural land cover (from 75.2 percent in 2005), the highest proportion of any scenario. Developed land use was projected to expand, albeit at a slower rate than in the economically oriented scenarios. Only 2,030 km^2 of new developed lands was projected to be added by 2050 (from 4,720 km^2 in 2005), with the majority of the land conversions coming from agricultural lands and hay/pasture lands. Agricultural land was projected to decline by 12 percent with projected losses of nearly 340 km^2 of cultivated crops and 900 km^2 of hay/pasture lands; nearly 60 percent of the projected loss in agricultural land was in the Willamette Valley ecoregion. Figure 6.8 shows a comparison between projections for the A1B, A2, and B1 scenarios.

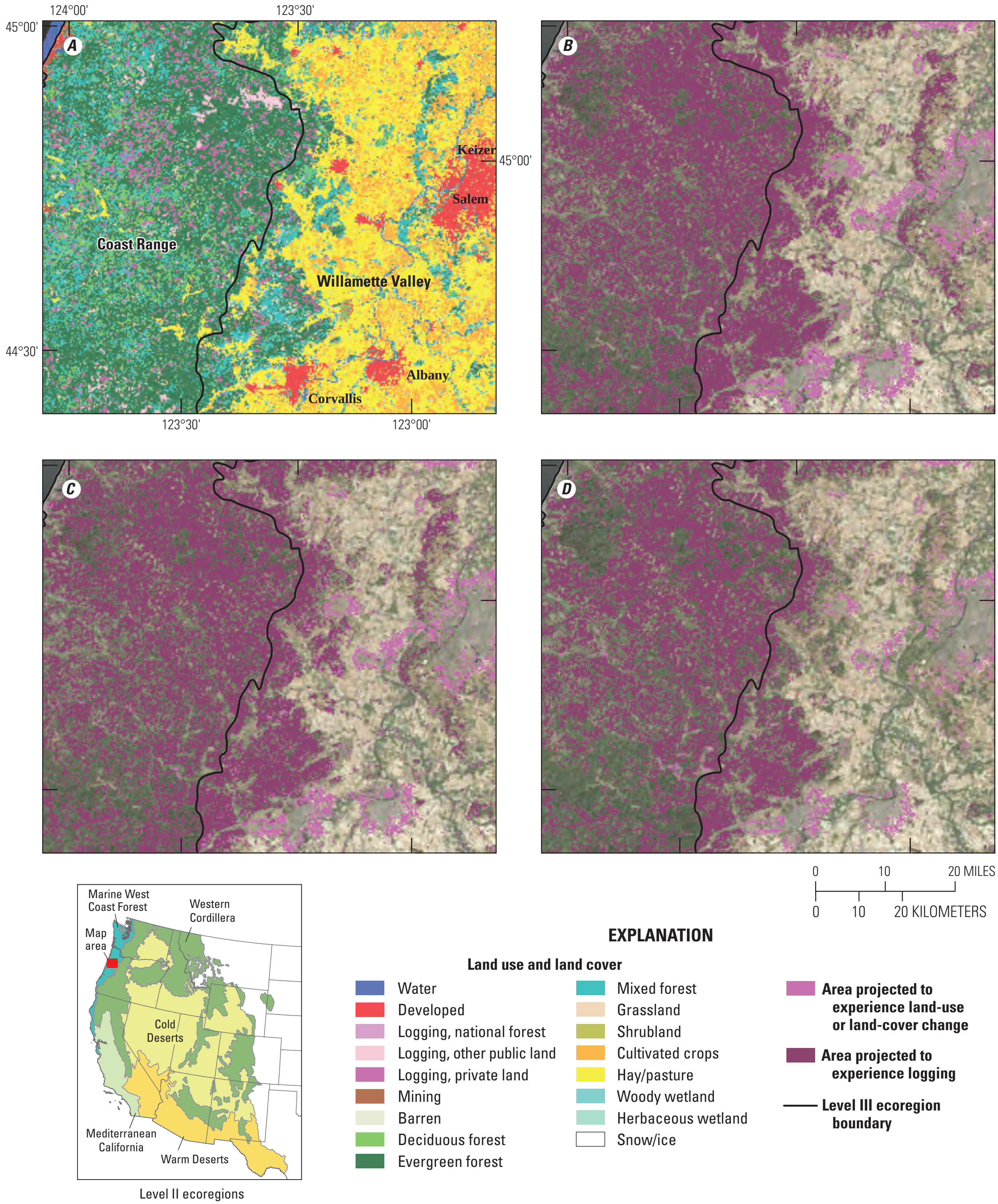

Figure 6.8. Maps showing land use and land cover (LULC) in 2005 and a comparison of projected LULC changes in the A1B, A2, and B1 scenarios in 2050 for an area near Salem, Oregon, in the Marine West Coast Forest ecoregion. Changes were projected to be the result of either land-use change or forest clearcutting. *A*, LULC in 2005. *B*, Projected LULC change in the A1B scenario. *C*, Projected LULC change in the A2 scenario. *D*, Projected LULC change in the B1 scenario.

6.3.2.3. Cold Deserts

The Cold Deserts level II ecoregion includes the following level III ecoregions: Columbia Plateau, Snake River Plain, Northern Basin and Range, Central Basin and Range, Wyoming Basin, Colorado Plateaus, and Arizona-New Mexico Plateau. The ecoregion is characterized by low rainfall and large temperature contrasts between winter and summer. This arid region has a variety of landforms, including a series of basins and mountain ranges, broad plateaus, and valleys. Rare perennial streams typically originate in the bordering mountainous ecoregions. The few small perennial streams that originate in the higher mountain ranges within the Cold Deserts commonly disappear before they reach the lower elevations, which contributes to the aridity. Natural landscapes dominate, with about three-fourths of the region covered by natural grasslands and shrublands. Agricultural land is the most common anthropogenic land use where irrigation is possible from groundwater or from the Snake or Columbia Rivers. Urbanization is sparse and dispersed because of the vast open space, limited access to water, and poor proximity to goods and services. Salt Lake City, Utah; and the Reno and Carson City, Nevada, corridor are the two most notable developed areas. Data from the USGS Land Cover Trends project indicated that only 3 percent of the Cold Deserts experienced a change in land use or land cover between 1973 and 2000 (Sleeter, Soulard, and others, 2012). Historically, the largest conversion was an increase of 6,000 km^2 in agricultural lands from grasslands/shrublands. Over 50 percent of this change occurred in the Columbia Plateau. In general, LULC change was geographically highly variable and ranged from 9.2 percent in the Columbia Plateau to 1.2 percent in the Arizona-New Mexico Plateau.

