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Teleconnection Influences on Extreme Daily Temperatures in California, 1950–2005

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Abstract

Frequencies of extreme daily temperature events are compared between high and low phases of two teleconnection patterns that affect California—the Pacific/North America (PNA) pattern and the Southern Oscillation Index (SOI, representing ENSO). The positive phase of the PNA is associated with an increased number of hot extremes, especially in fall and winter, along with a decrease in winter and spring cold extremes. The positive phase of the SOI corresponds to an increased frequency of extreme events in both maximum and minimum temperatures, with the most effect on minimum temperatures in spring. Variations in these relationships with changes in the phase of the Pacific Decadal Oscillation (PDO) are also examined—the PNA pattern produces fewer cold extremes when the PDO is positive, and the difference is larger for the negative PNA. The positive SOI produces more spring hot events and fewer cold events when the PDO is also positive.

Introduction

THE ASPECTS OF WEATHER and climate that tend to be most noticeable to people, and which tend to have the most dramatic impacts on humans and the environment, are extreme events. Extreme temperatures in particular, both hot and cold, can have serious implications for health and mortality, agriculture, and energy usage (Curreiro et al. 2002; Colombo, Etkin, and Karney 1999; Downton and Miller 1993; Easterling, Meehl et al. 2000; Parmesan, Root, and Willig 2000; Wigley 1985; White et al. 2006). As global climates change and fluctuate, the frequency of extreme temperature events is likely to change. However, the probability of extreme values in a variable is not likely to change linearly with the mean of that variable; rather, extreme-event frequencies are a complex outcome of both the position (mean) and scale (variability) of a variable's probability distribution (Katz and Brown 1992; Mearns, Katz, and Schneider 1984; Wigley 1999; Wagner 1999; Liu et al. 2006). Furthermore, local and regional climates tend to vary in ways that are often different—and sometimes opposed—to global and hemispheric scale variations (Easterling, Karl et al. 2000; McGuffie et al. 1999; Stott et al. 2000). In order to understand the future likelihood of potentially disruptive extreme events, therefore, it is important to directly examine the mechanisms influencing extreme daily temperatures at the regional scale.

One mechanism that has been found to significantly influence regional climates, and which is reproducible in climate models, is the occurrence of recurrent, persistent, hemispheric-scale circulation patterns in the atmosphere known as teleconnections. These patterns are produced and influenced by a variety of factors, including sea surface temperatures (SSTs), snow cover, topography, and natural internal variability. The persistence of these patterns is generally on the order of days to months, but it is not uncommon for a particular phase of a teleconnection pattern to dominate for consecutive years. As a result, surface conditions in one part of the hemisphere are linked ("teleconnected") to conditions at another, often distant, location through the occurrence of particular mid-tropospheric flow patterns (Barnston and Livezey 1987; Cheng and Wallace 1993; Vega, Henderson, and Rohli 1995; Higgins, Leetmaa, and Kousky 2002; Mestas-Nunez and Miller 2006; Mori and Watanabe 2008). Many of these well-defined upper-level flow patterns have significant impacts on the surface climate of North America (as well as other regions), affecting such variables as the timing and intensity of precipitation (e.g., Henderson and Robinson 1994; Serreze et al. 1998; Jin et al. 2006), the magnitude, persistence, and variability of maximum and minimum temperatures (e.g., Wolter, Dole, and Smith 1999; Smith and Sardeshmukh 2000; Higgins, Leetmaa, and Kousky 2002; Bodri and Cermak 2003; Budikova 2005), or weather type frequencies (e.g., Sheridan 2003; Coleman and Rogers 2007). For the North American sector in particular, the Pacific/North American (PNA) pattern and the El Niño/Southern Oscillation (ENSO) influence temperature and precipitation at the monthly to annual scales, and the Pacific Decadal Oscillation (PDO) is correlated with climate at the decadal scale.

ENSO events have numerous linkages to extra-tropical surface weather conditions. For North America, these linkages result from alterations to tropospheric flow patterns initiated from the tropical Pacific, resulting in changes to storm tracks, temperature, and moisture advection into and across the U.S., particularly in winter and spring. During warm ENSO events (El Niño), the dominant circulation change is a strengthening of the southern branch of the

Pacific jet stream across the southern tier of the U.S., along with a reduction in the amount of cold air advecting southward from Canada due to a more zonal flow of the northern branch of the polar front jet. Cold phase (La Niña) events are characterized by increased meridionality in the flow across North America with frequent ridging over the eastern Pacific (Higgins, Leetmaa, and Kousky 2002; Yarnal 1985; Yu and Zwiers 2007). Cold phase events are associated with increases in the frequency of extreme wintertime cold days for much of the western U.S., while warm phase events are associated with decreases in the frequency of cold extremes (Higgins, Leetmaa, and Kousky 2002; Smith and Sardeshmukh 2000).

In this study, the strength and phase of the ENSO is represented by the Southern Oscillation Index (SOI), in which negative values indicate a warm-phase (El Niño) event. The monthly SOI is calculated by subtracting the standardized monthly sea level pressure anomaly at Darwin from the corresponding value for Tahiti. The resulting time series of monthly SOI values is itself standardized (CPC, 2008). Neutral conditions are represented by SOI values near zero, while values less than -1 or greater than 1 typically indicate warm and cold phase events, respectively. Values more extreme than +/-2 are uncommon and indicate particularly pronounced ENSO events. Since 1950, a handful of monthly values have exceeded -3, although fewer than 10% of the total values have been more extreme than +/- 2.

The PNA pattern is one of upper-level circulation characterized by, in its positive phase, ridging over the western portion of North America (approximately centered on the Rocky Mountains) and troughing over eastern North America. The negative phase of the teleconnection pattern is characterized by zonal flow over the continent or, in extreme cases, a reverse-PNA with troughing in the West and ridging over the eastern U.S. The mechanisms that lead to the establishment of a PNA flow pattern are complex—SSTs and convective activity in the tropical Pacific as well as surface temperatures over East Asia and the strength/position of the East Asian jet all play a role (Leathers and Palecki 1992; Mori and Watanabe 2008). In addition, the PNA pattern is correlated with ENSO events, with positive (negative) PNA index values common during warm (cold) ENSO events (Yarnal and Diaz 1986; Leathers and Palecki 1992; Vega, Rohli, and Henderson 1998). The PNA is not a major mode of Northern Hemisphere circulation in June and July, but it does show positive correlations with western U.S. temperatures in the other months of the year (e.g., Leathers, Yarnal, and Palecki 1991; Cayan 1996), as well as significant effects on synoptic weather type frequencies (Sheridan 2003).

The PNA index used here is calculated by combining 500 mb height anomalies (Z*) at four locations across North America as follows: *PNA = Z*(15°N-25°N,180-140°W)-Z*(40°N-50°N,180-140°W)+Z*(45°N-60°N,125°W-105°W)-Z*(25°N-35°N,90°W-70°W)* (CPC 2008).

Monthly PNA index values more extreme than +/- 1 indicate well-developed occurrences of the pattern. During the 1950–2005 period, fewer than 5% of the monthly PNA values exceeded +/- 2.

The Pacific Decadal Oscillation is a pattern in North Pacific SST variability that is somewhat similar to the El Niño pattern, although at a much longer time scale—PDO events persist for decades, as opposed to the months-to-years life span of an ENSO event. The PDO index is defined as the leading principal component of monthly sea surface temperature variability in the North Pacific (JISAO 2000), and index values more extreme than +/- 1 typically indicate positive or negative phases of the pattern (monthly values more extreme than +/- 2 occurred during fewer than 10% of the months in this study period). The basic pattern of a positive (warm phase) PDO event is warm SST anomalies along the west coast of the U.S., and cold anomalies in the central North Pacific. The negative (cold) phase of the PDO shows the opposite pattern. Over the past century, several long-term switches in the PDO time series are evident: the positive (warm) phase was dominant from 1925 through 1947, negative (cold) phase conditions then dominated until 1977, and positive values were common through the end of the century (Mantua et al. 1997; JISAO 2000). Negative values appeared to be regaining dominance in the late 1990s, but recent observations do not clearly indicate that another reversal has occurred. The positive phase of the PDO correlates with warmer wintertime temperatures on the west coast, including California, as well as reduced winter precipitation in the interior west (Mantua et al. 1997; LaDochy, Medina, and Patzert 2007).

While the PDO has significant direct effects on North American weather, it may have more critical impacts through a modulating effect on both ENSO events and the PNA pattern. In general, warm-phase ENSO events have stronger North American impacts during the positive PDO phase, when the ENSO and PDO SST anomalies are synchronized, with weaker ENSO signals detected across North

America during the negative PDO. Conversely, La Niña conditions synergize with negative PDO events and thus have a stronger signal in North American climate; effects of La Niña conditions are dampened by the warm phase of the PDO (Gershunov and Barnett 1998; Gershunov, Barnett, and Cayan 1999; Yu and Zwiers 2007). Additionally, the positive phase of the PDO encourages a PNA-like flow pattern over the North American continent, with higher-than-normal upper-level geopotential heights over the western part of the continent, and lower-than-normal heights over the northern Pacific (Mantua et al. 1997; Yu and Zwiers 2007).

While relationships between teleconnection patterns and mean temperatures have been intensively studied, linkages between hemispheric-scale circulation and extreme events have been directly addressed less frequently. The objective of this study is to explore correlations between seasonal frequencies of anomalous hot and cold days in California and the ENSO and PNA indices, as well as to explore whether the phase of the PDO modifies these correlations. For the two shorter-term indices, the differences in the numbers of extreme events occurring during high versus low phases of the index are examined. Next, the impact of the PDO phase is addressed by computing the differences in extreme-event frequencies for a given phase of the PNA or ENSO, but comparing seasons classified by either the high or low PDO phase.

Data and Methods

The temperature data used in this study are the daily maximum and minimum temperatures observed at National Weather Service Cooperative Observer Program (COOP) sites from 1950 to 2005, obtained online from the National Climatic Data Center (NCDC). To qualify for inclusion, sites were required to have observations for both maximum (TMAX) and minimum (TMIN) temperature on at least 95% of the total days in the 56-year study period. Additionally, any individual month missing more than 10% of its daily observations for either variable was marked as missing, and sites were rejected if more than 10% (i.e., six or more) of any given calendar month was missing. A total of 90 COOP sites were sufficiently complete to be used in the study (Figure 1).

