
Appendix V

Climate Change and Urbanization in California: Potential Effects on the Extent and Distribution of Major Vegetation Community Types

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Summary

This study integrates information on current distributions of major vegetation community types in California with projections of climate change and future urbanization patterns. The goal of this analysis was to identify how the future distribution and spatial extent of these community types might be altered. The main results of our work follow.

- ▶ We estimate that climate change will substantially change the distribution and spatial extent of many community types in California. We project that the extent of many community types will be reduced (e.g., alpine tundra, boreal conifer forest, C3 grassland, and subtropical shrub desert), and that the extent of others (e.g., C4 grassland and warm temperate mixed forest) will increase.
- ▶ Urbanization in California is estimated to increase as a result of population growth. This would reduce the spatial extent of community types as undeveloped areas become developed (although some development will take place on lands that are currently used for agriculture). We project that urbanization will most affect Mediterranean shrubland (e.g., southern coastal scrub), temperate mixed xeromorphic woodlands (e.g., oak and juniper woodlands), and maritime temperate forests (e.g., redwoods).
- ▶ Climate change would have a much larger impact on the extent of the major vegetation community types studied (e.g., Mediterranean shrubland and C3 grassland) than would urbanization.
- ▶ In a landscape context, habitat heterogeneity in California may be reduced if climate change results in lowered soil moisture (from a combination of higher temperatures and no change in precipitation) or substantially higher temperatures (i.e., approximately 5°C). We expect that diversity will increase slightly if climate change results in wetter conditions with smaller increases in temperature (i.e., 3°C or less).
- ▶ Coastal sage scrub (CSS) is particularly threatened by future urbanization, with more than a 20% loss of existing habitat expected by 2100. Furthermore, climate change could result in three times greater loss of coastal sage habitat.
- ▶ Potential refugia for CSS have been preliminarily identified. These, and areas where urbanization — but not climate change — threatens CSS, could be the focus of future conservation efforts.

- ▶ Some results of this study should be treated with caution. In particular, there is substantial uncertainty about exactly where, if anywhere, CSS would survive climate change. In addition, there are many uncertainties about future development patterns. Conducting more detailed and site-specific analyses on CSS and development in the areas identified in this study as those where CSS would survive (but could be threatened by development) would reduce uncertainty.

1. Introduction

Largely because of its great variability in elevation, topography, soils, and climate, California is perhaps the most ecologically diverse area in North America (Schoenherr, 1992; Field et al., 1999; Wilkinson, 2002). Major vegetation communities range from alpine tundra meadows at the highest elevations, to temperate rain forests and intertidal wetlands along the coast, to grasslands in the interior, to arid deserts in the south and east. This habitat diversity in turn supports many plants and animal species, including more than 5,000 native plants and almost 1,000 vertebrates (Wilkinson, 2002). California also supports high rates of endemism (approximately 48% of its species are endemic to the state), large numbers of rare species, and species with restricted distributions (Schoenherr, 1992).

Unfortunately, many of California's unique or rare ecological resources are already under considerable anthropogenic stress. Since the European colonization, human activities, particularly agriculture and urbanization, have resulted in widespread and severe habitat loss; for example, approximately 86% of the wetlands in the Central Valley have been destroyed since the 1850s (Frayer et al., 1989). With continued human population growth, the potential for further loss and modification of the remaining natural habitats is significant. Another important and growing anthropogenic stressor is the intentional or unintentional introduction of exotic species, which has consequences of displacing competitors and disrupting ecosystem processes. Approximately 20% of the state's current flora are introduced species, and some particularly successful exotics dominate large and previously diverse areas; yellow star thistle (*Centaurea solstitialis*), for example, now infests more than 10 million acres (4 million hectares). Many of these stressors continue to increase in intensity and range, posing difficulties for conserving the remaining resources.

The advent of global climate change has introduced yet another stressor into this already deteriorating situation. Acting through the changes that it may cause to vegetation communities, climate change has the potential to be a substantial new disruptor of California's ecological landscape (Lenihan et al., Appendix IV).

Identifying adaptation measures to address this new situation will require that we understand how climate change might affect the spatial extent and distribution of the state's major ecosystems and vegetation communities. Studies of the possible effects of climate change on vegetation communities are an essential first step toward this goal (e.g., Bachelet et al., 2001). However, predictive studies of areas that have been highly modified by human activities without considering these other stressors do not paint a realistic picture of how future ecological landscapes may be changed. Climate change does not happen in a vacuum, but may be just one more stressor exerting its effects on an ecological landscape that is already challenged and altered by many other important stressors. In California, urbanization, agriculture, habitat destruction, introduction of exotic species, contaminants, and overexploitation of ecological resources have all been major forcing factors that produced the current landscape, and many of these continue to exert changes (particularly urbanization, agriculture, and the introduction of exotic species). The effects of climate change may be separate from those of the existing stressors, or they may exacerbate or sometimes mitigate them. For example, Galbraith et al. (2002) showed that future losses of coastal wetlands in southern San Francisco Bay because of sea level rises resulting from climate change may be magnified by water extractions from the underground aquifer, causing the land surface to subside. In this case, focusing on climate change alone leads to seriously underestimating potential future rates of habitat loss. Thus, when predicting the future effects of climate change on ecological resources in California, it is important to take an approach in which the intersecting effects of all the important stressors are integrated.

Table 1 summarizes the potential vegetation changes projected by Lenihan et al. (Appendix IV). Although the results vary depending on the climate change scenario employed, marked consistencies can be seen in some of the projections. For example, all scenarios result in a major reduction in the area of Mediterranean shrubland (chaparral), C3 grasslands, conifer savanna, tundra, and boreal conifer forest. Less marked, but still fairly consistent, reductions are projected for arid shrubland, mixed xeromorphic woodland, and continental temperate conifer forest. All scenarios result in major projected increases in the spatial extent of C4 grassland and warm temperate mixed forest.

Table 2 displays the population scenarios used in this assessment (Mendelsohn and Smith, Appendix II). California's current population of 33 million is estimated to grow by at least a factor of 2, and possibly 3, by 2100.

Urbanization modeling (Table 3) projects major increases in urbanized land in the state by 2020 and 2060 (25% and 69% increases, respectively), and at least a doubling in this area by 2100 under the high population-growth scenario. Figure 1 displays the projected distributions of urban areas in California under the different scenarios (Landis and Reilly, Appendix III).

Table 1. Summary of projected percent changes in the spatial extent of potential vegetation communities by 2100 under various climate change scenarios (Lenihan et al., Appendix IV)

Community type	Climate change scenarios ^a					
	HadCM2	PCM	T3P0	T3P18	T5P0	T5P30
Tundra	-60.7	-42.9	-42.9	-42.9	-82.1	-82.1
Boreal conifer forest	-48.3	-37.9	-51.7	-51.7	-48.3	-48.3
Maritime conifer forest	+115.8	-8.3	-15.8	-0.8	-20.3	-2.3
Continental temperate conifer forest	+1.9	-33.3	-5.6	-1.9	-33.3	-31.5
Warm temperate mixed forest	+236.5	+14.9	+41.9	+82.4	+75.7	+143.2
Mixed xeromorphic woodland	+2.5	-47.1	-20.7	-15.7	-29.8	-9.9
Conifer savanna	-73.3	-73.3	-86.7	-93.3	-80.0	-93.3
C3 grassland	-84.4	+0.6	-27.8	-38.6	-69.9	-79.7
C4 grassland	+510.9	+236.6	+284.2	+295.0	+426.7	+466.3
Mediterranean shrubland	-59.4	-54.3	-35.5	-33.3	-35.0	-30.3
Temperate arid shrubland	-84.6	15.4	-61.5	-53.8	-69.2	-76.9
Subtropical arid shrubland	-51.4	-1.8	-7.2	-13.0	-6.5	-23.4

a. Table 4 provides temperature and precipitation changes estimated by these scenarios.

Table 2. Population scenarios for California (millions of people; Mendelsohn and Smith, Appendix II)

	2020	2060	2100
Low estimate	45	67	67
High estimate	45	67	92

Table 3. Summary of projected changes in California in population (millions of people) and area of urbanized land (thousands of acres) up to 2100 (Landis and Reilly, Appendix III)

	Current	2020	2060	2100
Population	33	45	67	92
			(also 2100 low estimate)	(2100 high estimate)
Urbanized land (percent change since 1998)	3,611	4,532 (+25%)	6,117 (+69%)	7,863 (+117)

A doubling in the area of urbanized land in the state (already a major landscape feature) will have important implications for the actual expression of the potential vegetation changes projected by the Lenihan et al. (Appendix IV) study.

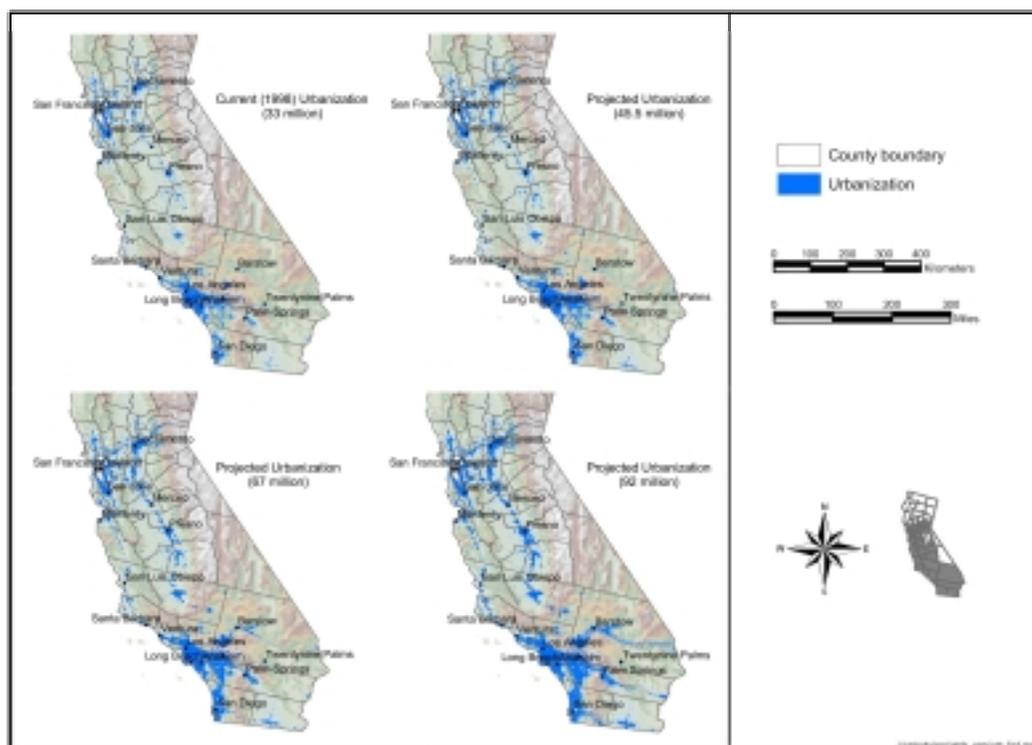


Figure 1. Estimated distribution of urban areas under 33 million (1998), 45.5 million, 67 million, and 92 million scenarios