In the A1B scenario, the projected LULC change between 2005 and 2050 was characterized by agricultural expansion coupled with a moderate increase in developed lands (fig. 6.9).

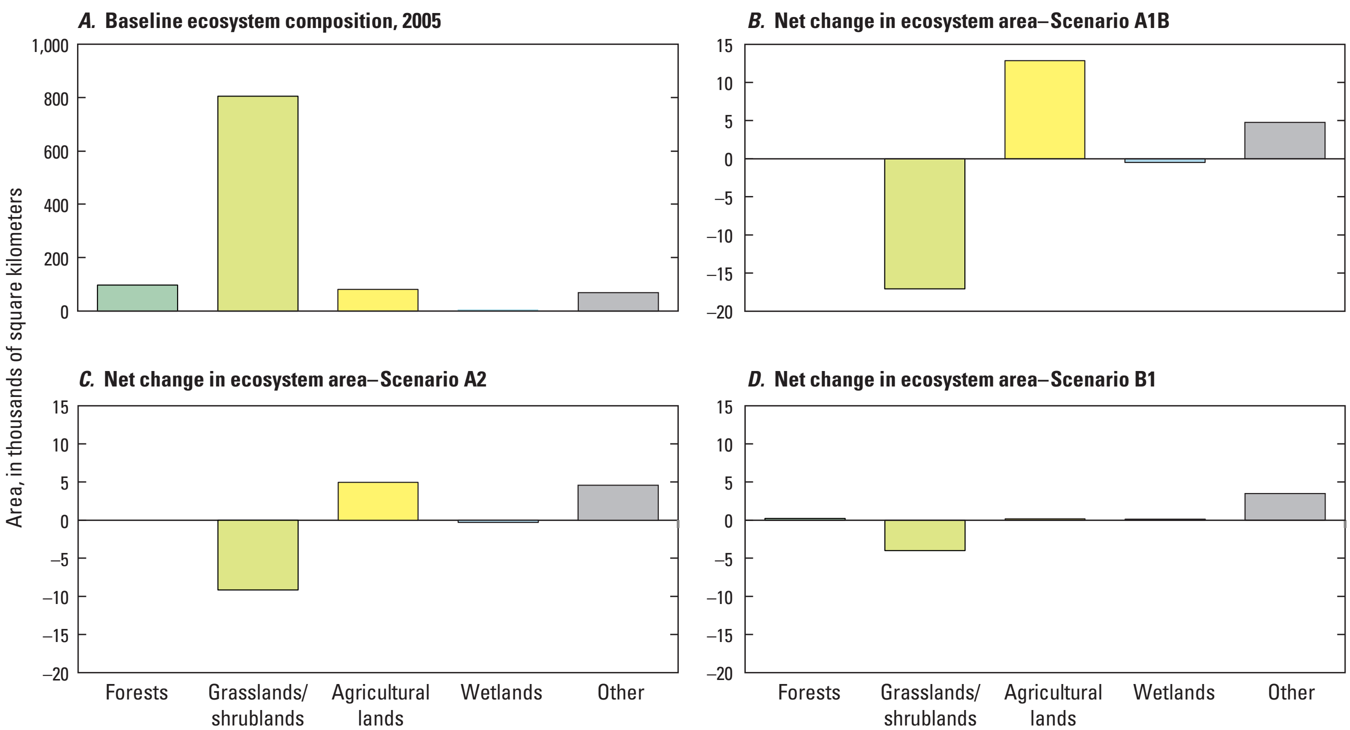

Figure 6.9. Charts showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Cold Deserts ecoregion for the final year of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The "other" ecosystem includes developed lands, mined lands, barren lands, and water. The large projected net changes in the "other" class were primarily attributed to projected increases in developed lands.

Agricultural lands were projected to increase by 16 percent, from 81,190 km^2 in 2005 to 94,040 km^2 in 2050. The most common projected conversion was from grasslands/shrublands to agricultural lands. Approximately 80 percent of this conversion was projected to occur in the Columbia Plateau and Snake River Plain. The increase in agricultural land was driven by the projected increase of cultivated cropland (11,400 km^2) and a small projected increase in hay/pasture land (1,450 km^2). Developed land was projected to expand by 4,440 km^2 (from 6,240 km^2 in 2005). About 50 percent of the new developed land was projected to be located in the Central Basin and Range, where the urban areas associated with Salt Lake City, Utah; and Reno, Nevada, are located. Collectively, the projected expansion of agricultural and developed lands contributed to over 17,100 km^2 in grassland/shrubland losses by 2050, a 2 percent decline from the baseline areal extent. Figure 6.10 shows a comparison of agricultural growth and grassland/shrubland loss between the three scenarios.