At each site, extreme events in TMAX and TMIN were defined as exceedances of the 90th and 10th percentiles (respectively) of all non-missing values for each individual day of the year. The 90th (10th) percentile for a given day will be exceeded by the five warmest (cool-

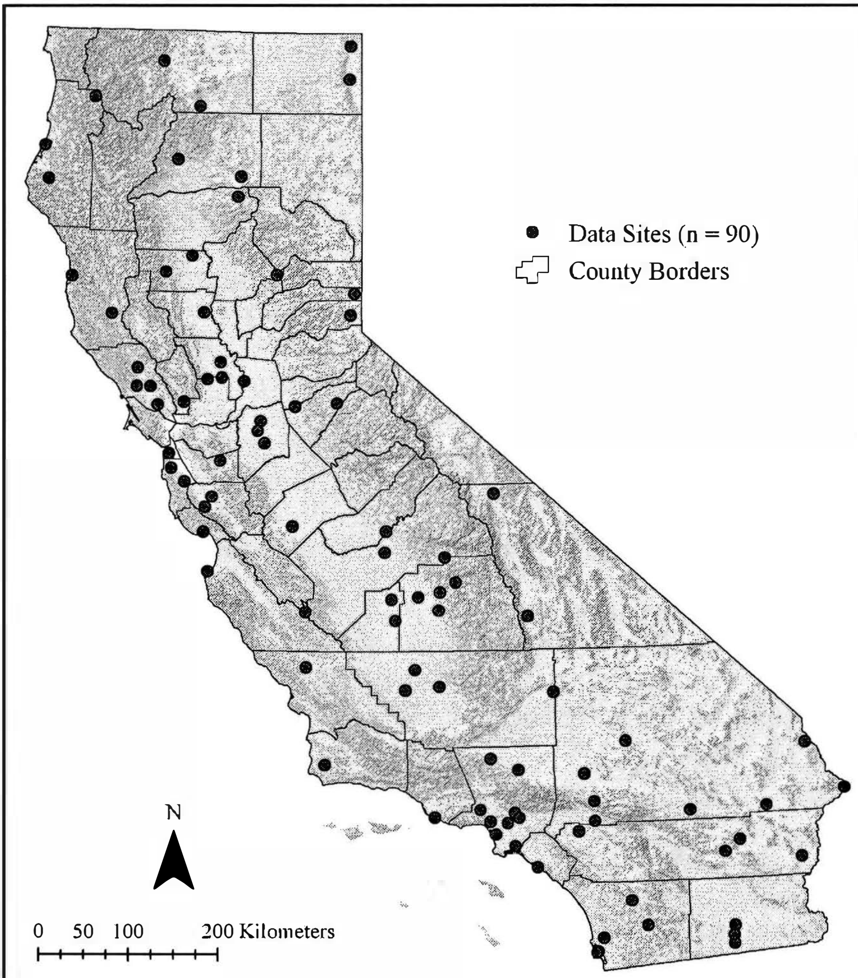

Figure 1.—Locations of 90 NWS COOP weather stations used in study.

est) observations for that date over the period of record. This method defines extreme events on a day-by-day basis and identifies unusually warm and unusually cold events throughout the year. Once each day was classified as extreme or not, the total number of each type of exceedance was summed by site for four seasons—winter (DJF), spring (MAM), summer (JJA), and fall (SON)—for years in which all three months were non-missing. The result of these calculations was 56-year time series of the seasonal frequencies of hot TMAX extremes and cold TMIN extremes at 90 sites across California.

Standardized monthly values for the PNA and SOI for 1950–2005 were obtained online from the Climate Prediction Center (http://www.cpc.ncep.noaa.gov/), and for the PDO from the Joint Institute for the Study of the Atmosphere and Ocean (http://jisao.washington.edu/pdo/). Seasonal values by year for each index were calculated as the average values for the same three-month periods used above. Positive and negative phases of the PNA and SOI were defined as seasonal values above 0.5 or below -0.5. Values between -0.5 and 0.5 were considered neutral. Although these cut-off values appear moderate compared to the range of monthly values observed in these teleconnection indices, they were chosen because they approximate the tercile values of the seasonal indices calculated here. The phases of the PDO were defined more broadly than the others: the positive and negative phases were defined as the top and bottom thirds of all 56 values for a given season, plus any additional values more extreme than +/- 0.5. Each season over the 56-year period was classified as high (positive), neutral, or low (negative) for each index. The three seasonal teleconnection indices are highly correlated (Table 1), with particularly strong relationships between the PDO and each of the others. This correlation created some difficulty in producing sufficiently large sample sizes of the various PNA/PDO and SOI/PDO combinations; the expanded definitions of the PDO phase was a response to this problem.

Table 1. Pearson's r correlations between the seasonal teleconnection indices, with correlations significant at the 0.05 level shown in bold.

	PNA/PDO	PNA/SOI	SOI/PDO
Spring	**0.52**	**-0.30**	**-0.54**
Summer	**0.32**	0.20	**-0.45**
Fall	0.26	-0.12	**-0.51**
Winter	**0.73**	**-0.36**	**-0.45**

To examine the relationships between the teleconnection patterns and extreme temperature events, the mean frequency of each type of extreme event was calculated for seasons classified as positive and for seasons classified as negative for each index. The difference between these values at each site (by season and index) was tested for significance using the non-parametric Wilcoxon rank-sum test in SAS software. Similar analyses were performed to test the effects of the PDO phase: the difference in the mean frequency of extremes during a single phase of the PNA or ENSO was compared between positive and negative phases of the PDO. For example, the mean number of extremes during the positive PNA/positive PDO combination was compared to the positive PNA/negative PDO condition. Significant differences in these values indicate that the specified phase of the shorter-scale pattern (PNA or ENSO) is associated with different frequencies of extreme events during different PDO phases.

Results and Discussion

Overall, the PNA pattern shows more widespread correlations with the frequency of both TMAX and TMIN than the SOI (Table 1). Throughout the year, the positive phase of the PNA is related to an increased frequency of unusually hot TMAX values, and a decreased number of cold TMIN events. Not surprisingly, this pattern shows little impact in summer, when it is not one of the primary modes of northern hemisphere circulation. The SOI, in contrast, is related to an increased frequency of both warm and cold extremes during the positive phase of the index (La Niña events), and a reduced frequency during negative phase (El Niño) events. Both indices appear to correlate slightly more strongly with minimum temperature events, based on the larger number of significant differences for TMIN; however, there are clear seasonal differences in the strength and direction of the teleconnection influences.

Table 2. Number of sites with significant ($\alpha = 0.05$) differences between the frequency of extreme daily temperatures between the high and low phases of the PNA and SOI. All comparisons have a possible total of 90 sites.

	PNA		SOI	
	TMAX	TMIN	TMAX	TMIN
Spring	11	41	1	26
Summer	2	2	15	2
Fall	19	10	4	14
Winter	46	75	12	4

The PNA has its most widespread impact on maximum temperatures during the fall and winter (SON, DJF). In both seasons, all statistically significant differences are increases in unusually warm events during the positive phase—these significant trends range from 5 to 10 additional warm events during positive PNA seasons, with an average increase of 7 days. This impact is unsurprising, as the positive PNA is characterized by ridging over the western U.S. and thus should be indicative of reduced northerly flow and warmer, clearer, anticyclonic conditions.

For fall, the sites with significant differences show a tendency to cluster in the half of the state north of the Bay Area. In the southernmost 10 counties, only four sites have significant fall differences between the two phases, and none of these sites are in the more populated coastal areas. This north-south division may be at least partially explainable by the generally earlier onset of winter weather in the north—during fall, winter conditions are delayed in the north by the positive PNA, but the difference is less noticeable in the south due to the generally later arrival of cold season conditions.

Half of the sites have significant differences in TMAX extreme frequency in winter between the high and low PNA phases. As in fall, these differences are clustered in the north, but there is also a strong tendency for coastal sites throughout the state to have more warm exceedances during positive PNA seasons (Figure 2). This effect may be partially explained by the negative correlation between the PNA and the SOI. The negative SOI (El Niño) is characterized by warmer SSTs offshore, which may contribute to warmer coastal conditions during positive PNA seasons.

The positive PNA is correlated with decreased numbers of extreme cold events across the state in spring and especially in winter, which is likely due to the enhanced ridging over the region during this phase, which blocks northerly flow and steers frontal systems away from the state. In spring, significant differences range from 5 to 11 fewer extreme cold events, with an average of 8 fewer days during this phase. For winter, the differences tend to be higher, with a range of 5 to approximately 14 fewer days, and an average of 9. A decrease in winter time extreme cold events during the positive PNA may be considered a beneficial impact, as these events have significant consequences for both human comfort and agriculture. Overall, the decrease in extreme cold events for the positive PNA is greater than the increase in extreme hot events, indicating the