An integrated approach is vital if we hope to develop meaningful results that can be used in, for example, conservation planning and land management. As far as we know, this study is the first attempt that has been made to forge this new analytical method. In this study we use the climate change scenarios described elsewhere in this volume, along with potential vegetation change (Lenihan et al., Appendix IV), and urbanization levels (Landis and Reilly, Appendix II) to evaluate the potential overall effects on the status and distribution of California’s major vegetation communities. Our overall objectives are

- ▶ To integrate the potential effects of these major stressors into a more comprehensive appraisal of how the current ecological landscapes may change between now and 2100.
- ▶ To evaluate the relative contributions of urbanization and climate change to the estimated ecological effects, and to determine the proportional impacts of urbanization and climate change on the distributions of the community types, how their interaction will change over time, and how it will vary among ecosystems and under different climate change scenarios.

- ▶ To use the results of these analyses to explore the utility of this approach in potential adaptation planning. This can be done by estimating where particularly valued vegetation communities may survive, but be threatened by urbanization, and could suggest areas for conservation.
- ▶ To identify what further work is needed to refine this approach, so that the ecological impacts of climate change can be evaluated.

2. Methods

Our overall approach in this analysis was to combine estimations of changes in the spatial extent and distribution of potential vegetation community types under future climate change scenarios (Lenihan et al., Appendix IV) with spatial projections of future urban development patterns (Landis and Reilly, Appendix III) on a geographic information system (GIS) platform (Figure 2). Both studies estimate changes until 2100. We then analyzed the combined data sets to identify and quantify future vegetation community changes that could result from climate change, urbanization, or the interaction of both. For finer resolution analyses of one community type, CSS, we combined data from the California Gap analysis project (Davis et al., 1998) with the urbanization and potential vegetation projections. Figure 2 charts our approach to this analysis.

The study area considered was not the entire state of California, but a more limited area extending from the Central Valley south to the border with Mexico (Figure 3). This was the area for which urbanization projections were available (Landis and Reilly, Appendix III). The area includes counties that are currently heavily urbanized. It is possible that more northern California counties would experience such widespread urbanization as well, particularly under high population-growth scenarios.

The climate scenarios used in this analysis, which were the same as those used in the potential vegetation analysis (Lenihan et al., Appendix IV), are summarized in Table 4. The last four scenarios assume uniform spatial and monthly change in climate; the numbers in the scenarios label denote the increase in temperature “Tx” and precipitation “Py.”

The Hadley scenario (HadCM2) results in much wetter conditions and the PCM scenario results in drier conditions across most of the state (see Miller et al., Appendix VIII). The T3P0 and T5P0 scenarios would result in drier soil moisture conditions over the baseline climate because evapotranspiration would increase with higher temperatures, but precipitation would not. The other scenarios would result either in little change in soil moisture or in an increase with increasing temperatures.

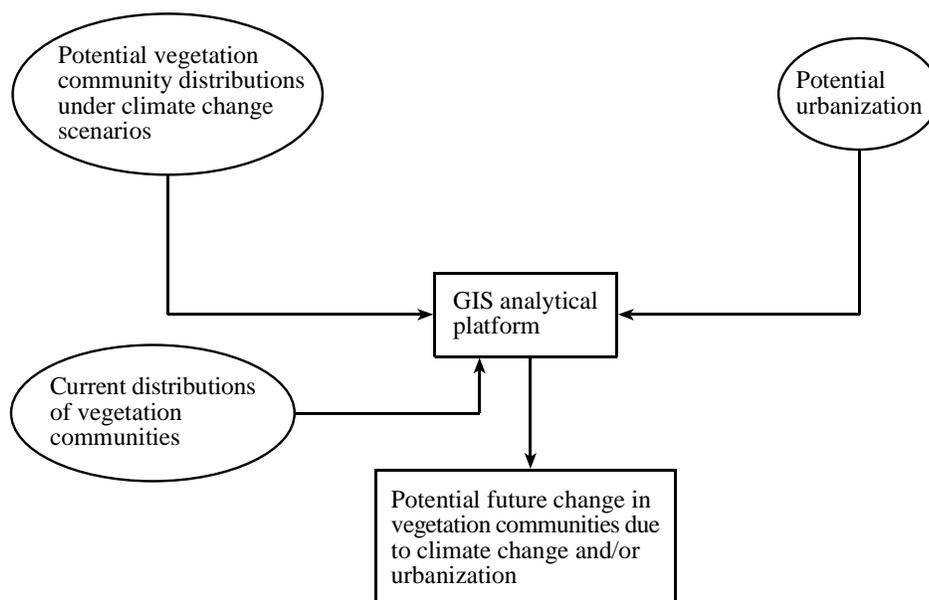


Figure 2. Methodological approach

Once combined on the GIS platform, the urbanization results were overlaid on the potential vegetation results (Lenihan et al., Appendix IV) and used as a “mask” to not include projected potential vegetation changes that would not occur because of current or future urbanization. The current distribution of agricultural lands was also included in this mask. No projections of change in agricultural land were available in time for this analysis. However, it is most likely that the spatial extent of agricultural land in California will be stable or contract slightly in the next few decades (California Water Plan [CWP], 1998; Wilkinson, 2002). Consequently, using the current distribution of agriculture as a “future mask” is unlikely to seriously affect the future projections of vegetation community shifts.

Scale mismatches were noted between the two data sets (Landis and Reilly and Lenihan et al.). Landis and Reilly estimated urbanization at a 1 ha scale and Lenihan and colleagues estimated vegetation distribution at a 100 km² (10 km grid cell size) scale. To make the data sets compatible, the urbanization projections were scaled up to 100 km² by assuming that grids that are 50% or more urbanized are urban and those less than 50% urbanized are natural or seminatural vegetation communities. The GAP data have a spatial resolution of 1 ha and were therefore directly compatible with the urbanization projections. Note that the decision to call cells that are 50.1% urbanized “completely urban” is arbitrary. The degree to which any level of urbanization will be disruptive to ecosystems varies considerably. Some may be healthy in spite of higher levels of urbanization, but the health of others may be disrupted at much lower levels of urbanization.



Figure 3. Study area (shaded counties)

Table 4. Climate change scenarios used in vegetation analysis (Lenihan et al., Appendix IV)

	HadCM2	PCM	T3P0	T3P18	T5P0	T5P30
Δtemperature (°C)	+1.5 – +4	<+1 – +2.5	+3	+3	+5	+5
Δ%precipitation	+20 – +100	-43 – -6%	0	+18%	0	+30%

Uncertainties

Estimating the behavior of complex systems long into the future under changes in driving forces — such as climate and population growth — is fraught with uncertainty. For example, we cannot be sure how California’s climate will change as a result of increased greenhouse gas concentrations (we tried to capture this uncertainty by using a wide range of regional climate change scenarios) and how vegetation will be affected. In addition, we cannot predict future socioeconomic conditions in California, including population levels, employment trends, and housing patterns. We used different climate models and scenarios, but only one vegetation and urbanization model in this study. Different models with different assumptions might have yielded different results. For these reasons, the results should not be taken as accurate or precise predictions, but as plausible outcomes.

One of the uncertainties in the vegetation model used in this analysis, MC1, is that it estimates where vegetation should be present, based on which vegetation community type is best correlated with estimated climate in a particular grid box. The model does not estimate migration or factors that impede it. This adds uncertainty to estimates of change in the location of vegetation communities. However, given the heterogeneity of ecosystems in California, species will not have to migrate very far, which increases the likelihood that vegetation types will migrate to the new locations estimated by the model. Another uncertainty is that the model does not estimate shifts among individual species. Even though the model may estimate the shift from one vegetative type to another within a grid cell, it does not estimate the composition of the changed vegetation. We can presume that at least some species in a vegetative community will be in grid boxes estimated to be dominated by that community type. We do not know if most or all species will be present. We examine CSS below, but keep in mind that the vegetation model estimated location of a class of vegetation that includes CSS, but not solely CSS (see Lenihan et al., Appendix IV, for more discussion of the model and results).

One of the key uncertainties in the projection of urbanization changes is that we use only one development scenario. Landis and Reilly (Appendix III) estimated development under different scenarios, but we used only the baseline scenario. This assumes that current patterns continue through the end of the 21st century. Indeed the patterns are based on the examination of 10 recent years of data. Housing preferences, laws, and other factors that affect development could change over the century, in turn affecting the extent of land cover. With the population scenarios used in this study, new employment centers will arise. But it is difficult to know *where*

these centers will spring up, so Landis and Reilly used their best judgment. However, it is most likely that development will proceed out from currently heavily developed areas, and in particular into the low-lying, near-urban areas in southern California (see Landis and Reilly, Appendix III, for more discussion of the model and results).

Even in light of these uncertainties, exercises such as this are important in helping us gain a better understanding of the behavior of the systems we are studying and their potential sensitivities to the forces that drive them. In addition, we can gain insight into the relative effects of climate change and urbanization, plausible future outcomes, and potentially important areas for conservation.

3. Results

All community types

Figures 4 through 6 show the projected potential vegetation community changes at 2020, 2060, and 2100 with and without changes in the extent of urbanization taken into account. The leftmost bar for each community type and year is the current acreage; the next bar to the right is the current acreage minus losses to urbanization (no climate change effects). The next six bars to the right show the projected community acres under urbanization and the HadCM2, PCM, T3P0, T3P18, T5P0, and T5P30 scenarios, respectively.