In the A2 scenario, the projected expansions of agricultural and new developed lands were common themes, although less pronounced than in the A1B scenario. Agricultural lands were projected to increase from 81,190 km^2 in 2005 to 86,160 km^2 in 2050, while grasslands/shrublands were projected to decrease by 9,160 km^2 (from 804,700 km^2 in 2005). A total of 6,690 km^2 of grasslands/shrublands was projected to be converted to cultivated cropland between 2005 and 2050, which accounted for the largest amount of LULC change in the A2 scenario for the projected time period; however, 2,800 km^2 of cultivated cropland and hay/pasture was projected to be converted to new developed lands, thus offsetting the projected increases in agricultural land. Developed lands were projected to expand by 4,370 km^2 (from 6,240 km^2 in 2005), which is a rate similar to that projected in the A1B scenario. Collectively, the expansion of agricultural and developed lands resulted in the projected decline of grasslands/shrublands by 1 percent, from 804,660 km^2 in 2005 to 795,500 km^2 in 2050.

The projected LULC change was smallest under the B1 scenario. Between 2005 and 2050, agricultural land was projected to increase by less than 1 percent, by only 190 km^2 (from 81,190 km^2 in 2005). Cultivated crops were projected to expand by 270 km^2 (from 51,870 km^2 in 2005), while hay/pasture land was projected to decline by 80 km^2 (from 29,330 km^2 in 2005). Developed land was projected to increase by 3,620 km^2 (from 6,240 km^2 in 2005), primarily in the Central Basin and Range (by 1,700 km^2) and the Columbia Plateau (by 600 km^2). The projected loss of grasslands/shrublands to anthropogenic land use totaled 3,980 km^2 by 2050 (from 804,660 km^2 in 2005). Wetlands were projected to remain relatively stable with a small increase of 110 km^2 (from 4,640 km^2 in 2005) because of the projected reduction in demand for agricultural and developed land in this scenario.

6.3.2.4. Warm Deserts

The Warm Deserts level II ecoregion includes four level III ecoregions: Mojave Basin and Range, Sonoran Basin and Range, Madrean Archipelago, and Chihuahuan Deserts. The ecoregion is characterized by the subtropical continental Mojave, Sonoran, and Chihuahuan Deserts and the Sky Islands (mountains surrounded by lowlands of a drastically different environment in the Madrean Archipelago ecoregion). The basin-and-range terrain has typically north-to-south-trending mountains separated by broad basins, and these valleys are bordered by sloping alluvial fans. The region is also characterized by extreme aridity and extremely high air and soil temperatures. Winter snow is rare. Compared to the Cold Deserts to the north, most of the annual precipitation in these deserts falls during the summer months, contributing to a diversity of plants and animals. Desert scrub consisting of creosote bush and white bursage is common in the Mojave Desert and western and central Sonoran Desert. In the eastern Sonoran Desert, the vegetation consists of various palo verde and cacti species, and mixed scrub. The higher Chihuahuan Desert to the east consists of some desert grassland and large areas of arid shrubland dominated by creosote bush. Oaks, juniper, and pinyon woodlands occur on the higher mountains. Large parts of the Warm Deserts are Federally owned.

Urbanization was the primary projected type of LULC change in the Warm Deserts. In the A1B scenario, developed land was projected to increase by 119 percent between 2005 and 2050 with a projected increase of 6,840 km^2 of new urban-industrial areas. Nearly all of the new developed land use was projected to be converted from the grasslands/shrublands ecosystems, which were projected to decline by 2 percent, from 403,390 km^2 in 2005 to 395,350 km^2 in 2050. The projected spatial pattern of urbanization was distributed heterogeneously across the landscape, with most expansion projected to occur adjacent to the Las Vegas, Nevada, Phoenix, Arizona, and Tucson, Arizona, metropolitan areas. Urban expansion was also projected to be common along the boundary of the Mojave Basin and Range and the Southern California Mountains near the Los Angeles, California, metropolitan area. Major environmental factors (limited moisture and high temperatures) potentially limit the expansion of agricultural lands throughout the Warm Deserts; however, small areas, generally near perennial streams, potentially could support the production of cultivated crops and hay/pasture land. These areas were projected to increase by 7 percent in the A1B scenario, from 11,340 km^2 in 2005 to 12,130 km^2 in 2050. Forests and wetlands remained relatively unchanged throughout the projection period.