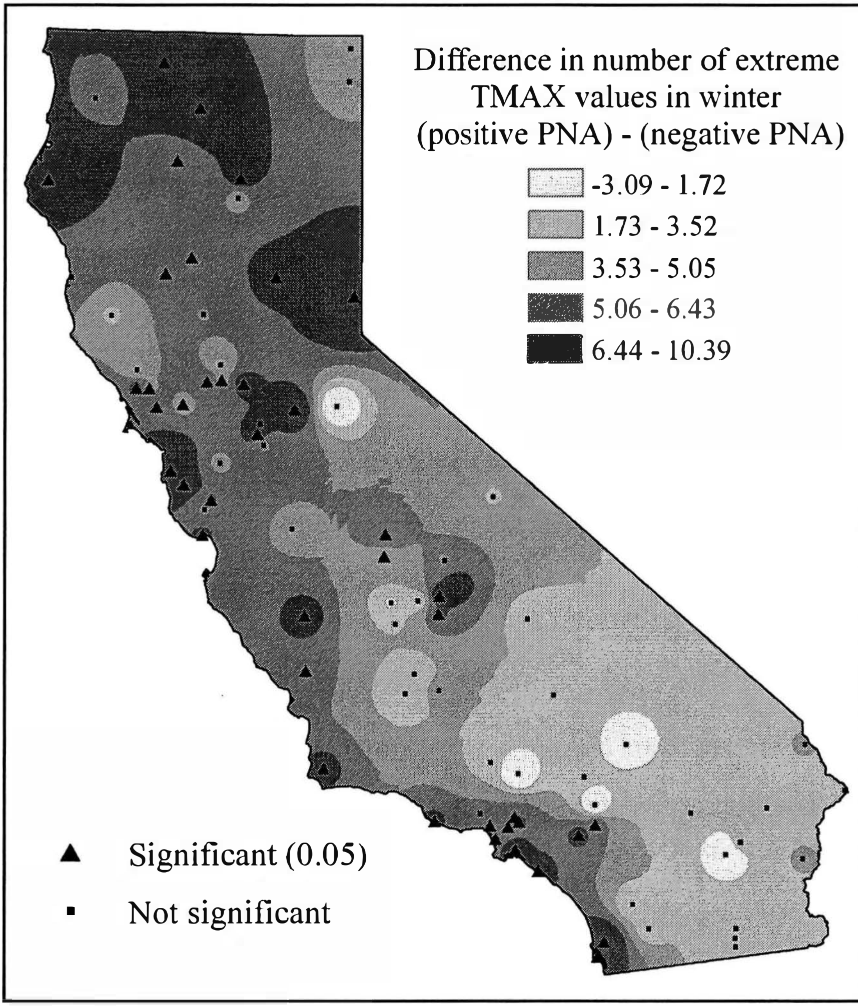

Figure 2.—Difference in the number of winter extreme TMAX events between high and low phases of the PNA (PNA+ minus PNA-). In this and all subsequent figures, an inverse distance weighted interpolation based on all 90 difference values was used.

importance of directly examining variations in the extreme tails of the temperature distribution.

Spatial patterns in the difference between TMIN extreme frequencies for the PNA are somewhat similar to the patterns for the TMAX events. In winter, the 75 sites with significant differences are widespread across the state, with no clear tendency for the larger differences to cluster in any area. In spring, however, the significant values tend to be found along the coast and in the northern half of the state (Figure 3). The strongest decreases in unusually cold spring events for the positive PNA are seen in the northwestern region, perhaps indicative of an earlier onset of warm-season patterns during this phase of the teleconnection.

The SOI shows fewer significant impacts on temperature extremes compared to the PNA, with the largest effect on TMIN in spring (Figure 4). During this season, 26 predominately coastal sites in central and southern California experience significant increases, ranging

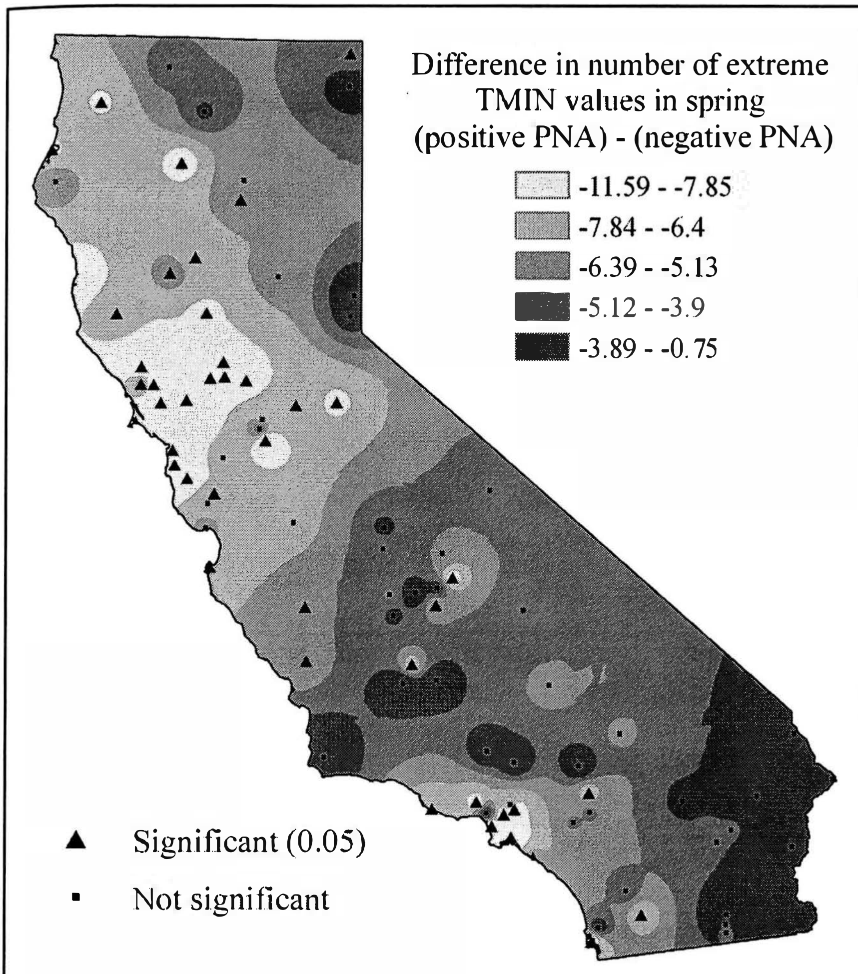

Figure 3.—Difference in the number of spring extreme TMIN events between high and low phases of the PNA (PNA+ minus PNA-).

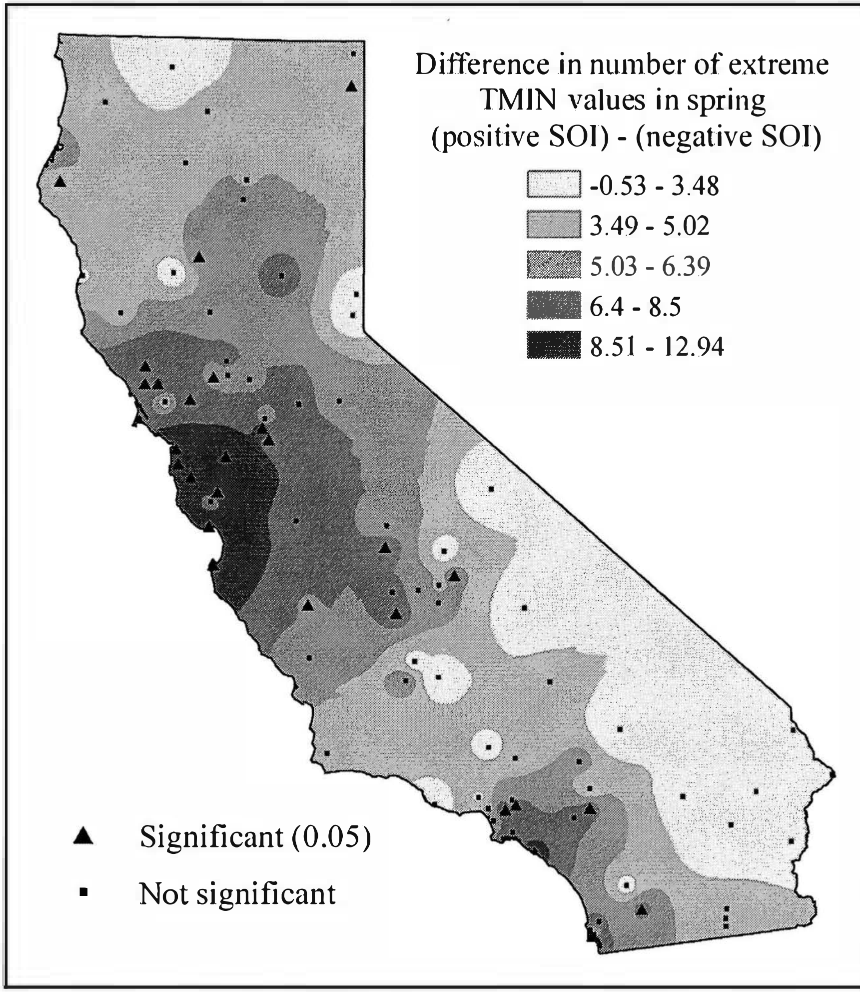

Figure 4.—Difference in the number of spring extreme TMIN events between high and low phases of the SOI (SOI+ minus SOI-).

from 5 to 13 with an average of 9, in the number of unusually cold days during the positive phase of the SOI (La Niña). This pattern is probably explainable by the increased northerly flow along the California coast during the cold phase, and possibly by an increase in radiative cooling due to the associated drier, clearer conditions. The converse of this is a decrease in the number of cold TMIN extremes during the El Niño pattern, likely due to the increased flow of moist subtropical air into the southern coast during the warm phase, as well as the warmer water offshore.

Summertime TMAX extremes are particularly noticeable to humans, and the SOI is positively related with increased frequencies of these events at 15 of the study sites. These sites are strongly clustered in the central part of the state (Figure 5) and show average differences of approximately 6 more hot JJA extremes during La Niña-type SOI patterns than during El Niño-type conditions. A possible reason for this is that La Niña events tend to lead to drier conditions in California, and the reduced moisture may allow increased sensible heating of the lower atmosphere in the interior regions.