By comparing the data in these figures (particularly Figure 6), we can see that, except in areas where urban development is unlikely because of topography and climate (higher elevation tundra and boreal forest communities), habitat losses are projected for many communities as a result of urbanization alone (the leftmost two bars). Nevertheless, the greatest changes for all community types and losses for most community types occur when climate change is also included (the rightmost six bars). By 2100, climate change is projected to be responsible for much larger changes in habitat area for most communities than urban growth.

Table 5 presents these changes for six community types, and Figures 7 and 8 are illustrative maps of the projected distributions.

Under all climate change scenarios, tundra, boreal conifer forest, Mediterranean shrubland, C3 grasslands, and subtropical arid shrubland are projected to decrease in extent (Table 5), most of them significantly. However, Figures 4 through 8 and Table 5 also indicate that the extent of some communities is estimated to increase under climate change. C4 grasslands and warm temperate/subtropical mixed forests benefit under all climate change scenarios, and maritime temperate conifer forest benefits under the relatively wet Hadley scenario.

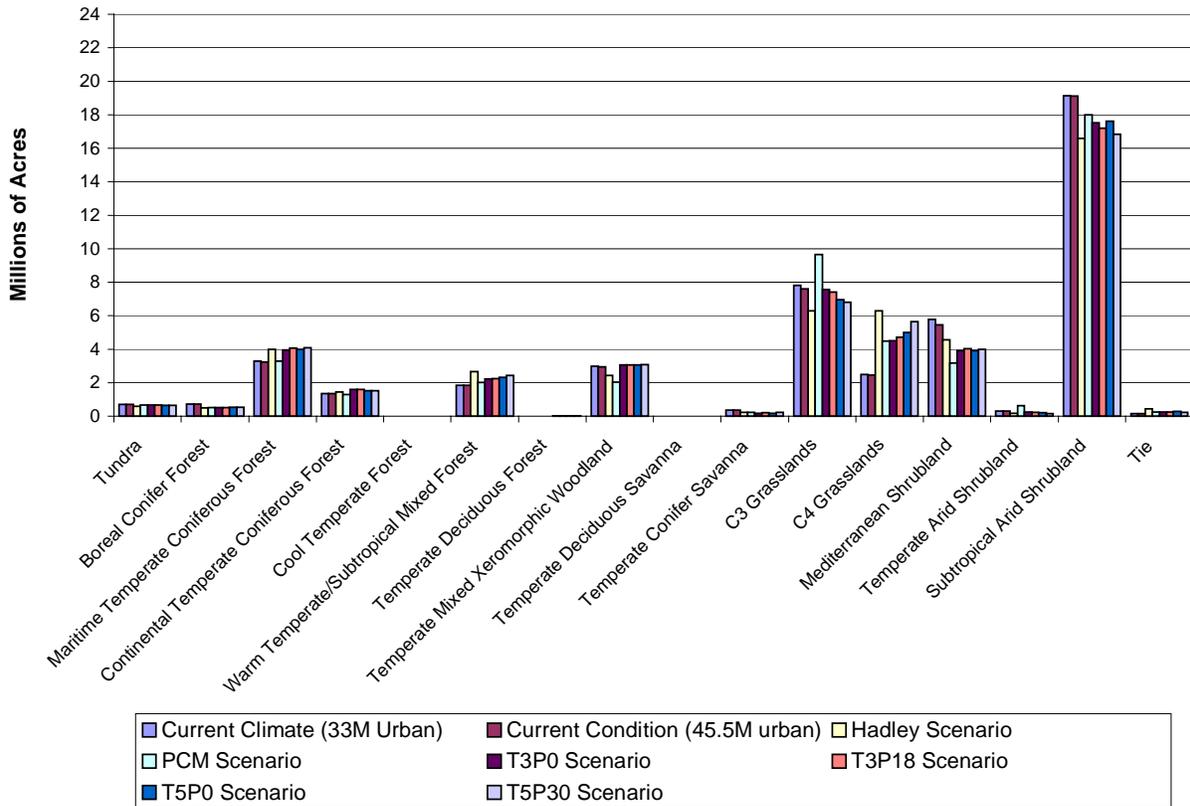


Figure 4. Potential acreage of vegetation communities for 2020 from estimated urbanization of 45.5 million and climate change scenarios as compared to current acreage for each community type

Landscape ecological diversity

California’s ecological diversity is apparent both within communities and at the landscape level, where large numbers of distinctly different habitat types occur in close proximity. We investigated the potential effects of future urbanization and climate change on this landscape ecological diversity by calculating Shannon-Wiener indices (Krebs, 1978) from the current potential vegetation data. We then compared the results with projected indices for the future potential vegetation under climate change and urbanization. Shannon-Wiener indices are basically nonparametric scores of the degree to which a landscape exhibits habitat heterogeneity. A highly diverse landscape (i.e., one in which many different habitat types are in close proximity) would have a higher index than one under a monoculture or one that has relatively few habitats.

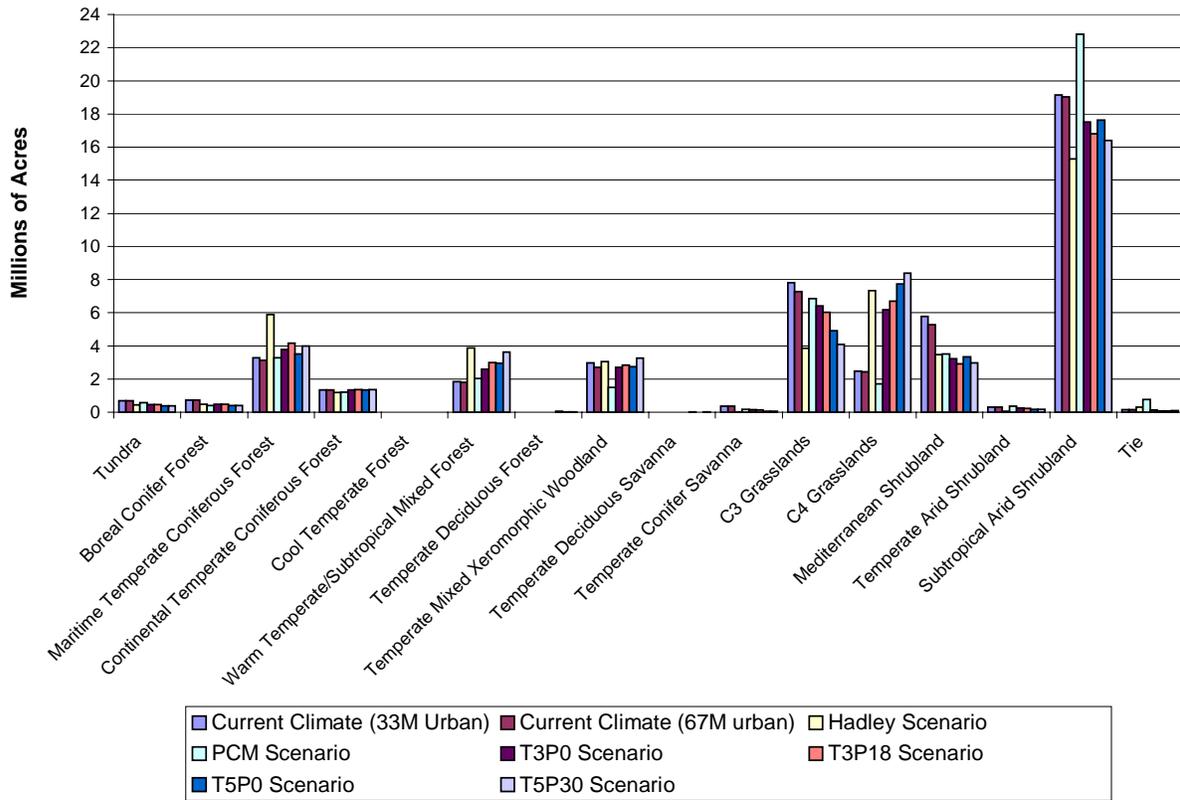


Figure 5. Potential acreage of vegetation communities for 2060 from estimated urbanization of 67 million and climate change scenarios as compared to current acreage for each community type

Figure 9 displays the changes in landscape diversity as measured using the Shannon-Wiener index based on the estimated changes in community type extents. These data suggest that urbanization alone will result in a slight reduction in diversity, but climate change and urbanization together may result in greater impacts at the landscape level. The degree and direction of this effect vary with the temperature and precipitation change assumptions — little or no reduction is estimated under the relatively wet Hadley or T3P18 scenarios. However, reductions are projected under all the other scenarios, with the greatest reductions associated with the relatively dry PCM and T5P0 scenarios, because of the increased aridity that is contingent on these scenarios and its constraining effect on the potential for plant community development. Hotter and drier conditions result in grasslands moving into areas currently occupied by shrubs and woodlands, while diversity of arid areas remains unchanged (J. Lenihan, Oregon State University, Forestry Science Laboratory, personal communication, October 11, 2002).