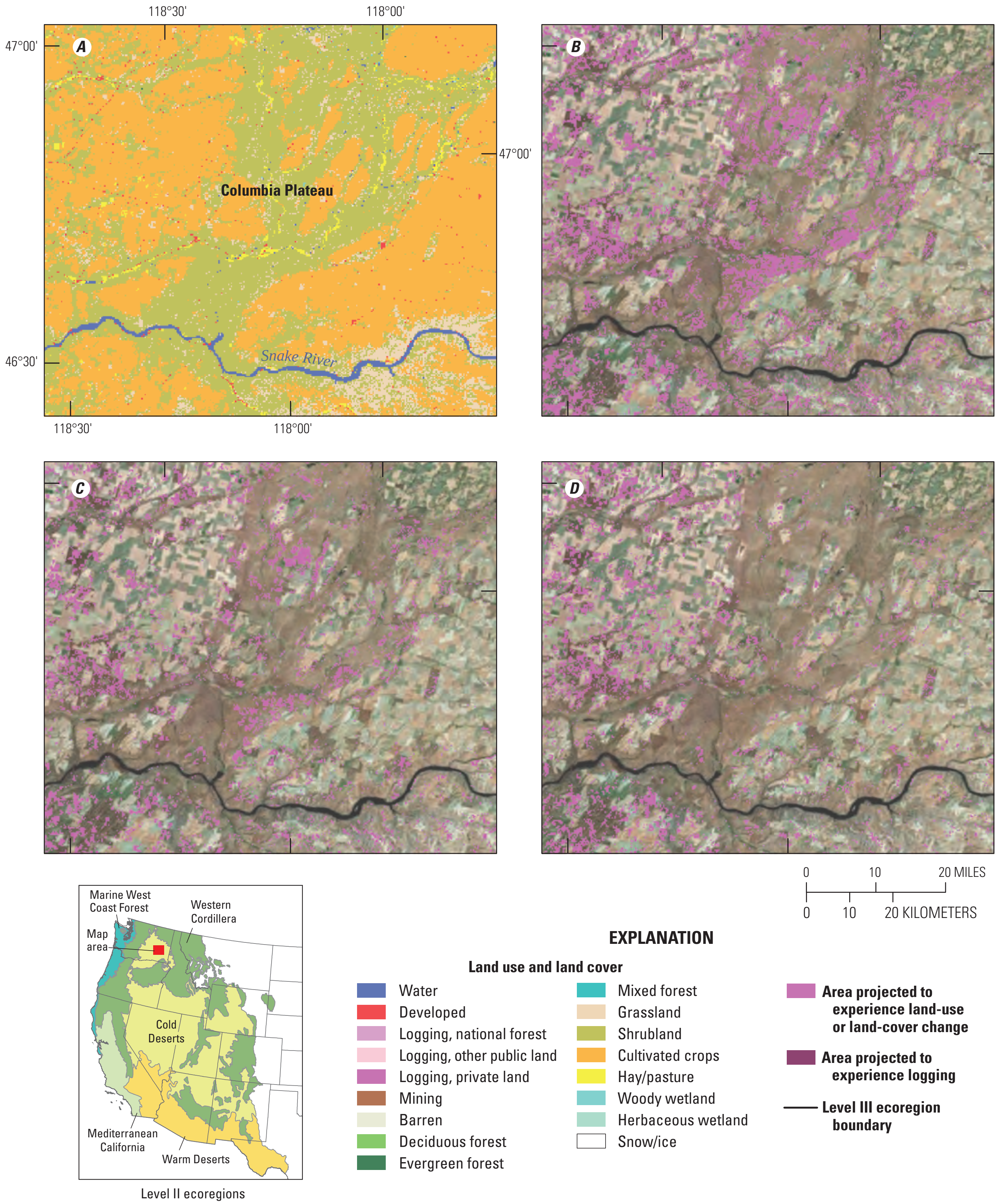

Figure 6.10. Maps showing land use and land cover (LULC) in 2005 and a comparison of the A1B, A2, and B1 scenarios in 2050 for an intensively agricultural area along the Snake River in Washington in the Cold Deserts ecoregion. Changes were projected to be the result of either land-use change or forest clearcutting. *A*, LULC in 2005. *B*, Projected LULC change in the A1B scenario. *C*, Projected LULC change in the A2 scenario. *D*, Projected LULC change in the B1 scenario.

The A2 scenario had the smallest projected increase in new developed land of all the scenarios. New urban areas were projected to increase 71 percent, from 5,750 km^2 in 2005 to 9,810 km^2 in 2050. The result is a projected 1 percent decline in grasslands/shrublands (a projected loss of 4,860 km^2). All of the other ecosystems remained relatively stable throughout the projection period (fig. 6.11). In the B1 scenario, developed land was projected to increase by 86 percent, rising to 10,710 km^2 by 2050. As in the economically oriented scenarios, the vast majority of the projected new developed land resulted from the projected conversion of grasslands/shrublands. Overall, grassland/shrublands were projected to decline by 5,340 km^2, a loss of 1 percent of their area from 2005. Forests, agricultural lands, and wetlands were projected to remain relatively stable (fig. 6.11). Figure 6.12 shows both the initial and the projected urbanization near Las Vegas, Nevada, in all three scenarios.

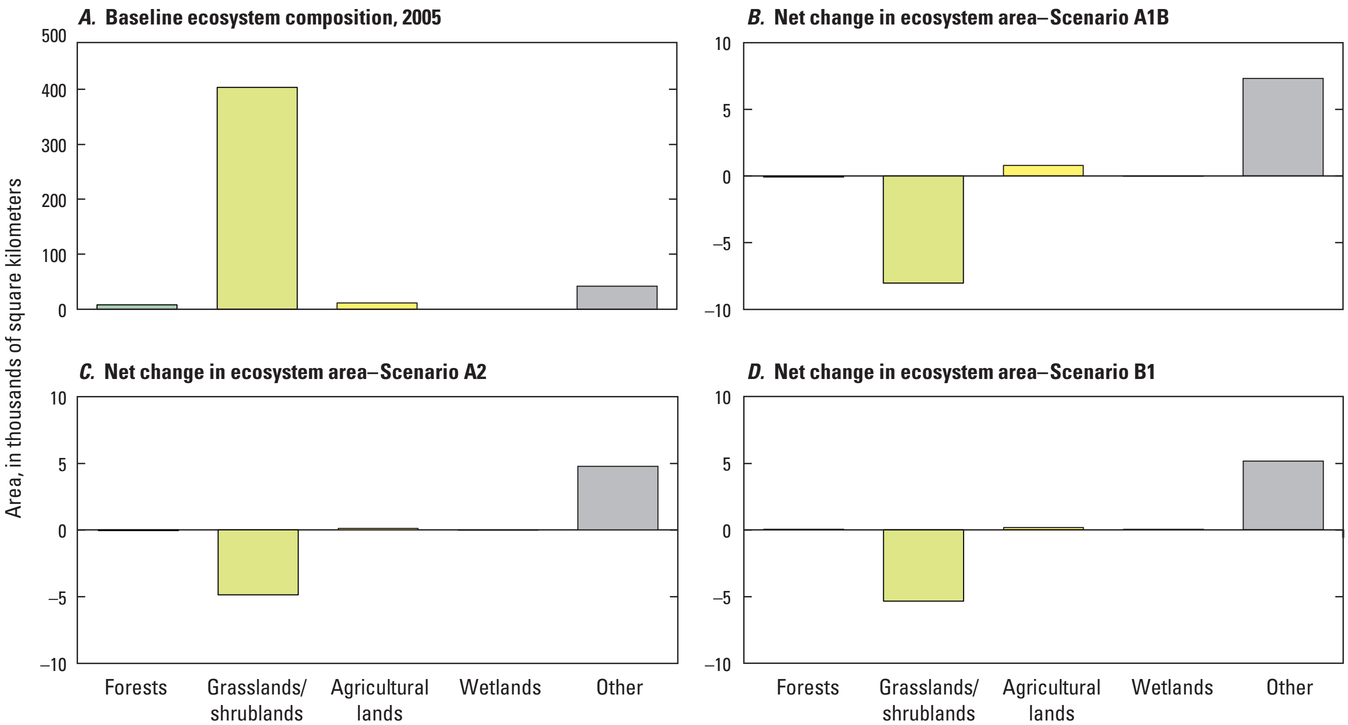

Figure 6.11. Charts showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Warm Deserts ecoregion for the final year of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The “other” ecosystem includes developed lands, mined lands, barren lands, and water. The large projected net changes in the “other” ecosystem were primarily attributed to projected increases in developed lands.