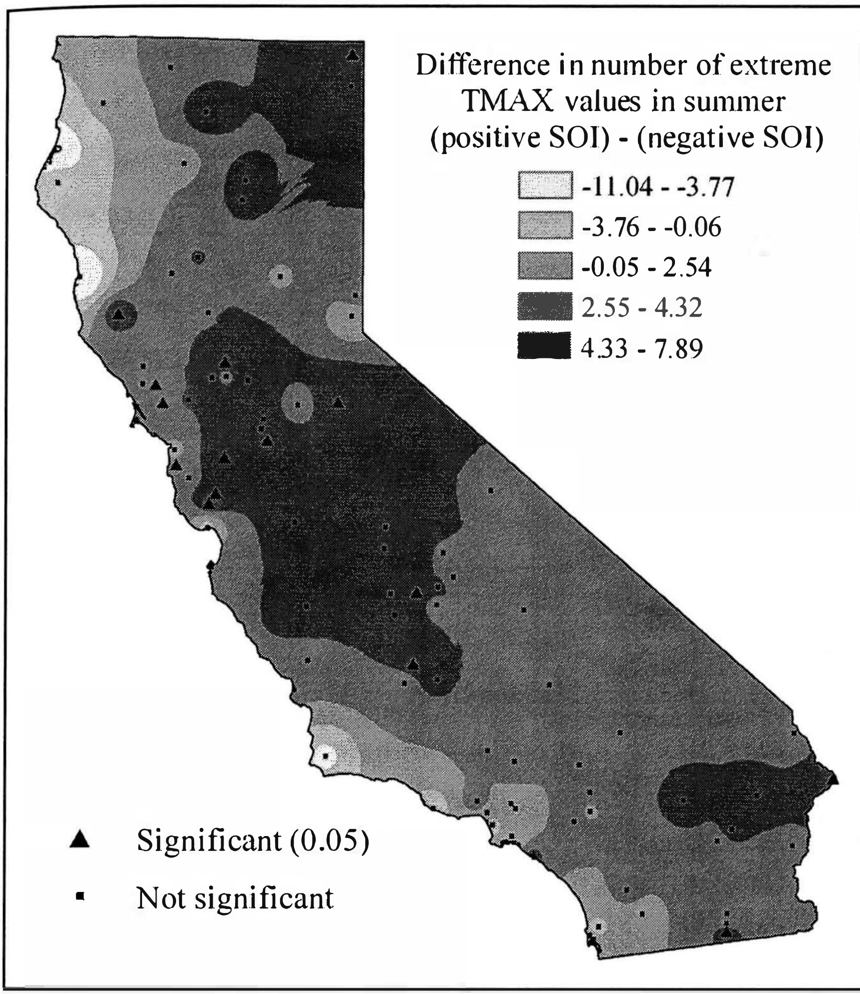

Figure 5.—Difference in the number of summer extreme TMAX events between high and low phases of the SOI (SOI+ minus SOI-).

As discussed above, the PDO is related in its own right to temperature patterns in North America and has also been found to encourage and enhance particular phases of the PNA and ENSO. Accordingly, the PDO can be expected to modify the relationships between these teleconnections and extreme events described here. This impact is examined by comparing the frequency of extreme temperature events between combinations of single phases of the shorter-term teleconnections (SOI and PNA) and the two phases of the PDO. Table 3 lists the numbers of sites that had significant differences in these comparisons for the PNA.

Table 3. Number of sites (out of a possible 90) with significant differences in extreme events for the positive phase of the PNA, comparing positive and negative PDO seasons, and for the negative phase of the PNA compared between positive and negative PDO seasons.

	Positive PNA		Negative PNA	
	(PNA^+ / PDO^+)—(PNA^+ / PDO^-)		(PNA^- / PDO^+)—(PNA^- / PDO^-)	
	TMAX	TMIN	TMAX	TMIN
Spring	7	35	4	22
Summer	5	11	10	20
Fall	15	2	2	36
Winter	*	*	4	23

* Due to the correlation between the patterns, there were insufficient seasons in these categories to perform analysis.

When the PNA is positive, variations in the PDO have relatively minor effects on extreme temperatures. The exception is during spring, when more than a third of the sites have significantly fewer cold TMIN days when the PDO is also positive (Figure 6). Given that the positive PDO is associated with above-average sea level pressure and upper-level geopotential heights (ridging) along the western coast, it appears that the positive PDO amplifies and supports the positive PNA, leading to reduced cold events. These sites are distributed throughout the state, but there is a tendency for larger decreases to be found in the central and far southern areas. Overall, the statistically significant sites average 12 fewer TMIN extremes during the PNA^+/PDO^+ combination, compared to the PNA^+/PDO^- seasons. The PDO has shown indications of switching to a predominantly nega-

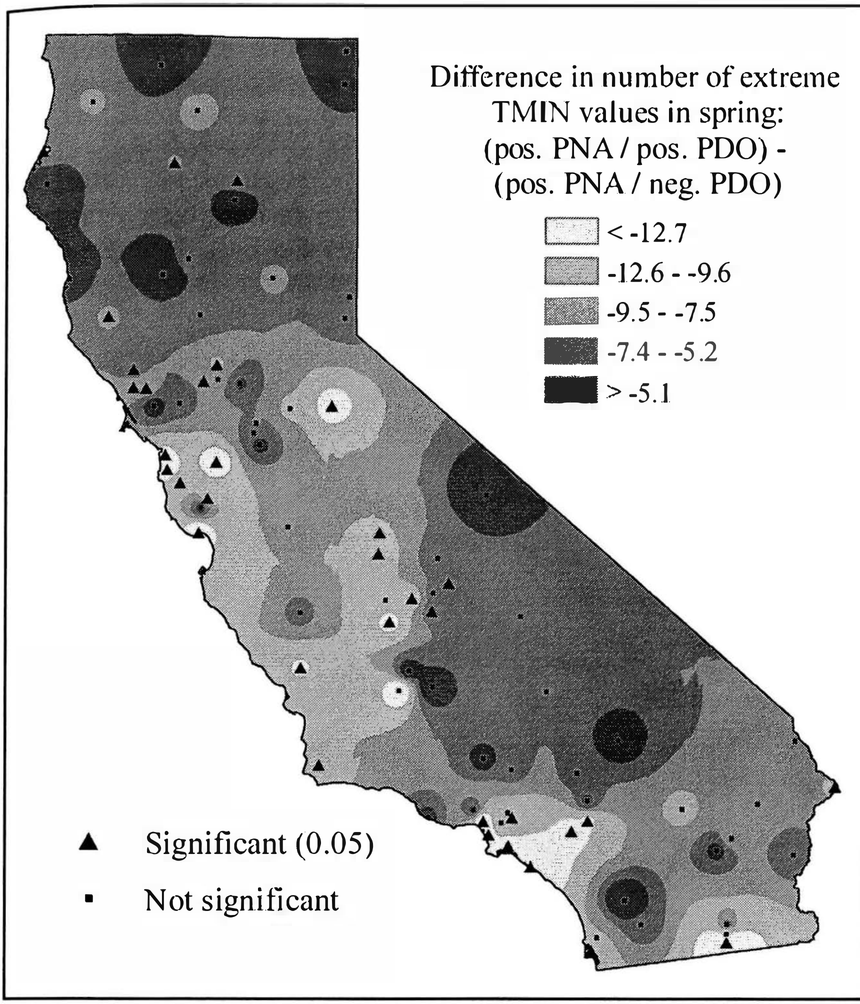

Figure 6.—Impact of the PDO on the frequency of extreme spring TMIN events during the positive PNA (PNA+/PDO+ minus PNA+/PDO-).

tive regime, which suggests a switch to an increased number of cold extremes during the positive PNA as the constructive interference between the two patterns is removed.

During the negative phase of the PNA, which is a generally zonal upper-level pattern across the U.S., variations in the PDO correspond to significant differences in the frequency of extreme cold events throughout the year. In winter, the 23 sites with significant differences average nearly 12 fewer cold TMIN days during years with the PNA^{-}/PDO^{+} combination than the seasons when the indices are in phase. The statistically significant differences are well distributed across California (Figure 7), but the southern half of the state shows a generally larger magnitude of change. As with the positive PNA, the PDO appears to augment the negative PNA when the two indices are in phase. The negative PDO corresponds to reduced geopotential heights and lower SLPs over the west coast—this pattern allows increased cold air intrusion from the north and more frequent cyclonic activity over the state. A switch toward a more negative PDO regime may result in an increased frequency of cold events during the negative PNA.

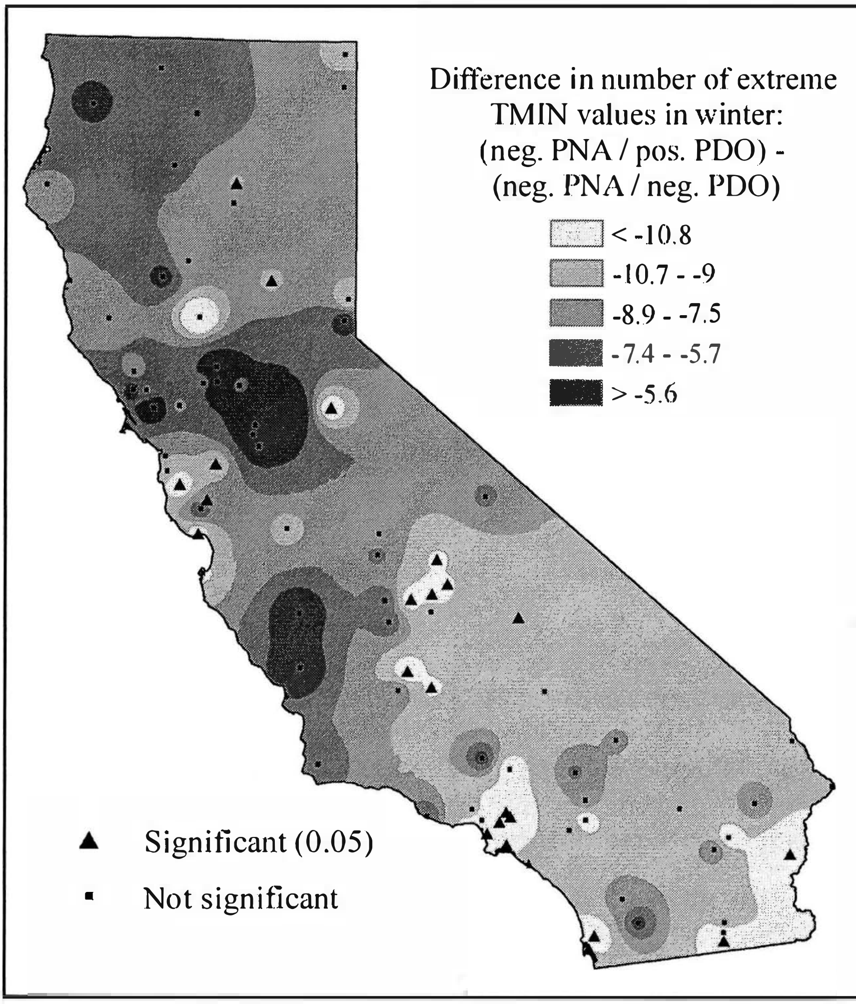

Figure 7.—Impact of the PDO on the frequency of extreme winter TMIN events during the negative PNA (PNA-/PDO+ minus PNA-/PDO-).