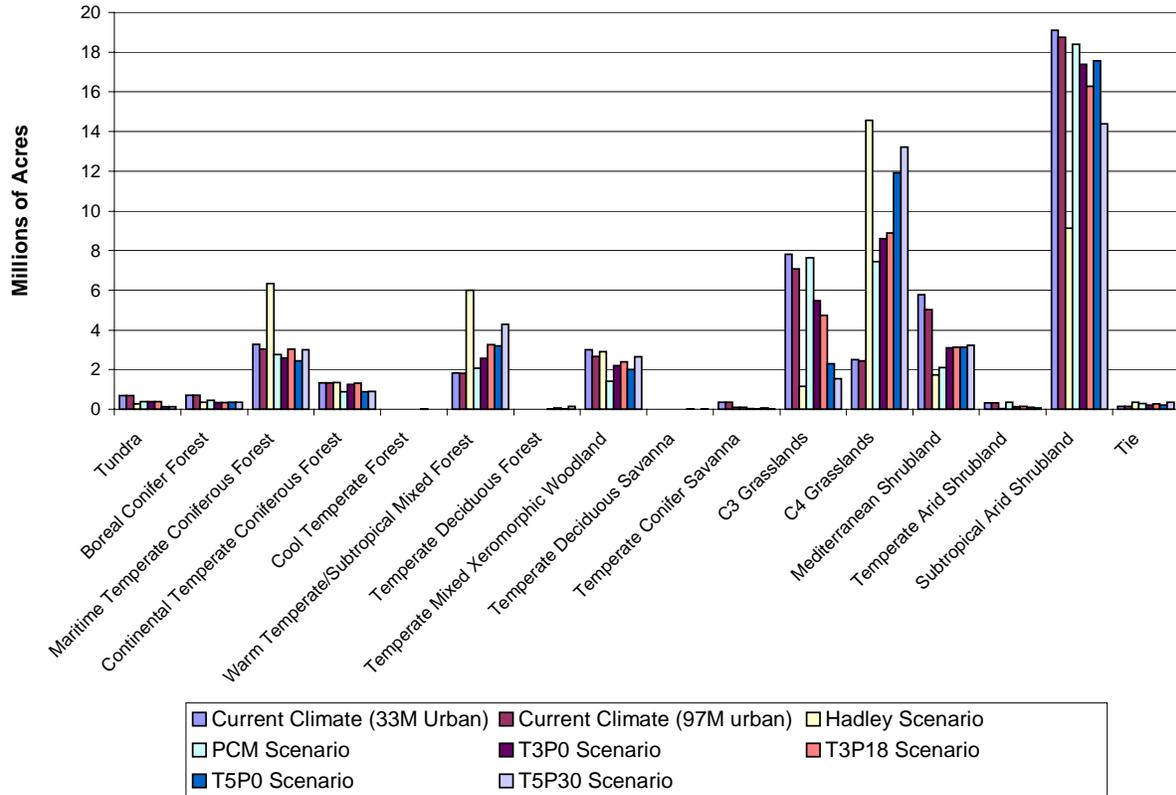


Figure 6. Potential acreage of vegetation communities for 2100 from estimated urbanization of 92 million and climate change scenarios as compared to current acreage for each community type

Table 5. Examples of projected effects (changes in acreage) of urbanization and climate change scenarios on vegetation types by 2100

Community type	Percent change resulting from urbanization	Percent change resulting from climate change
Tundra	0	-42.9 ⇔ -82.1
Boreal conifer forest	0	-37.9 ⇔ -51.7
C3 grassland	-9.5	0 ⇔ -84.8
C4 grassland	-2.0	+236.6 ⇔ +510.9
Mediterranean shrubland	-13.2	-30.3 ⇔ -59.4
Subtropical arid shrubland	-1.9	-1.8 ⇔ -51.4

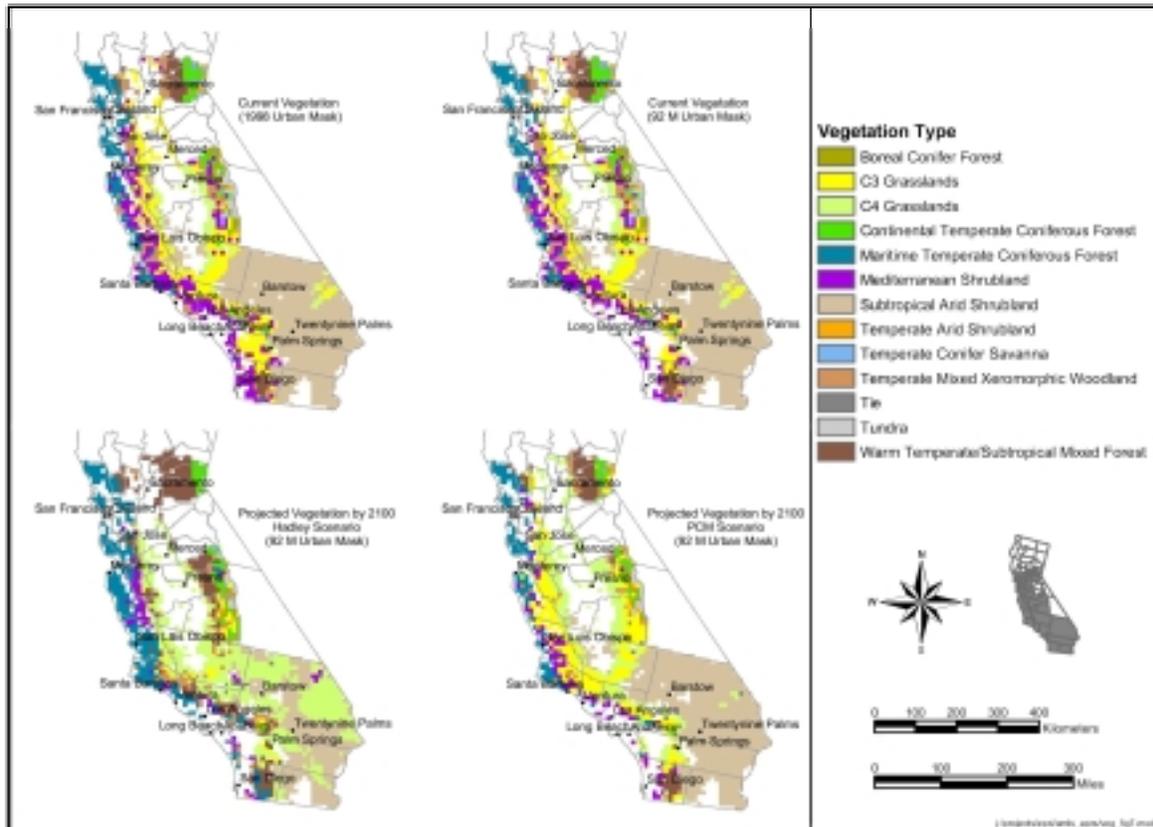


Figure 7. Potential distribution of vegetation communities under current and climate change scenarios. Top-left to lower-right: current modeled vegetation with 1998 urbanization; current modeled vegetation with 92 million population scenario; estimated vegetation by 2100 under the Hadley climate change scenario with 92 million population; and estimated vegetation by 2100 under the PCM climate change scenario with 92 million population.

California coastal sage scrub

Mediterranean shrubland was one of the community types that this study projected to be most affected by urbanization and climate change. Table 5 projects decreases in spatial extent of between 30% and 60% of its current area. Mediterranean shrubland comprises a number of more or less different community types. One of these is CSS, which is a shrub community dominated typically by drought-deciduous species of the genera *Artemisia* (sageworts), *Eriogonum* (buckwheats), and *Salvia* (sages). It occurs mainly closer to the coast, on sandier soils, and in situations that are more xeric than those where other chaparrals are found (Keeley and Keeley, 1988). CSS currently extends from the central California coast south into northern Baja California (Mexico).

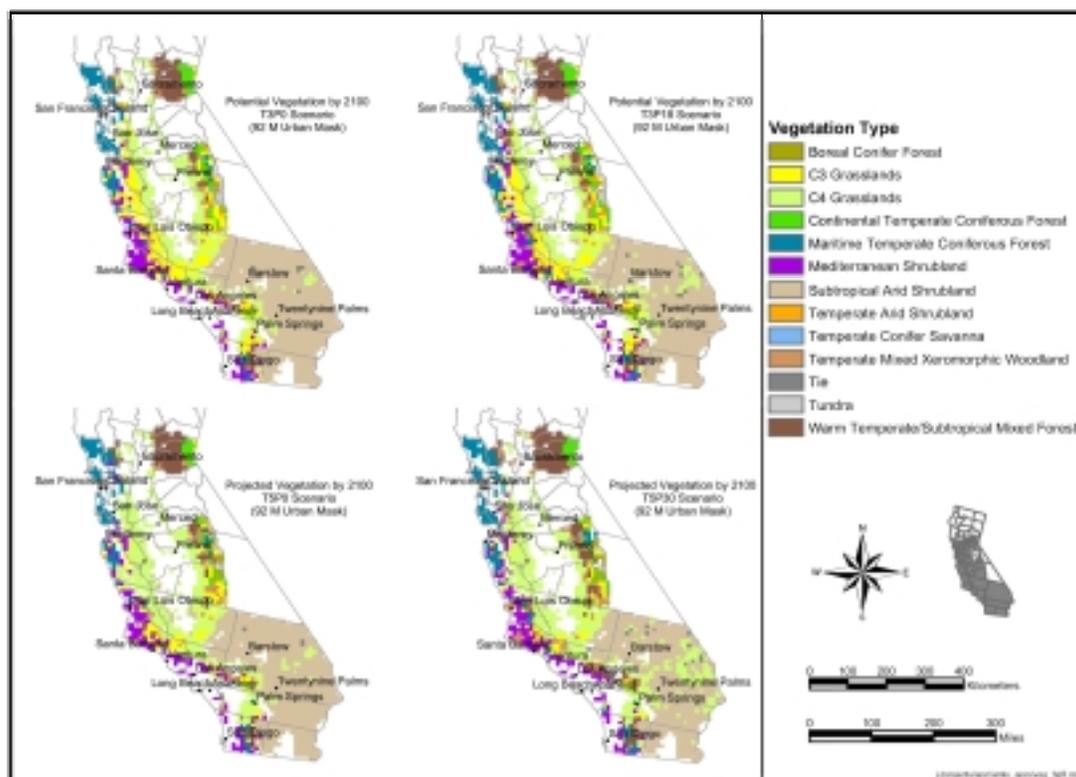


Figure 8. Potential distribution of vegetation communities under climate change scenarios. Top-left to lower-right: estimated vegetation by 2100 under the T3P0 climate change scenario with 92 million population; estimated vegetation by 2100 under the T3P18 climate change scenario with 92 million population; estimated vegetation by 2100 under the T5P0 climate change scenario with 92 million population; and estimated vegetation by 2100 under the T5P30 climate change scenario with 92 million population.

Throughout its California range, the largest contiguous areas of CSS occur on the Pismo Dunes (south of San Luis Obispo), on Vandenberg Air Force Base, and along the southern coast adjacent to San Diego. Figure 10 shows the current distribution of CSS as determined by the GAP project (Davis et al., 1998).¹ Larger contiguous areas occur immediately south of the U.S.-Mexico border in Baja California (Westman and Malanson, 1992).

1. Although CSS wasn't explicitly defined by the GAP project, it was selected from the primary wildlife habitat relationship (WHR) habitat type of coastal scrub, and codominant species include: California sagebrush, black sage, white sage, California buckwheat, California encelia, purple sage, coyote brush, and *Mimulus aurantiacus*.