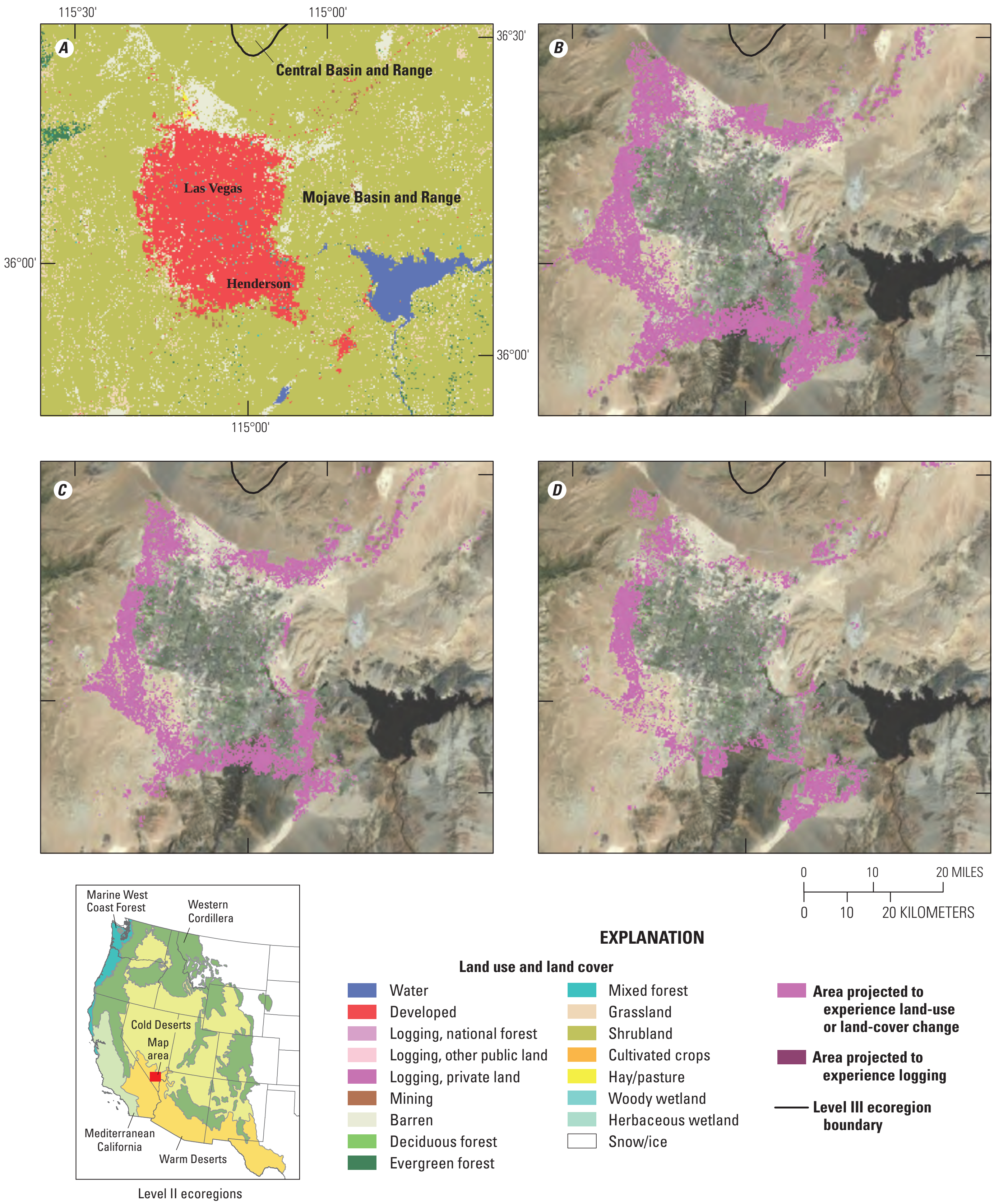

Figure 6.12. Maps showing land use and land cover (LULC) in 2005 and a comparison of the A1B, A2, and B1 scenarios in 2050 for the Las Vegas, Nevada, area in the Warm Deserts ecoregion. Changes were projected to be the result of either land-use change or forest clearcutting. *A*, LULC in 2005. *B*, Projected LULC change in the A1B scenario. *C*, Projected LULC change in the A2 scenario. *D*, Projected LULC change in the B1 scenario.