The fall season experiences the most widespread difference in cold event frequencies between the PNA/PDO phase combinations, with significant differences averaging approximately 10 fewer cold extremes during the PNA⁻/PDO⁺ combination at 36 sites. These sites are distributed along the coastal half of the state from north of the Bay Area to the southern border, with a cluster of large differences in the southern Central Valley (Figure 8). Spatially, the spring pattern is similar to the fall pattern, except that fewer sites have significance.

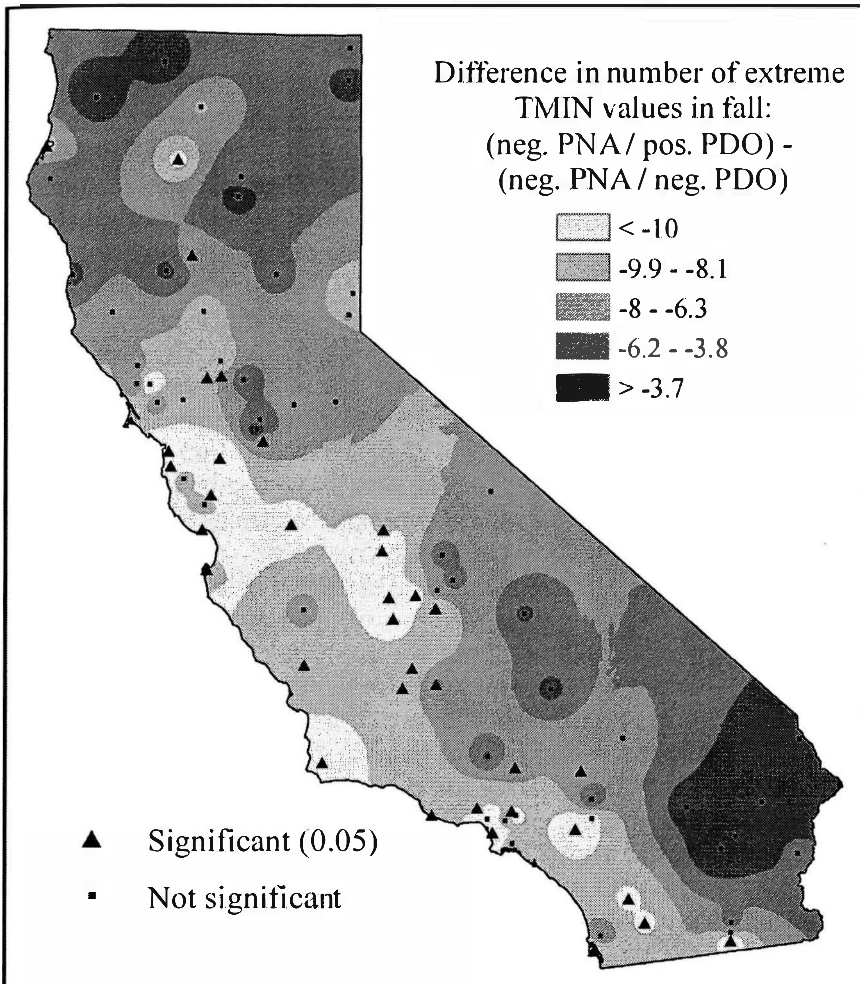

Figure 8.—Impact of the PDO on the frequency of extreme fall TMIN events during the negative PNA (PNA-/PDO+ minus PNA-/PDO-).

As with the PNA, the phase of the PDO has been found to augment or interfere with the patterns produced by variations in the SOI. In general, the positive phase of the PDO enhances the North Pacific troughing associated with the negative (warm) phase of the SOI, while the negative phase of the PDO interferes with the warm SOI pattern. Conversely, the positive (cold) SOI is enhanced by the negative PDO. Significantly, the west coast ridging associated with cold-phase (La Niña) SOI patterns appears to be shifted westward and offshore during negative PDO phases (Gershunov and Barnett 1998; Yu and Zwiers 2007).

The numbers of sites that have significant differences in extreme-event frequencies between the positive/negative SOI and PDO combinations are shown in Table 4. For both phases of the SOI, variations in the PDO predominantly affect extremes in the spring, with few significant differences in the rest of the year. The positive (La Niña) phase of the SOI experiences particularly widespread modification by the PDO during spring; half of the sites have significantly more spring TMAX extremes (13 more days/season, on average) when the SOI and PDO are in phase (Figure 9). This is likely due to the enhanced ridging directly over the region during this teleconnection combination. The largest differences are found in the southern quarter of the state and all the way up the coast—the central valley and eastern portions of the state show only small and insignificant differences. Also in spring, a third of the sites show significant decreases in the frequency of extreme cold events during the SOI^{+}/PDO^{+} combination compared to when the PDO is negative—these differences are larger than the concurrent increase in TMAX extremes, averaging approximately 16 fewer days per season, and are concentrated in the western half of the state from the Bay Area to the south coast. When the PDO is negative, the offshore shift of the ridge during La Niña events allows an increased flow of cold air from the north and thus an increase (decrease) in cold (warm) extremes. Given that the PDO has been mainly positive for the past few decades, this result suggests that the impact of La Niña events on extreme events has been skewed in the warm direction—a regime change in the PDO may allow cold ENSO patterns to produce more spring cold events and fewer spring hot days.

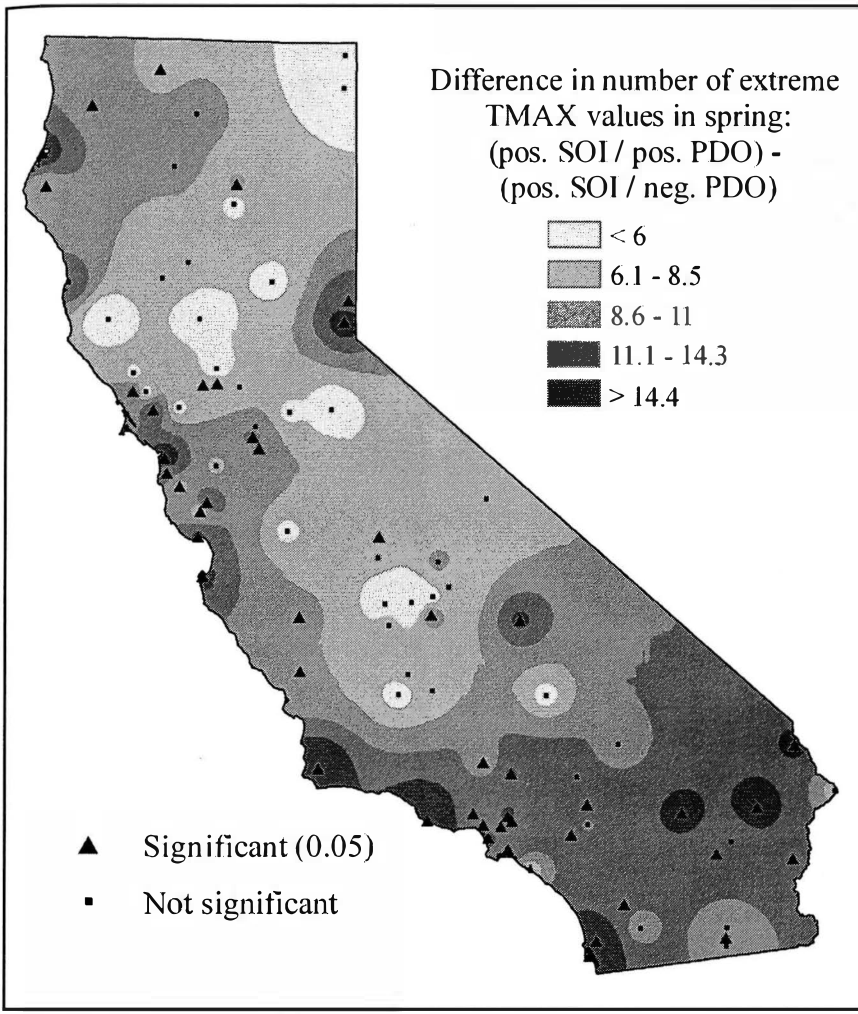

Figure 9.—Impact of the PDO on the frequency of extreme spring TMAX events during the positive SOI (SOI+/PDO+ minus SOI+/PDO-).

Table 4. Number of sites with significant differences in extreme events for the positive phase of the SOI, comparing positive and negative PDO seasons, and for the negative phase of the SOI compared between positive and negative PDO seasons.

	Positive SOI		Negative SOI	
	(SOI^+ / PDO^+)—(SOI^+ / PDO^-)		(SOI^- / PDO^+)—(SOI^- / PDO^-)	
	TMAX	TMIN	TMAX	TMIN
Spring	48	30	1	28
Summer	8	14	2	13
Fall	5	10	3	0
Winter	0	3	4	10

The phase of the PDO has less of an impact on extreme-event frequencies during the negative (El Niño) phase of the SOI. The only widespread impacts are in spring, when almost a third (28) of the sites have significantly fewer (by approximately 8 days/season) cold TMIN events during the SOI^-/PDO^+ combination. The mechanism for this result is likely the lower-than-normal sea-level pressures in the North Pacific when the positive PDO is augmenting the El Niño pattern, which would result in an enhanced flow of warm subtropical air, especially into the southern half of the state. These sites are heavily concentrated in the coastal half of the state between Sonoma and San Luis Obispo counties (Figure 10), with a few sites grouped on the north coast. Again, a negative shift in the PDO may result in more cold spring days during warm ENSO events, as this constructive interference is reduced.