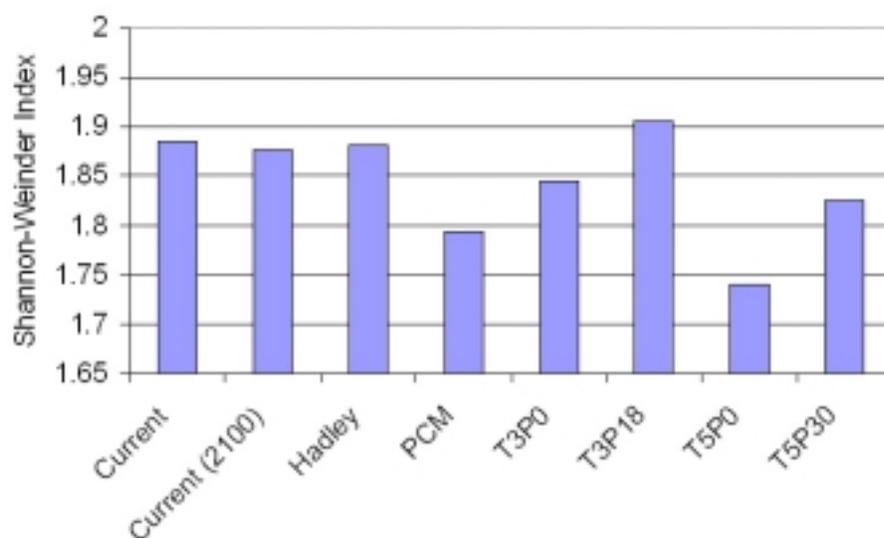


Figure 9. Landscape diversity as measured using the Shannon-Wiener index based on the estimated changes in community type extents under climate change scenarios by 2100 and 92 million estimated population

The current distribution of CSS is highly reduced and fragmented compared with its historical range. Since the middle of the 18th century, approximately 90% of the land surface that was historically occupied by the community has been lost to agricultural, residential, and industrial development (Westman, 1981). Any further losses resulting from urbanization, climate change, or other causes, then, will exacerbate an already highly tenuous situation. Furthermore, Davis et al. (1998) showed that approximately 70% of the CSS that remains in California is on private land, which makes it relatively vulnerable to development.

The limited and fragmented distribution of CSS is reflected in the rarity of many of the animals and plants typical of the community type. Most prominent of these has been the California gnatcatcher, *Poliophtila californica*, which the U.S. Fish and Wildlife Service (USFWS) listed in 1993 as threatened under the federal Endangered Species Act. Protecting this species and its supporting habitat has been the flashpoint for many of the coastal conservation-development conflicts in recent years in the Los Angeles and San Diego areas.

We focused more closely on CSS to investigate, with greater spatial resolution, the projected ecological effects of future urbanization and climate change. We then used this finer grain analysis to evaluate the extent to which our overall analytical approach permits us to identify and evaluate potential conservation constraints and opportunities. We first combined the potential

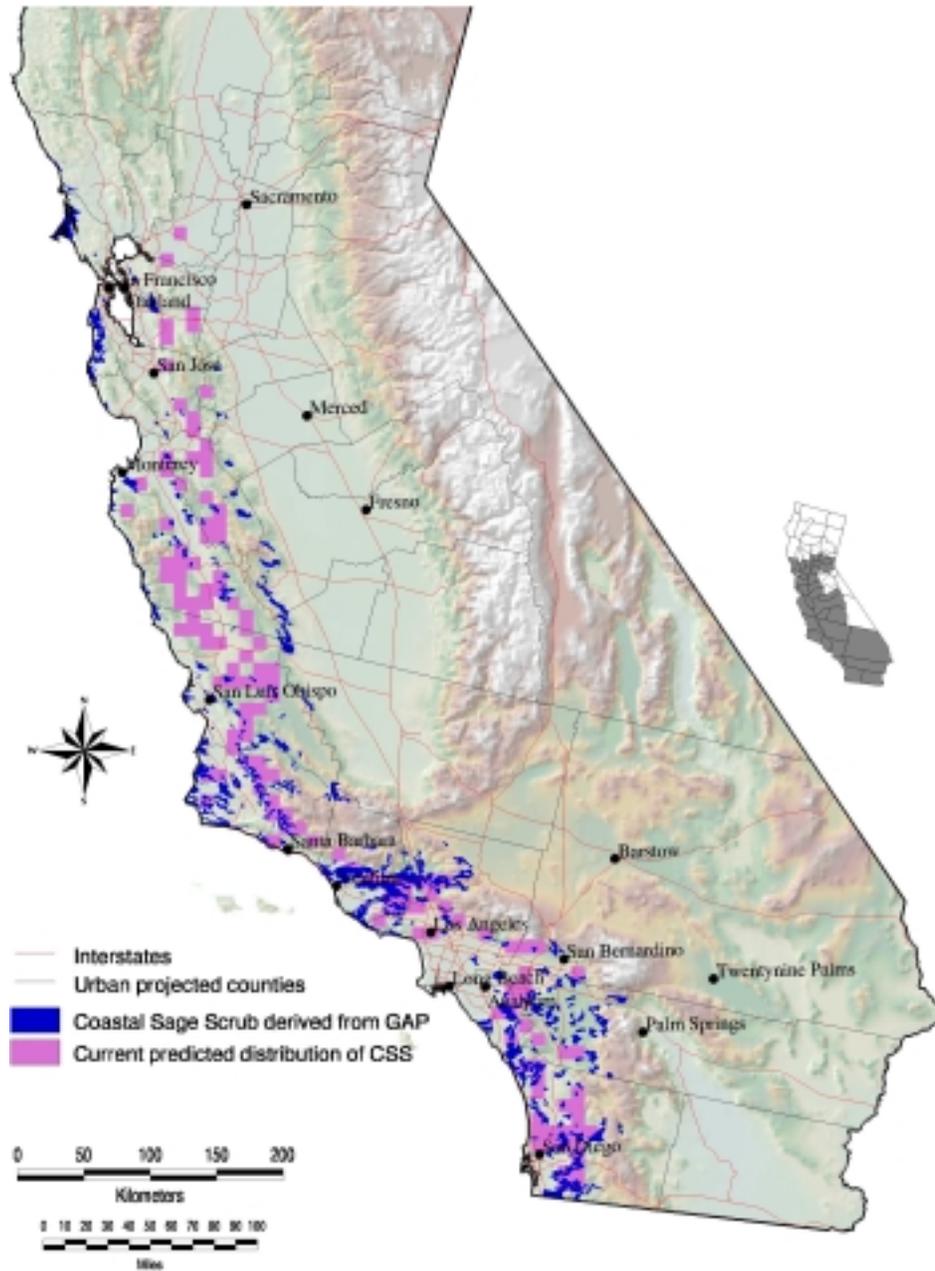


Figure 10. Comparison of current distribution of CSS as derived from the GAP project (Davis et al., 1998) at 1 ha resolution and modeled CSS at 100 km² resolution

vegetation (Lenihan et al., Appendix IV) and the urbanization projections (Landis and Reilly, Appendix III) to investigate potential effects of urbanization and climate change on the future distribution of the CSS community at a 10-km grid cell scale. In the potential vegetation projections, CSS is a component of Mediterranean shrubland. To partition out the CSS distributions, we assumed that all Mediterranean shrubland within 70 km of the southern coast, at elevations of less than 700 m, and west of any topographic barrier is CSS. Figure 10 shows the resulting distribution of 10 km grid cells. Comparing the distributions in Figure 10 shows that our modeled distribution matches the empirically derived GAP distribution reasonably closely.

Table 6 shows the results of overlaying the future urbanization projections and climate scenarios on the modeled distribution of CSS.

Under a population scenario of 92 million people in California, urbanization alone is estimated to result in a more than 20% further reduction in the current acreage of CSS (Table 6). Because most of the CSS habitat losses in the last few decades have resulted from the expansion of residential areas, this is not unexpected. However, the estimated losses increase greatly when climate change is factored into the model — to between approximately 20% and 60% for 2060, and to between 32% and 63% for 2100 — roughly a doubling to tripling of the projected losses caused by urbanization alone. Interestingly, the greatest rate of loss occurs between the present day and 2020 in most of the urbanization plus climate change scenarios. This may be because these rates of destruction leave little CSS to be further modified after 2050 in areas where development is feasible.

Figure 11a shows the current potential distribution of CSS, assuming a human population of 92 million. Figures 11b through 12d show the projected 2100 distributions of CSS, also assuming a human population of 92 million. These can be compared with the current distribution in Figure 10. These figures show that, in general, the greatest losses of CSS to urbanization are estimated to occur in the southern part of the community’s range, particularly in the Los Angeles Basin and the Ventura coastline.

Table 6. Projected effects of future urbanization and climate change^a on CSS area (percent changes in acres)

Year	Urban. only	Urban. plus HadCM2	Urban. plus PCM	Urban. plus T3P0	Urban. plus T3P18	Urban. plus T5P0	Urban. plus T5P30
2020	-9.2	-0.7	-37.6	-19.9	-16.3	-19.9	-18.4
2060	-14.2	-39.7	-61.7	-22.0	-21.3	-24.1	-22.7
2100 (92 million population scenario)	-21.3	-63.1	-52.5	-34.0	-32.6	-34.0	-29.8

a. Table 4 gives temperature and precipitation changes for each scenario.