6.3.2.5. Mediterranean California

The Mediterranean California level II ecoregion includes three unique level III ecoregions in California: the Southern and Central California Chaparral and Oak Woodlands (referred to herein as "Oak Woodlands" for simplicity), the Central California Valley, and the Southern California Mountains. The ecoregion is distinguished by its warm, mild Mediterranean climate with alternating wet and dry seasons. There is great variability in annual precipitation, and extreme droughts are not uncommon. The shrubland vegetation of chaparral mixed with areas of grassland and oak savanna is prone to wildland fires. The ecoregion has several agriculturally productive valleys and contains a high population (over 30 million people) in extensive urban agglomerations. Low coastal mountain ranges and the Sierra Nevada foothills surround the broad San Joaquin and Sacramento Valleys. Higher mountain ranges are located in the southern part of the ecoregion, which includes large areas of Federally owned land. In the larger valleys, the hydrological and ecological systems have been greatly altered by widespread agriculture and some sprawling urban and suburban development. Recent historical LULC change has been characterized most visibly by rapid urbanization. The Oak Woodlands and the Central California Valley combined contain most of the population of California, which has seen a 37 percent increase in the State's developed landscape since 1973 (Sleeter and others, 2011). Demand for agricultural land has also been an important component of LULC change in the ecoregion despite remaining relatively stable in terms of total area. Agricultural land in some parts of the ecoregion expanded while others experienced losses (Sleeter and others, 2011).

Urban development was the primary type of projected LULC change in the ecoregion in all three of the scenarios. In the A1B scenario, developed land was projected to increase 89 percent, from 13,160 km^2 in 2005 to 24,820 km^2 in 2050. New developed land was projected to increase primarily in the Oak Woodlands (7,650 km^2) and the Central California Valley (3,040 km^2). The low-lying valleys of the Oak Woodlands and periphery of large urban areas in the Central California Valley were projected to be the main locations for urban expansion. Grasslands/shrublands were projected to experience the largest change of any LULC class, declining 17 percent between 2005 and 2050 (from a baseline of 74,300 km^2) while forests and wetlands were projected to remain relatively stable (fig. 6.13). Agricultural lands were projected to increase by 1,320 km^2 by 2050 (from 41,050 km^2 in 2005); however, projected changes involving agricultural lands affected a much greater area than is reflected in the net change projections alone. For example, 4,750 km^2 of agricultural land was projected to be converted to developed land, whereas only 870 km^2 of agricultural land was projected to be converted to grasslands/shrublands. Conversely, the projected increased demand for new agricultural land resulted in a projected 6,700 km^2 of grassland/shrubland converting into new cultivated croplands or hay/pasture lands.

In the A2 scenario, developed land was projected to increase by 62 percent, from 13,160 km^2 in 2005 to 21,380 km^2 in 2050. The location of new developed land was projected to be generally in the same areas as in the A1B scenario, with the vast majority in the Oak Woodlands (62 percent) and Central California Valley (33 percent). New developed land was projected to increase by approximately 450 km^2 in the Southern California Mountains. The high demand for new developed land was projected to result in a 2 percent decline in agricultural lands (from 41,050 km^2 in 2005 to 40,060 km^2 in 2050) and an 8 percent decline in grasslands/shrublands (from 74,300 km^2 in 2005 to 67,390 km^2 in 2050) (fig. 6.13). By 2050, 3,870 km^2 of grasslands/shrublands and 4,200 km^2 of agricultural land was projected to be converted to new developed land; however, like the A1B scenario, the projected net change masked overall projected rates of LULC change; 3,600 km^2 of grasslands/shrublands were projected to be converted into agricultural land, whereas 530 km^2 of agriculture was projected to be converted into grasslands/shrublands. Forests and wetlands remained relatively stable (fig. 6.13).