Summary

The phase of teleconnection indices such as the PNA and SOI has been found to be significantly related to the frequency of occurrence of extreme temperature events, to a degree that varies both spatially and seasonally. Both indices predominantly affect the frequency of extreme cold (TMIN) events, particularly in the cold season.

The PNA is generally associated with a change in extreme-event frequencies that is commensurate with an upward shift in the overall temperature distribution during its positive phase. Throughout the

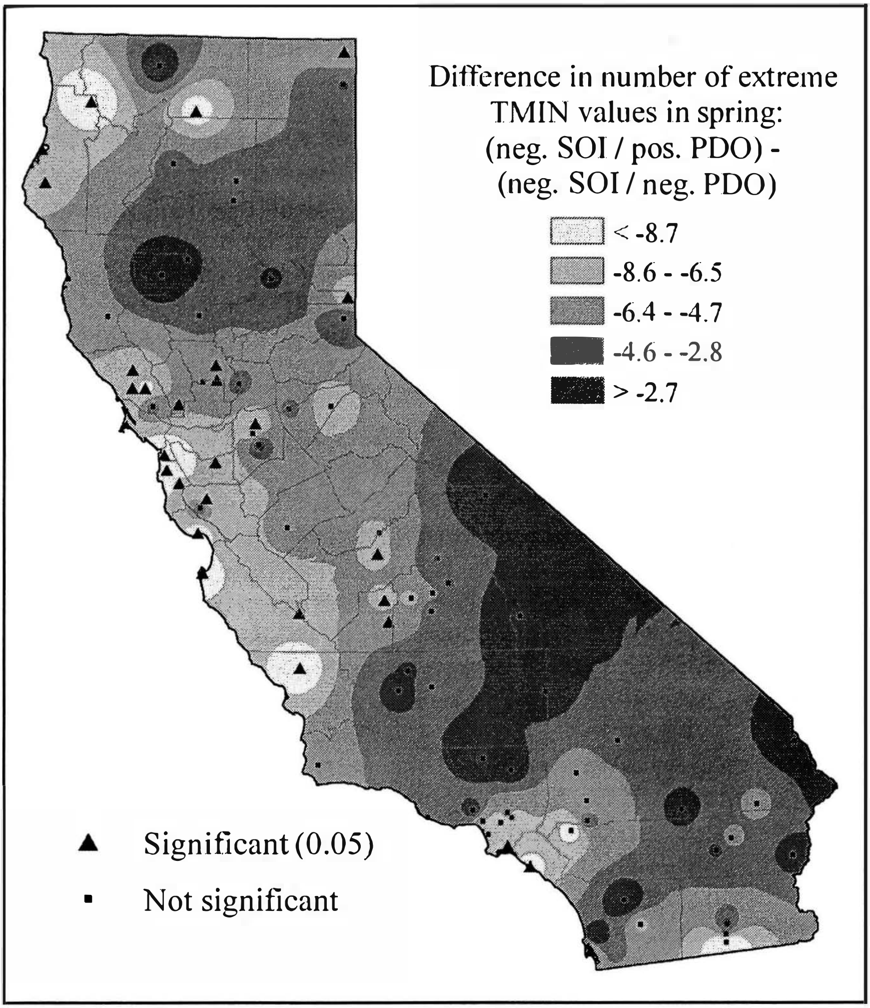

Figure 10.—Impact of the PDO on the frequency of extreme spring TMIN events during the negative SOI (SOI-/PDO+ minus SOI-/PDO-).

cold season, but especially in winter, the positive PNA produces an increased frequency of anomalously warm events and a decreased frequency of extreme cold events. The primary mechanism behind this relationship is likely the enhanced ridging over the region during the positive PNA, which steers cold northern air around the region and allows southerly flow and anticyclonic warming to dominate. The SOI significantly influences extreme-event frequencies at fewer sites than the PNA, and it differs in that the positive SOI (La Niña) produces an increased frequency of both hot and cold events, albeit at different times of the year. The impact on cold events is mainly seen in the spring, when clear conditions and northerly flow encourage colder nights during La Niña, while the smaller increase in hot events shows up in the summer.

The concurrent phase of the PDO appears to influence the effects that the other two teleconnections have on extreme temperatures in California. In particular, the PDO modifies the frequencies of extreme TMAX and TMIN events in spring during positive (La Niña) SOI events, with more hot events and fewer cold events when the indices are in phase. Both phases of the SOI are associated with fewer spring cold events when the PDO is positive compared to the negative PDO.

The PDO appears to enhance the impacts of the PNA when the indices are in phase, and counter the PNA impacts when out of phase. For the negative PNA, there tends to be a reduction in extreme cold days throughout the year when the PDO is positive. As the PDO is currently due for a switch back to the negative, these findings suggest that the negative PNA and both warm and cold ENSO events may be a source of more frequent cold days in the future. Overall, the PDO appears to have broader impacts on the positive phase of the SOI and the negative phase of the PNA than on the other phases.

An important caveat that applies to these results is that the climate processes addressed here do not operate in isolation. Extreme temperature events are influenced by a variety of factors, including other simultaneously operating teleconnection patterns, long-term trends in global/regional climate, and land cover changes at the observation sites. A particular concern is that the time period of this study overlaps with only one complete cycle of the PDO, which means that most of the positive PDO seasons are toward the end of the record. This is cause for caution, as any long-term trends in temperature (and extreme-event frequencies) from sources not associated with the PDO will be spuriously and unavoidably combined with the PDO impacts. Despite these issues, the results presented here should provide insight into the spatial and seasonal patterns of extreme temperatures that may be expected as the dominant modes of circulation in North America and the Pacific vary in phase. These findings may be of particular importance if/when the PDO completes its transition back to predominantly negative condition. Considering that extreme events tend to be potentially damaging and disruptive weather phenomena, understanding the mechanisms that influence their occurrence should prove beneficial as the regional climates of the west coast vary in the coming century.

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Late 20th Century Land Change in the Central California Valley Ecoregion

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Abstract

This research challenges two general assumptions of land-cover change in California's Central Valley ecoregion. They are (1) the primary land-cover change occurring in urbanization of agricultural lands, and (2) that the ecoregion experienced a rapid decline in farmland between 1973 and 2000. Our findings indicate that while urbanization is significant, it is secondary to conversions occurring between agriculture and rangelands (grasslands/shrublands). Furthermore, we estimate that farmland increased in area over the study period, expanding from 71.6% of the ecoregion in 1973 to 72.4% in 2000, a net increase of 357 km^2. New agricultural lands were often found at the ecoregion periphery in the form of nut orchards and grapes, indicating a general shift away from traditional low-risk and low-value field crops to high-risk and high-value specialty crops. Rangeland is estimated to have declined by nearly 20%, from 19.2% of the ecoregion in 1973 to 15.4% in 2000, while developed lands increased from 6.5% to 9.0% over the same time period. Changes between agriculture and rangeland accounted for over 70% of all estimated change, while changes directly associated with urbanization accounted for approximately 14% of all identified land-cover change. Across all land-cover classes, we estimated that 12.4% of the ecoregion changed from one land-cover type to another during the 27-year study and that the period of highest change was between 1973 and 1980. Many drivers may explain these results, including the influence of regional climate variability and drought. This research suggests that drought, if severe enough over an extended number of years, has the potential to significantly influence rates and types of regional land-cover change. Understanding these coupled human-environment relationships has implications for monitoring biogeochemical systems, natural resources, and ecosystem services at local to regional scales.

Introduction

Since the early 1970s, space-borne satellite imaging has facilitated the understanding of complex socio-environmental systems. The ability to analyze large amounts of spectral information regarding landscape condition has enabled researchers to gain perspective of earth-surface processes at multiple spatio-temporal resolutions. Space-borne imaging systems have been used to study Earth systems, including atmospheric and climate processes, ocean surface conditions, and quantification of landscape composition. Furthermore, there is an extensive body of scientific literature describing methods and efforts to detect and quantify land-use and land-cover change (LULCC) at various spatial and temporal scales. Despite the widespread use and acceptance of satellite remote-sensing techniques, there is generally a lack of comprehensive and consistent spatio-temporal information on the rates and types of LULCC.

In 1999 the National Research Council issued a report titled *Measures of Environmental Performance and Ecosystem Condition,* which emphasized a need for data on land-use and land-cover change (NRC 1999). In 2000 an NRC report titled *Ecological Indicators for the Nation* identified land use as the single largest driver of ecological change (NRC 2000). In 2000, at the request of the National Science Foundation, the NRC was tasked with identifying the grand challenges in Environmental Science and determined land-use dynamics to be one of eight grand challenges within the context of environmental problems. The NRC report identified LULC changes as "...major contributors to global climate change, to the loss of global biotic diversity, and to the reduced functioning of ecosystems and the essential services they provide to humans" (NRC 2001). Furthermore, the NRC identified important areas for research, the first being development of long-term, regional databases for land uses, land covers, and related social information (NRC 2001). Foley et al. (2005) contend that changes in land use have necessitated consumption of an increasing share of global resources at the potential expense of the capacity of ecosystems to sustain food production, maintain water and forest resources, regulate climate and air quality, and ameliorate infectious diseases.

While changes in LULC are generally recognized as having important influences on climate and air quality at multiple scales (Foley et al. 2005) with direct linkages to the fluid global systems of the biosphere (Turner and Meyer 1991), the role of LULCC and variability in altering regional temperatures, precipitation, vegetation, and other climate variables has been mostly ignored by the Intergovernmental Panel on Climate Change (Pielke 2005). Feddema et al. (2005) conclude that most significant regional climate effects are associated directly with land-cover conversions in mid-latitude and tropical areas and demonstrate that land-cover effects can significantly alter regional climate outcomes associated with global warming. Their results demonstrate the importance of including LULCC in forcing scenarios for future climate-change studies. Undertaken at various spatial and temporal scales, research in LULCC is needed to improve understanding of patterns and dynamics that affect the structure and function of Earth systems consistent with global environmental change (Rindfuss et al. 2004).