Figure 11a. Potential current distribution of CSS under 92 million population scenario

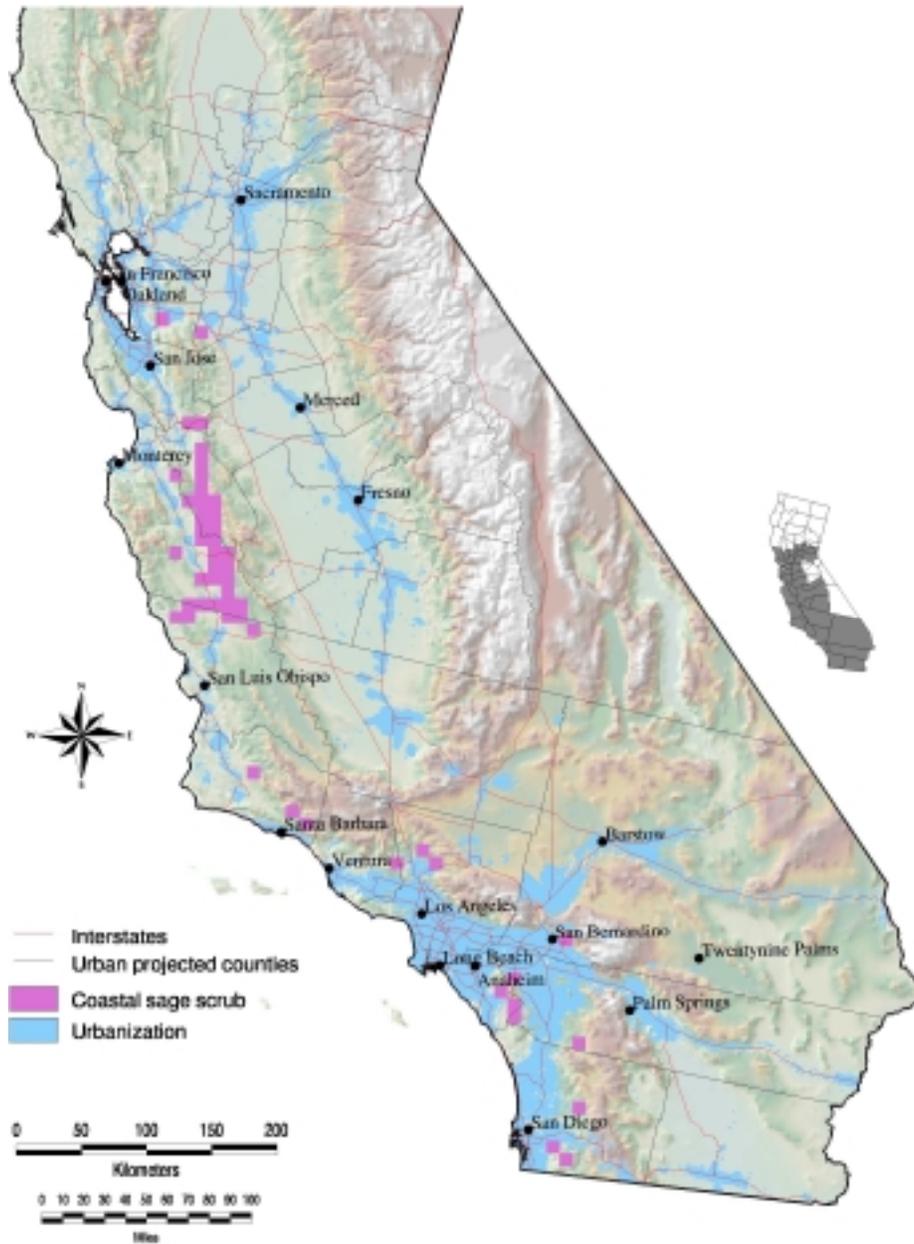


Figure 11b. Potential distribution of CSS by 2100 under the Hadley climate change scenario and 92 million population

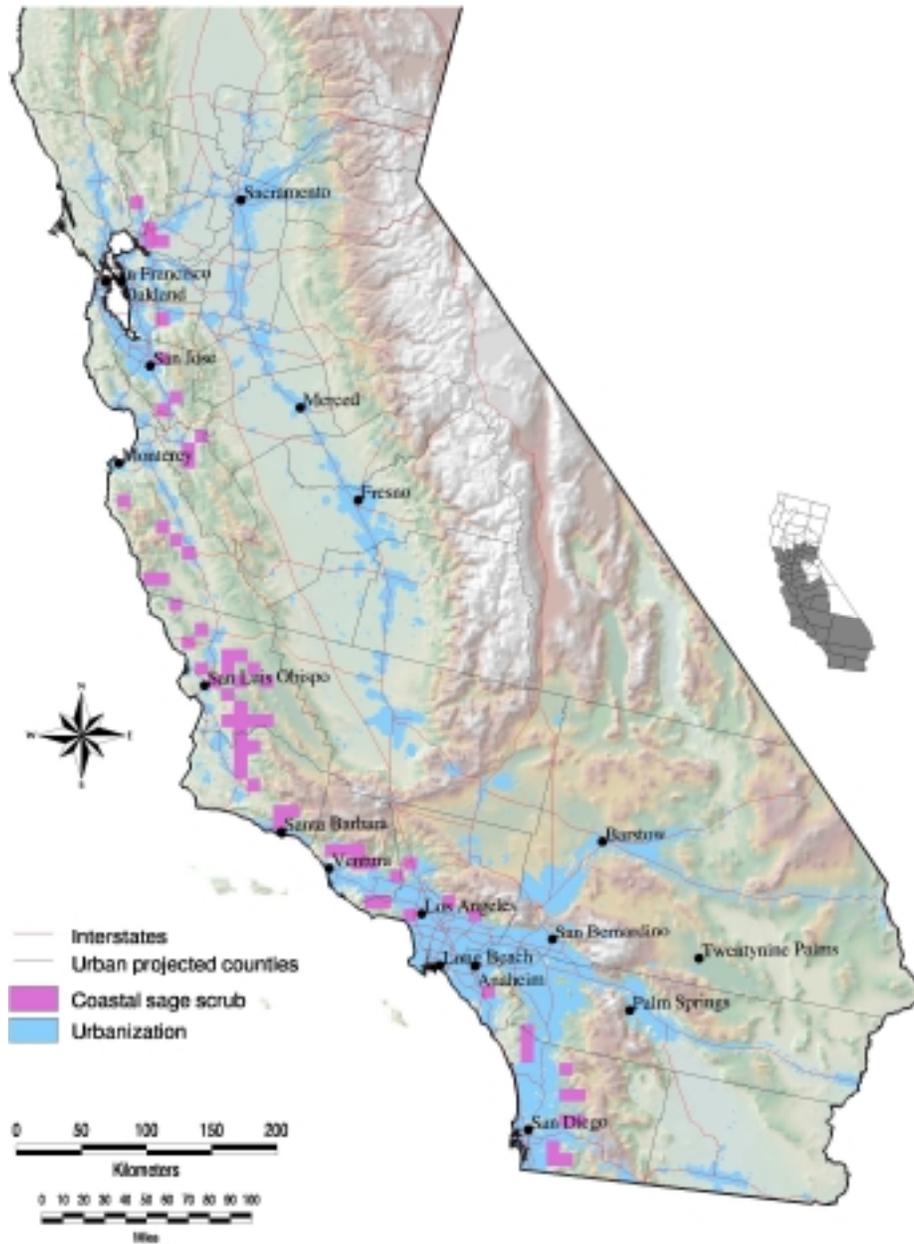


Figure 11c. Potential distribution of CSS by 2100 under the PCM climate change scenario and 92 million population



Figure 12a. Potential distribution of CSS by 2100 under the T3P0 climate change scenario and 92 million population



Figure 12b. Potential distribution of CSS by 2100 under the T3P18 climate change scenario and 92 million population



Figure 12c. Potential distribution of CSS by 2100 under the T5P0 climate change scenario and 92 million population



Figure 12d. Potential distribution of CSS by 2100 under the T5P30 climate change scenario and 92 million population

To identify potential CSS conservation opportunities in this southern part of the community's range, we identified those 10-km² grid cells that are currently CSS and are projected to stay CSS under *all* the climate scenarios at the three levels of population (Figures 13-15). This does not account for all potential climate changes; different vegetation models could yield different results, but our analysis gives a preliminary indication of where CSS may be most likely to survive climate change. In addition, we examined cells that are not currently CSS to see if any may become CSS under *all* the climate change scenarios (Figures 13-15).

Many cells were estimated to support CSS under all of the climate change scenarios by 2020. By 2060, far fewer cells support CSS. We found that only five cells would be likely to have CSS under all of the climate change scenarios by 2100. One cell is near Irvine, and the other four are east of San Diego.

We next overlaid the GAP distribution in southern California with the urbanization projections for that area. Because both these data sets are on a 1-ha scale, we can investigate the potential effects of urbanization and climate change on the distribution of this community type at a much finer resolution. Also, this area is where many of the rare species that are characteristic of CSS are found (e.g., California gnatcatcher). The results, then, are particularly relevant to protecting these resources.

Figures 16 and 17 show the projections to 2100 of this more detailed analysis for the 67 million and 92 million population scenarios for the area east of San Diego. (We did not examine the 10 km grid cell near Irvine because GAP shows it currently has little CSS.) The blue areas are the projected distributions of urbanization that are not currently CSS. The red areas are currently CSS and predicted to be urbanized, and the green areas are currently CSS and not threatened by development.

Thus far, this analysis does not consider the additional potential effects of climate change; the heavily outlined 10 km grid cells (six in Figure 16 and four in Figure 17) are the squares that the previous analysis projected would survive climate change. Thus, even in some of those areas that may survive climate change, further losses of CSS because of development are projected to occur. This is particularly the case in the western, northern, and central parts of the outlined area. By 2100, little of the current distribution of CSS is expected to survive, and only in steeper, more mountainous areas in the south of the outlined area where development may not reach. These areas, and the areas that are projected to survive climate change but are threatened by future development, could most effectively be the focus of future conservation efforts for this plant community type and its associated animals.