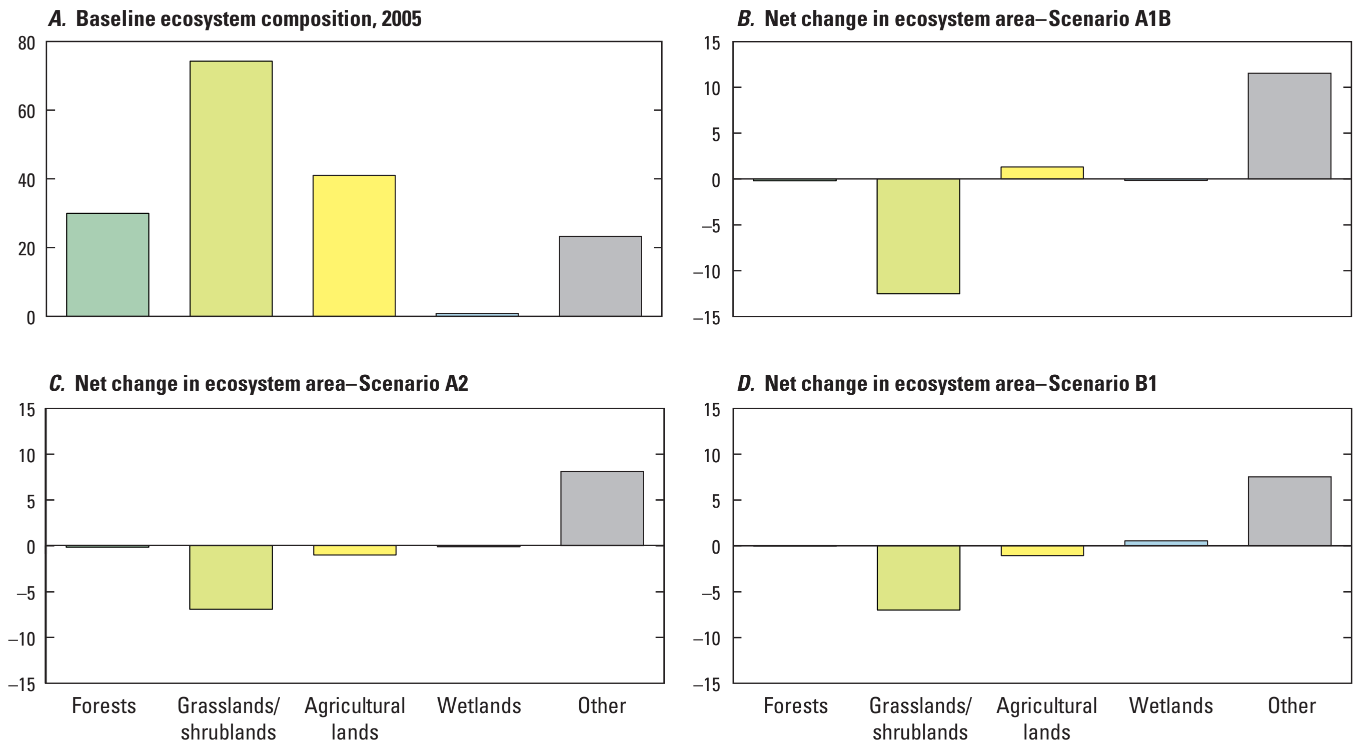

Figure 6.13. Charts showing the baseline composition of and projected net change in major ecosystems between 2005 and 2050 in the Mediterranean California ecoregion for the final year of the baseline period and for each scenario. *A*, The percent of land area assigned to each of the major ecosystems at the end of the baseline period (2005). *B*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A1B. *C*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario A2. *D*, The projected net land-use- and land-cover-change, in percent, between 2005 and 2050 for scenario B1. Forests that had been harvested (logged) were included within the forest ecosystem totals. The "other" ecosystem includes developed lands, mining lands, barren lands, and water. The large projected net changes in the "other" ecosystem were primarily attributed to projected increases in developed lands.

Despite dramatically different storylines, by 2050 the B1 scenario was projected to follow trends in LULC change that were similar to those in the A2 scenario. Developed land was projected to increase by 57 percent (7,500 km^2), with most of the expansion projected to occur in the Oak Woodlands and Central California Valley. Nearly 4,940 km^2 of grasslands/shrublands were projected to be converted to developed lands, whereas 2,500 km^2 of agricultural land was projected to be converted to developed land. By 2050, agricultural land was projected to decline by 3 percent, from 41,050 km^2 to 39,980 km^2. Also similar to the A2 scenario was the projected 9 percent decline in grasslands/shrublands needed to meet the projected demand for new developed land and agricultural land. Forests remained relatively unchanged at approximately 29,950 km^2. The greatest divergence from the economically oriented scenarios was the projected trend in wetlands. The strengthening of environmental protection in the B1 scenario resulted in a projected increase in wetlands of 62 percent, from approximately 910 km^2 to 1,470 km^2. Figure 6.14 shows both the initial LULC and the projected modeling results for each scenario for an area near Sacramento, California, in the Central California Valley.

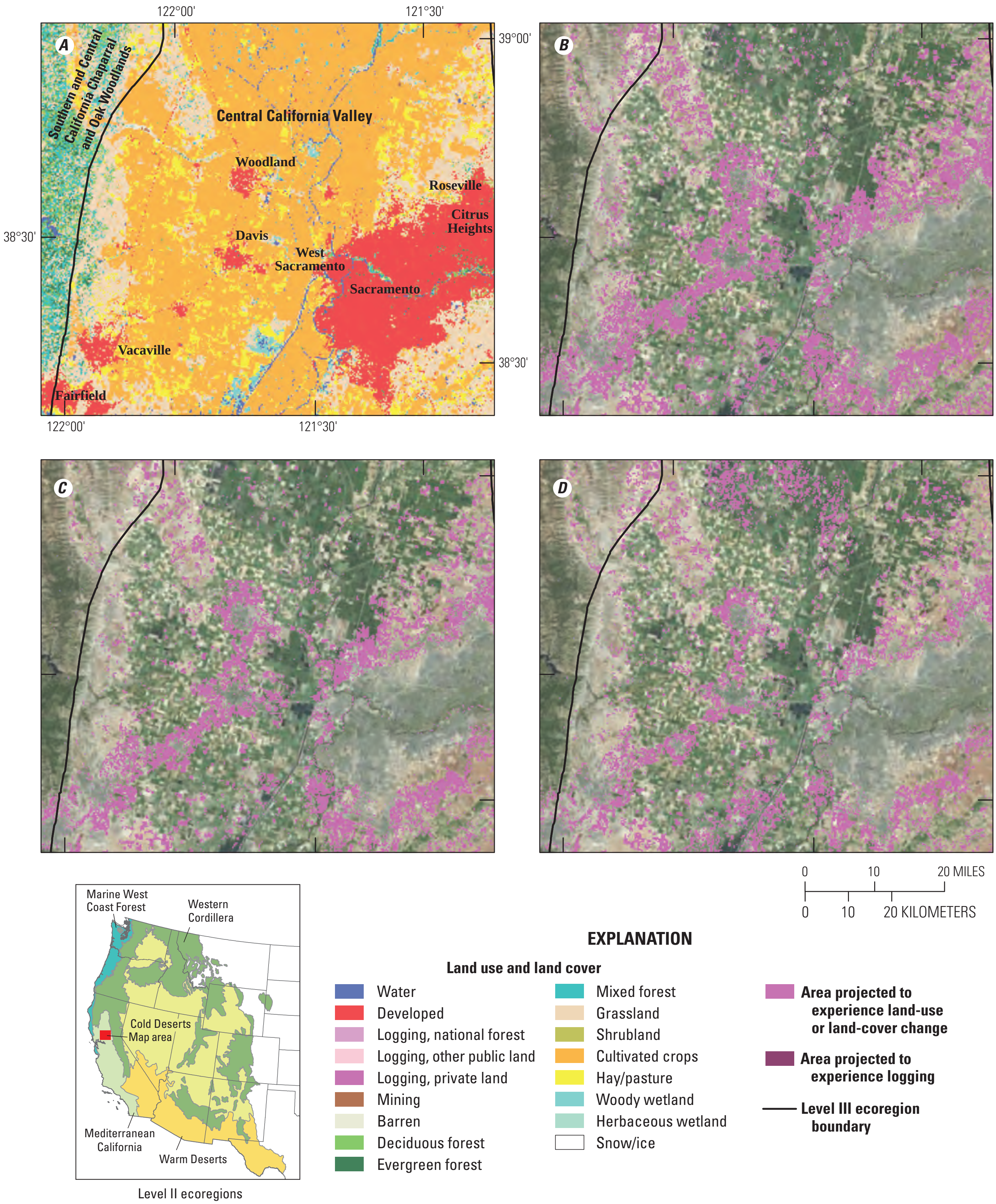

Figure 6.14. Maps showing land use and land cover (LULC) in 2005 and a comparison of the A1B, A2, and B1 scenarios in 2050 for an area near Sacramento, California, in the Mediterranean California ecoregion. *A*, LULC in 2005. *B*, Projected LULC change in the A1B scenario. *C*, Projected LULC change in the A2 scenario. *D*, Projected LULC change in the B1 scenario. Changes were projected to be the result of either land-use change or forest clearcutting.