In response to the need for regional information describing LULCC, the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) developed a regionally consistent approach, using an analysis framework based on EPA Level III Ecoregions (Omernik 1987; EPA 1999), to determine the rates, causes, and consequences of late 20th century LULCC for the conterminous United States (Loveland et al. 2002). This article describes efforts to detect, quantify, and describe LULCC change in the Central California Valley ecoregion (Central California Valley or "Central Valley") (Omernik 1987; EPA 1999).

Central California Valley ecoregion

The Central Valley is an elongated alluvial valley running north to south in excess of 650 km, with an average width of approximately 50 km (Figure 1). Agriculture is the dominant land cover found in the ecoregion and comprises approximately 70% of total land area (Vogelmann et al. 2001). Six of California's top eight agricultural counties are found at least partially within the Central Valley and are all located in the southern portion of the ecoregion (USDA 2008a). Major commodities produced in the Central Valley include milk and cream, grapes, almonds, cattle and calves, tomatoes, cotton, walnuts, and rice. California leads the nation in production of nearly 80 crops, including almonds, American Pima cotton, grapes (raisin, table, and wine), alfalfa, lettuce, lemons, milk, olives, tomatoes, and walnuts (USDA 2008a). California has led the nation every year since 1948 in agricultural cash receipts, recording $31.7 billion in 2005 (Sumner, Bervejillo, and Kuminoff 2003; USDA 2008b). A thorough discussion of the evolution of California agriculture can be found in Olmstead and Rhode (2003).

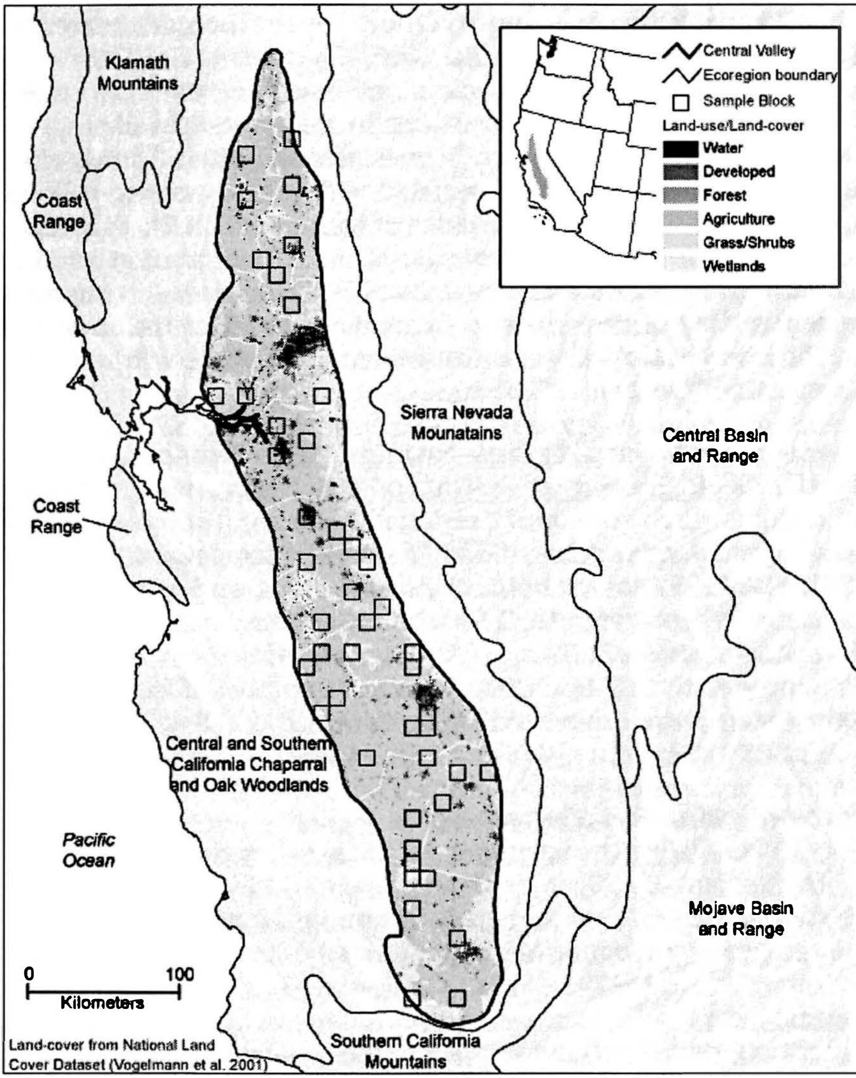


Figure 1.—Location map of the Central California Valley ecoregion, with ecoregion (Omernik 1987) and stratum boundary. Ecoregion stratum boundary is defined as the extent of all 10 km grid cells assigned to the Central California Valley ecoregion. Also present are the 48 randomly selected 10 km x 10 km sample blocks used for analysis in this research project.

The Central Valley is surrounded by the Oak Woodlands ecoregion (Figure 1). The transition between these two regions is characterized by gently sloping foothills dominated by grasslands and oak savannah (Figure 2). Due to the generalization of ecoregional boundaries,

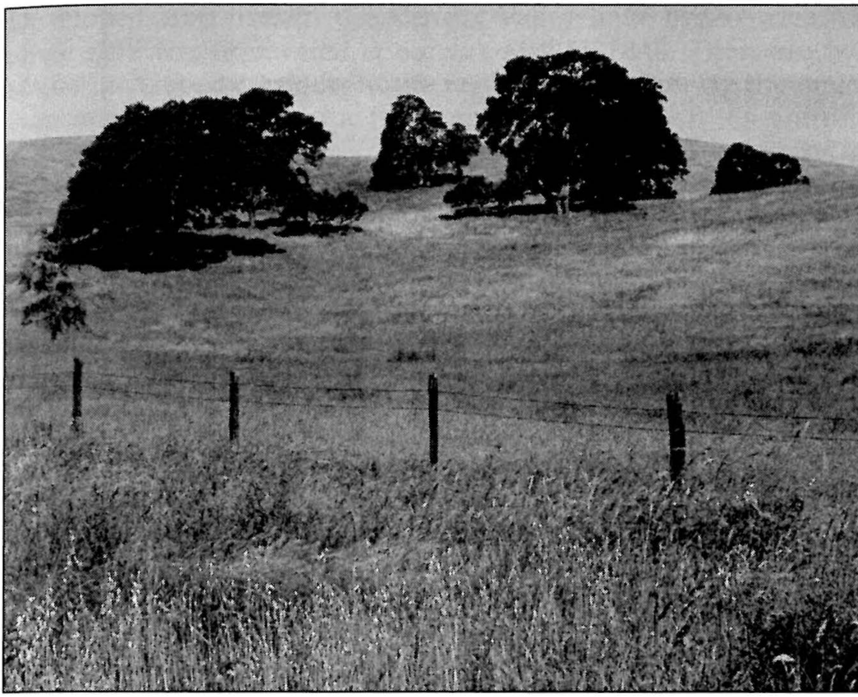


Figure 2.—The transition area between the Central California Valley and Central and Southern California Chaparral and Oak Woodlands ecoregions (Omernik 1987). This region is characterized by gently rolling hills, typically dominated by grasslands and oak savannahs. (Photograph by Christian Raumann, 18 May 2006.)

there are numerous areas where grassland-oak woodland savannahs are found within the Central Valley ecoregion, although they are not the primary landscape naturally occurring to the region. In these areas, livestock grazing has been the traditional land use, along with irrigated and dry-land cropping. Agriculture that does have a presence at the ecoregion periphery includes citrus, nut crops such as almonds and walnuts, and vineyards.

Grasslands/shrublands are not limited to the Central Valley ecoregion periphery, and at one time, prior to European settlement, they dominated the ecoregion's land cover. While agricultural development and expansion since the mid-19th century has largely removed most of the native grasslands, wetlands, and desert shrubs common to the ecoregion, the U.S. Fish and Wildlife Service manages numerous wildlife refuges and wildlife management areas where grasslands still exist (Figure 3).

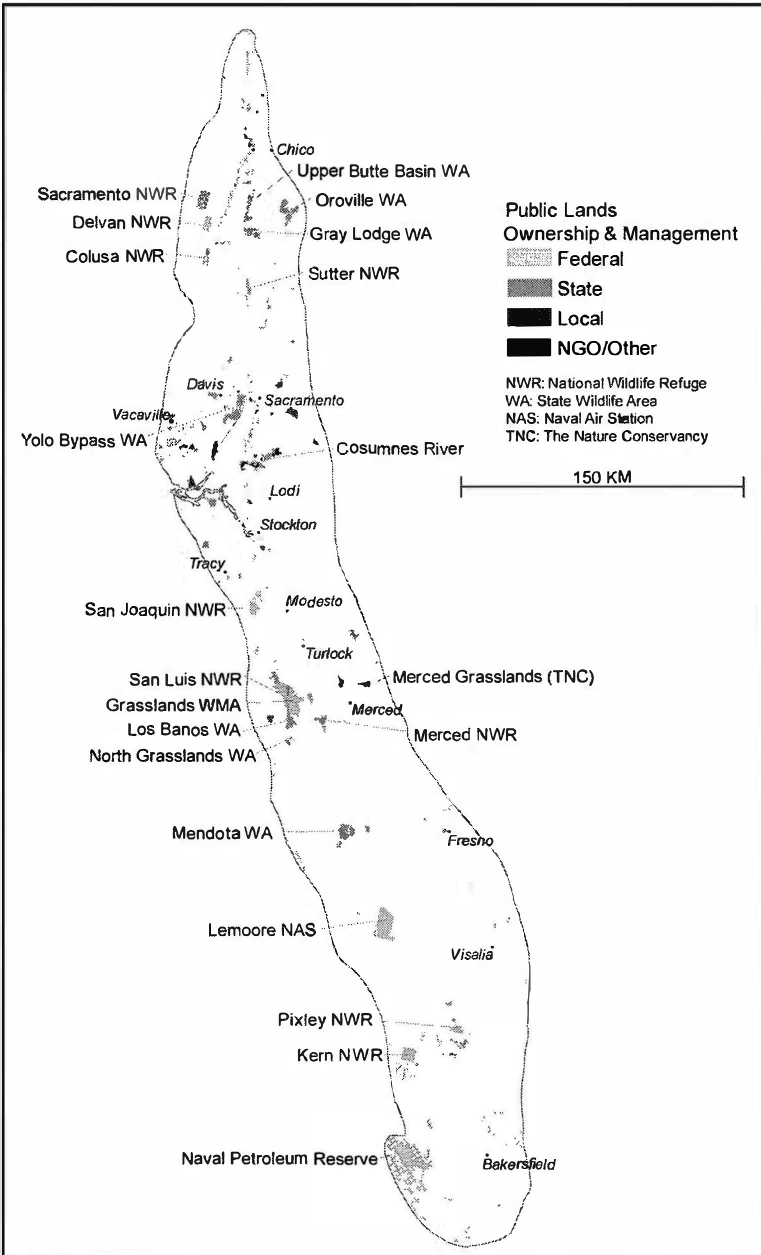


Figure 3.—State and federally managed wildlife and other "natural" areas within the CCV ecoregion. Organizations representing waterfowl interests, such as Ducks Unlimited and the California Waterfowl Association, also play an active role in management of wetlands and other critical wildlife habitat areas.