We can see that not all CSS need necessarily be lost. However, even if these areas were completely protected from development, under climate change there would still be a 7.8%-46.8% loss of CSS in California by 2100. Also, it is inevitable that the fragments that survived would be

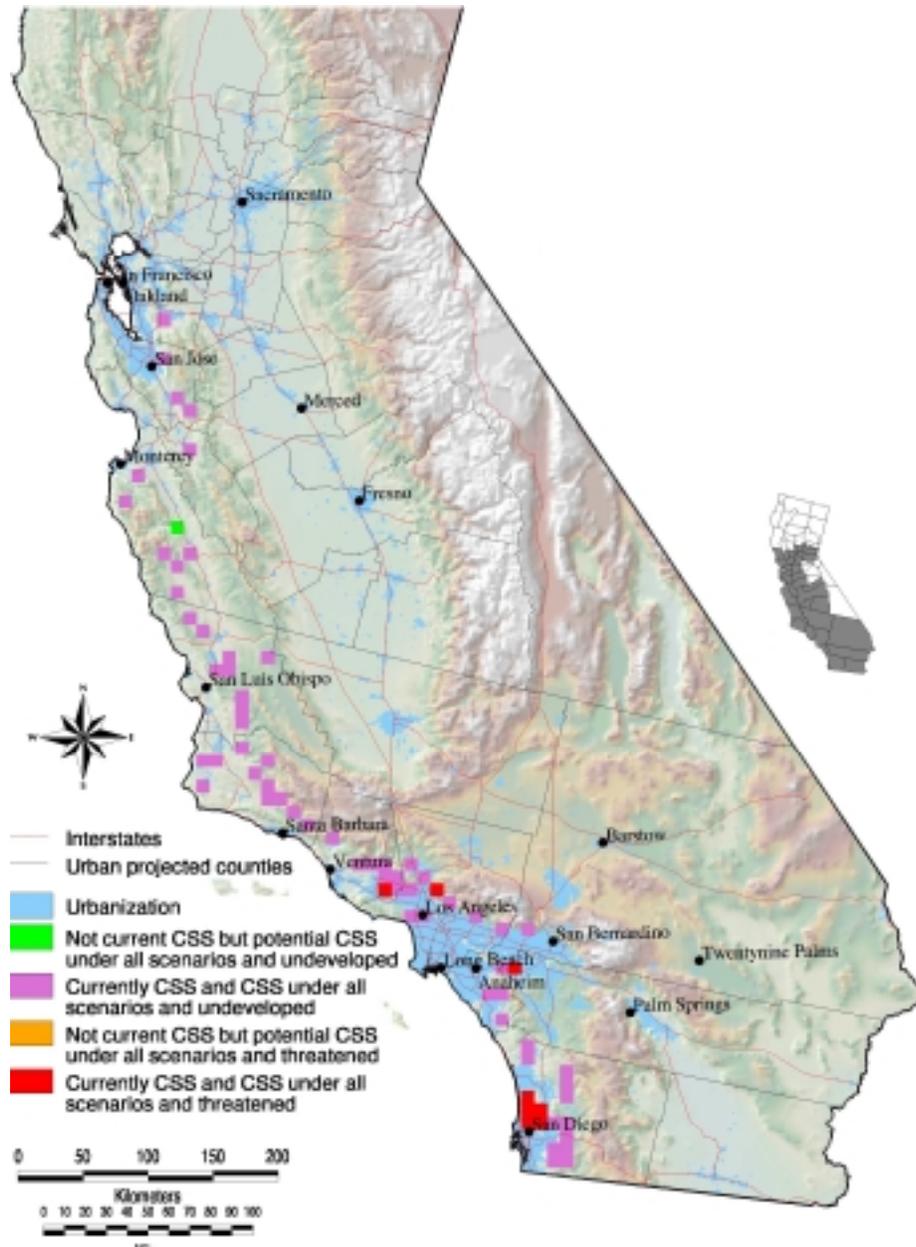


Figure 13. Potential distribution of CSS by 2020 under all climate change scenarios and 45.5 million population scenario

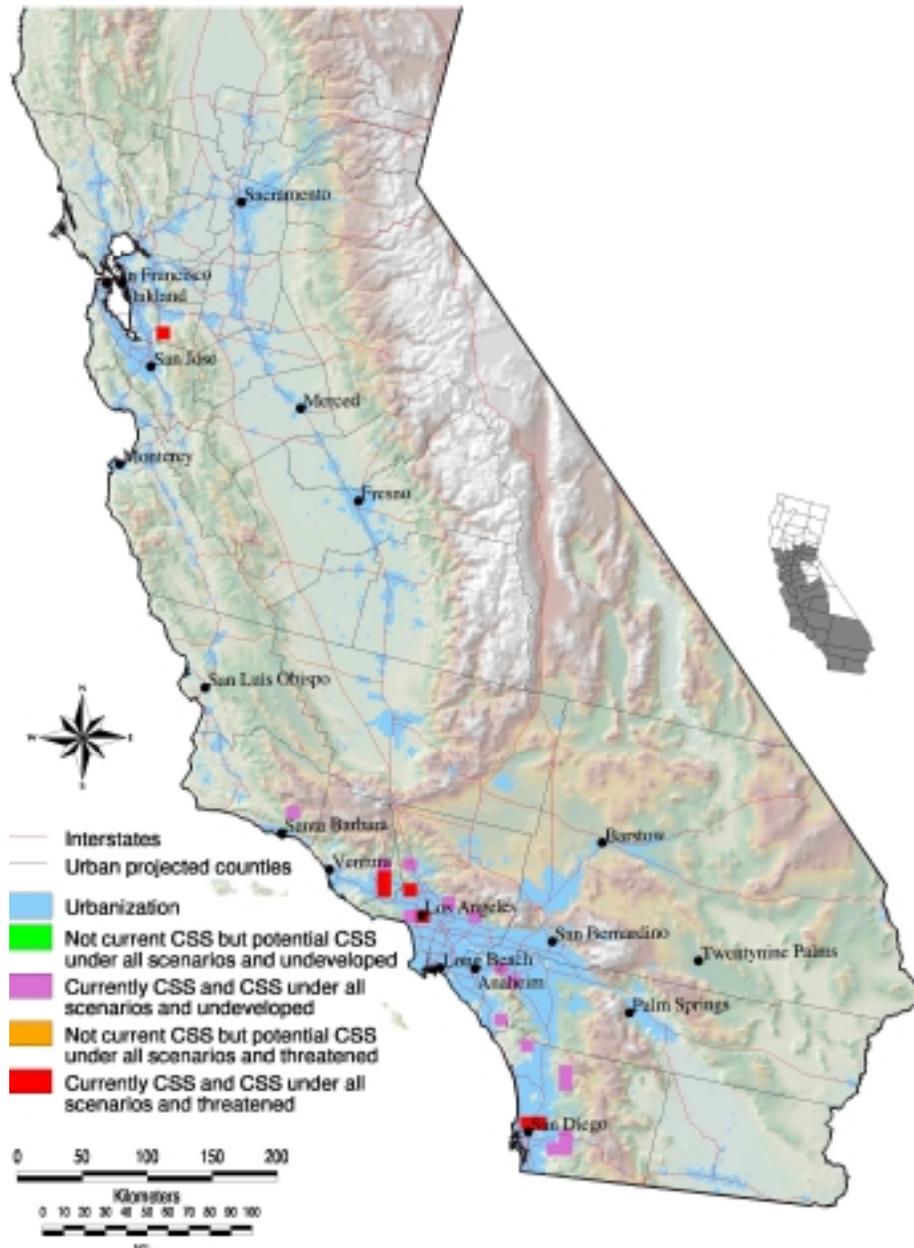


Figure 14. Potential distribution of CSS by 2060 under all climate change scenarios and 67 million population scenario

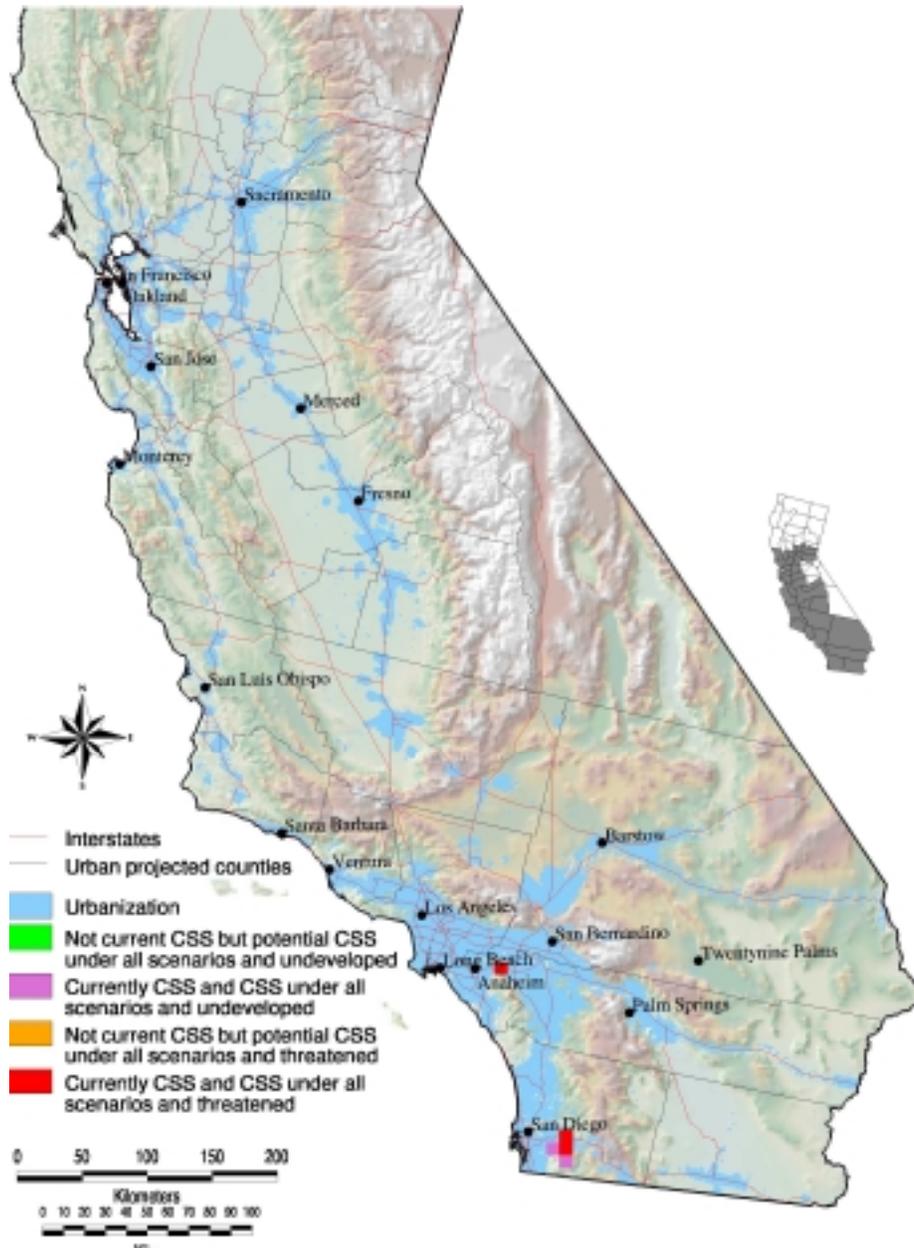


Figure 15. Potential distribution of CSS by 2100 under all climate change scenarios and 92 million population scenario