6.4. Validation and Uncertainty

A formal validation of the projected LULC changes is impossible because there is no reference data for a future time frame. Chapter 2 provides a summary of validation concerns for the LULC modeling they applied to the baseline period; however, the same quantity and allocation disagreement measures discussed in chapter 2 can be used to examine issues of uncertainty in the projected period of 2006 to 2050, and more specifically, to examine the sources of the differences between modeled scenarios (Pontius and Millones, 2012; Sohl, Sleeter, Zhu, and others, 2012). In this context, a quantity disagreement measure can be used to examine the differences in projected LULC proportions between scenarios, and an allocation disagreement measure can be used to examine differences in how the projected LULC changes are spatially allocated between scenarios.

In this assessment, the proportions of the projected LULC change in the scenarios themselves were used to frame overall uncertainties regarding future LULC proportions. Given that the FORE–SCE model can duplicate scenario-prescribed LULC proportions, there were no uncertainty issues related to the ability to accurately map the quantity of LULC change. Quantity disagreement was thus used to examine differences in the prescribed proportions of LULC change from the scenarios themselves. The spatial modeling component of the FORE–SCE model introduced allocation disagreement between scenarios in that the spatial pattern of change differed between scenarios even if the prescribed scenario LULC proportions were similar. An application of quantity and allocation disagreement measures to each scenario pair allowed for a determination of whether the differences between scenarios were because of the scenario LULC prescriptions themselves or were a result of the spatial modeling and the placement of LULC change.

The proportion of quantity disagreement and allocation disagreement varied by scenario pair (fig. 6.15). Total disagreement was lowest between the A2-B1 scenario pair, and higher but similar for the A1B-A2 and A1B-B1 pairs. Despite that similarity, quantity disagreement made up a much higher percentage of the total disagreement in the A1B-B1 scenario pair. In all of the scenario pairs, allocation disagreement made up a significantly higher proportion of the total disagreement than did quantity disagreement, which indicated that on a per-pixel basis, the differences between the spatially explicit scenarios were due more to the FORE–SCE spatial allocation model than to quantitative differences in the prescribed amounts of LULC change from the scenarios. These differences were expected, given the relatively low amount of LULC change projected to occur in the Western United States; however, the scenario-specific parameterization of the FORE–SCE model was a contributing factor. For example, assumptions were made that urban development will be more compact in the B1 scenario than in the two other scenarios, and the FORE–SCE model was parameterized accordingly for the individual scenarios. The parameterization of the spatial model thus affected the spatial allocation of change, and, as a result, the proportion of disagreement due to allocation. It is impossible to determine how much of the allocation disagreement is due to the random nature of the placement of LULC change versus the difference in model parameterization between scenarios. Overall, it is clear that the A1B and B1 scenarios were most dissimilar when accounting for the quantified scenarios, as that scenario pair exhibited the highest overall quantity disagreement.

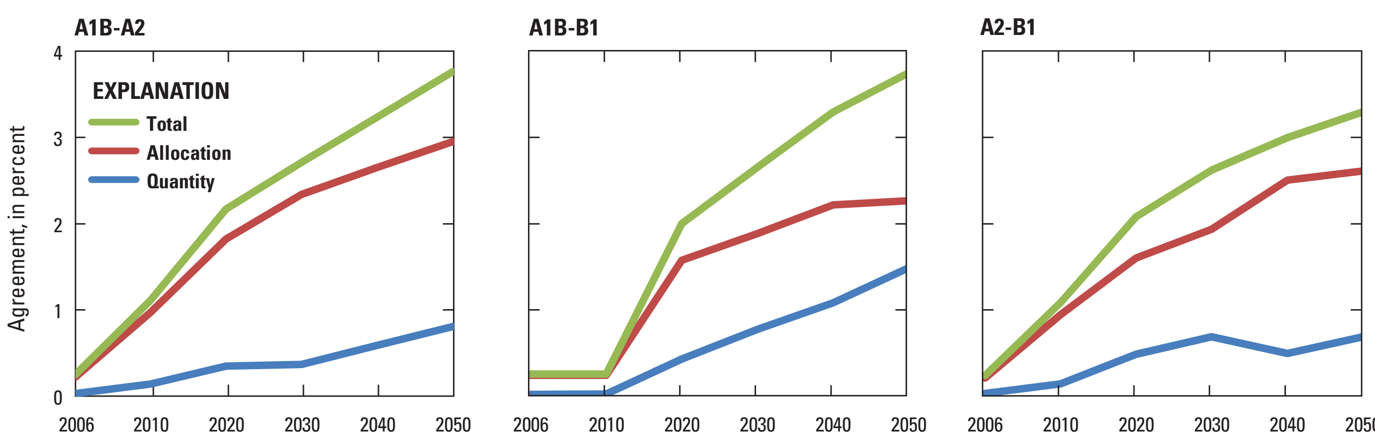

Figure 6.15. Graphs showing the quantity and allocation disagreement by scenario pair from 2006 to 2050. The total disagreement between scenario pairs is similar for A1B-A2, and A1B-B1 and smaller for A2-B1. Allocation disagreement makes up a higher proportion of total disagreement than does quantity disagreement for all scenario comparisons.