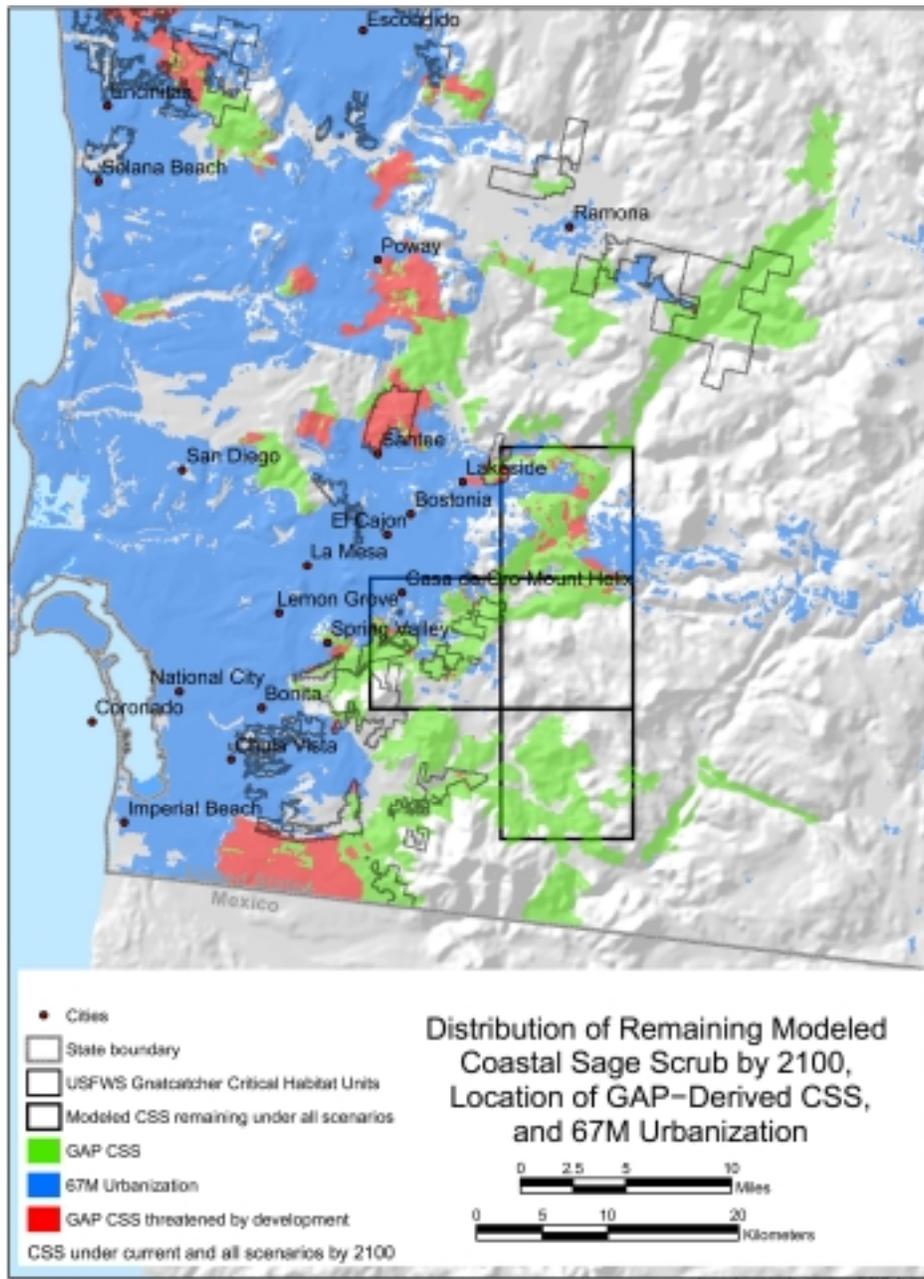


Figure 16. Current distribution of GAP-derived CSS (1 ha resolution) in San Diego region, estimated distribution of 67 million urbanization (1 ha resolution), and GAP-CSS that is threatened by 67 million urbanization. Black boxes outline 10 km² modeled CSS that are currently CSS and estimated to remain CSS under all climate change scenarios examined. Figure also indicates areas designated as critical habitat units for the California gnatcatcher by the USFWS (2000).

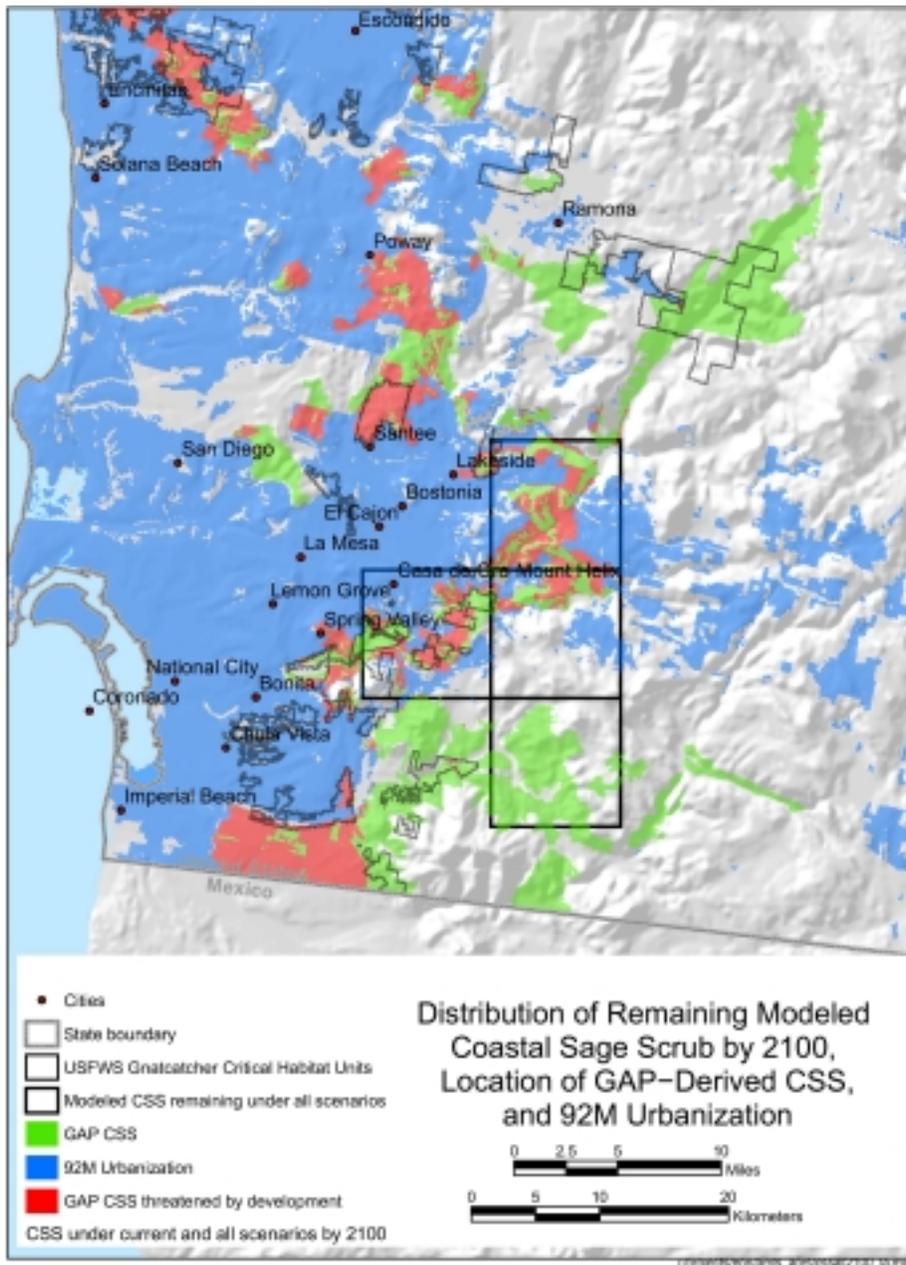


Figure 17. Current distribution of GAP-derived CSS (1 ha resolution) in San Diego region, estimated distribution of 92 million urbanization (1 ha resolution), and GAP-CSS that is threatened by 92 million urbanization. Black boxes outline 10 km² modeled CSS that are currently CSS and estimated to remain CSS under all climate change scenarios examined. Figure also indicates areas designated as critical habitat units for the California gnatcatcher by the USFWS (2000).

smaller, farther apart, and closer to developed areas than under current conditions. Smaller and more dispersed patches that are adjacent to developed areas could result in increased species extinction rates, reduced recolonization rates, increased human disturbance, and the enhanced potential for invasion by exotic species and non-native predators. Thus the projected changes could have important implications for whether the surviving patches would be functionally equivalent to CSS as it exists now.

4. Conclusions

This analysis led us to several important conclusions about the overlay of vegetation changes with urbanization:

- ▶ The analytical approach and the results demonstrate the potential for combining estimates of change in location of vegetation with estimates of change in urbanization. This is an important methodological advance for situations where stressors other than climate change may be important.
- ▶ The approach used can partition the relative effects of these important stressors and project their changing contributions over time.
- ▶ By combining urbanization and climate change data sets, we can preliminarily identify areas that could still support valuable vegetation communities under climate change, but would be threatened by development. This may allow us to focus future conservation efforts more effectively.

We draw the following conclusions about the relative and combined effects of climate change and urbanization on California's terrestrial vegetation:

- ▶ Climate change is estimated to have a much larger impact on the distribution and spatial extent of the major vegetation community types studied (e.g., Mediterranean shrubland, C3 grassland) than urbanization.
- ▶ Habitat heterogeneity in California may be reduced if climate change results in lowered soil moisture or substantially higher temperatures (i.e., approximately 5°C). Diversity is estimated to increase slightly if climate change results in wetter conditions and smaller increases in temperature (i.e., 3°C or less).
- ▶ CSS is particularly threatened by future urbanization (more than 20% loss of existing habitat by 2100). Furthermore, climate change could result in three times greater loss of coastal sage habitat.

- ▶ Potential refugia for coastal sage scrub have been preliminarily identified. These, and areas where urbanization but not climate change threatens CSS, could be the focus of future conservation efforts.

Readers should treat these results as approximations. The urbanization projections are based on a number of very specific assumptions and assume that current trends will continue. The vegetation model did not specifically model distribution of CSS. Nevertheless, this kind of analysis may be most useful for identifying where much more focused and detailed studies could take place.

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