Developed land uses in the Central Valley have been increasing since gold was discovered at Sutter's Mill in 1848. There are two major developed corridors in the region, both following the major transportation routes through the ecoregion. Highway 99, running north to south along the eastern edge of the ecoregion connects Bakersfield, Fresno, Modesto, Stockton, and Sacramento, while Interstate 80 joins Sacramento, Davis, Vacaville, and Fairfield with the San Francisco Bay Area. Significant growth has also occurred at Los Banos, which serves as a commuter shed for San Jose and Silicon Valley. U.S. Census estimates that in 2000, more than five million people resided in the ecoregion, adding more than a million residents in every decade since 1970 (U.S. Bureau of Census 2008) (Figure 4).

Methods

The Land Cover Trends project (referred to as "Trends") was developed to answer fundamental questions about the rates, causes, and consequences of land-cover change at a regional scale for the conterminous United States, while providing a baseline for future regional land-cover change research (Loveland et al. 2002). While other projects provide a data product or "snap shot" of land cover at a single interval (e.g., National Land Cover Dataset [Vogelmann et al. 2001]), the objective of Trends is to establish a temporal framework that is applied consistently across the nation for the purpose of comparative analysis, so as to understand the spatial and temporal variability associated with land change. Ideally, a wall-to-wall mapping effort would have been undertaken to accomplish this goal of providing LULCC information for the nation. However, such an approach, carried out at a regional scale, would be too costly and time prohibitive. To overcome these obstacles, a sampling approach was employed, using an ecoregion framework, to categorize local to regional landscape change (Stehman, Sohl, and Loveland 2003). Trends provides estimates of land-cover composition and change at the regional scale through the identification of local processes. Following is a brief description of the Trends methodology. For a complete description, see Loveland et al. (2002), Stehman, Sohl, and Loveland (2003), and Sohl, Gallant, and Loveland (2004).

Ecoregion Stratification

EPA Level III Ecoregions of the United States (Omernik 1987; U.S. Environmental Protection Agency 1999) were chosen to stratify the conterminous U.S. into primary reporting units. Ecoregions are char-

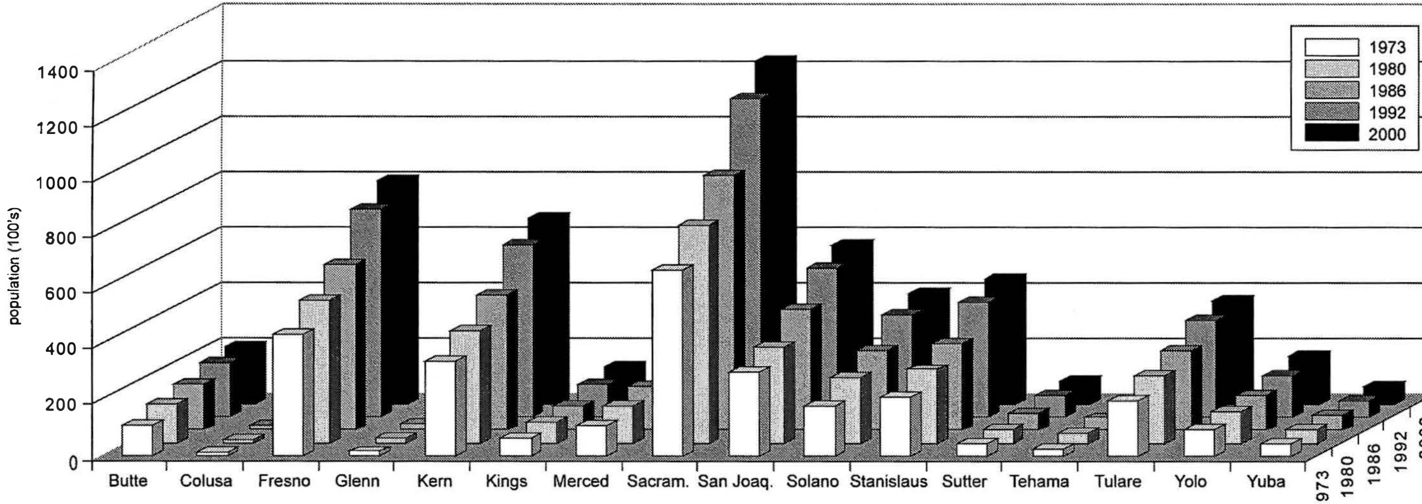


Figure 4.—Population trends in selected California counties between 1970 and 2000.

acterized by the range and availability of resources and thus reflect areas of relative homogeneity corresponding well with patterns of land cover, urban settlement, agricultural variability, and resource-based industries (Gallant et al. 2004). While other stratifications exist, Omernik ecoregions were chosen because they incorporate primary land use into the identification of regional boundaries (Omernik 1987; Loveland et al. 2002; Gallant et al. 2004).

Sampling Design

A pure panel sampling design was used where selected samples were the same for all time periods (Fuller 1999; Stehman, Sohl, and Loveland, 2003). Spatially, a stratified one-stage cluster sample was used where the clusters were 10 km by 10 km spatial units (hereinafter called "10 km blocks"). Within each 10 km block, features equal to or larger than a minimum unit of 60 m by 60 m were mapped. The 10 km blocks serve as the primary sampling unit (PSU), and the 60 m pixels serve as secondary sampling units (SSU). A fixed grid of 10 km blocks was overlain across the conterminous United States. Ten-kilometer blocks were then stratified geographically using EPA Level III Ecoregions and assigned to an ecoregion based on center-point location. The collection of 10 km blocks assigned to an ecoregion, or "stratum," corresponds closely, but not exactly, to the irregular shape of the ecoregion boundary. For this reason, we report results in this article for the stratum (i.e., the extent of all blocks assigned to an ecoregion; hereinafter Central Valley stratum or stratum) as opposed to the ecoregion. Next, a random sample of PSUs is selected with the *a priori* goal of estimating LULCC at ± one percent for an 85% confidence interval (Loveland et al. 2002).

Based on ecoregion size and expected LULC change and variability, sampling for the Central California Valley ecoregion consisted of 48 sample blocks (out of a total population of 458) (Figure 1). In addition to being randomly selected, sample blocks were assigned to image interpreters at random to reduce interpretative bias. Upon completion of interpretation of all sample blocks for an ecoregion, a consistency check was performed to identify illogical conversions followed by a peer review of mapping work. When compared to complete area coverage efforts, sampling is often the preferred method due to reduced costs, timely reporting, and comparable levels of uncertainty (Cochran 1977; Sohl, Gallant, and Loveland 2004). For a complete discussion of uncertainty associated with the Land Cover Trends sampling approach and uncertainty associated with a census approach, see Stehman (2005).

Data Sources

Five dates of Landsat imagery were used as reference images for detection of LULC change. Due to the cost typically associated with collection of these data at a national scale, several existing databases were leveraged to minimize data acquisition expenditures and ensure relatively high-quality, cloud-free scenes. Temporal center points were identified based on availability of existing Landsat data collections, namely the North American Landscape Characterization (NALC) Program (Sohl and Dwyer 1998) and the Multi-Resolution Land Characteristics (MRLC) Consortium (Loveland and Shaw 1996). NALC data holdings consisted of three dates of Landsat MSS imagery centered on 1973, 1986, and 1992. These data were re-sampled to a 60 m spatial resolution and projected to an Albers conical equal area projection. MRLC data consists of Landsat TM and ETM imagery at a 30 m spatial resolution centered on years 1992 and 2000. To supplement the imagery available from these two national programs and ensure a consistent 6- to 8-year temporal interval, a new data acquisition was made for Landsat MSS centered on year 1980. The new 1980 MSS images were also referenced to the Albers projection with a pixel resolution of 60 m. Terrain correction was applied to each new 1980 image to ensure proper co-registration between image dates. The final Trends Landsat database then consisted of images centered typically ± 2 years of 1973, 1980, 1986, 1992, and 2000 (Table 1).

Table 1: Landsat database used for Land Cover Trends research project.

INTERVAL	LANDSAT SENSOR	DATABASE	SPATIAL RESOLUTION
1973	MSS	NALC	60 meter
1980	MSS	New Acquisition	60 meter
1986	MSS	NALC	60 meter
1992	MSS; TM	NALC; MRLC	60 meter; 30 meter
2000	ETM	MRLC	30 meter

Classification Approach

The National Land Cover Dataset (NLCD) (Vogelmann et al. 2001) was chosen to serve as a reference product to derive an initial land-cover classification. The NLCD data was recoded from its original 21 Anderson level II classes to a modified Anderson level I scheme to meet LULC change mapping needs (Anderson et al. 1976). For the southwest region, NLCD level I overall accuracy was 85% with a standard error of 2% (Wickham et al. 2004). The 11 broad land-cover classes chosen were: water, developed or built-up, mining, barren, forest, grasslands and shrublands (rangeland), agriculture, wetlands, perennial snow and ice, mechanical disturbance (timber cutting and scraping and leveling of land prior to development), and non-mechanical disturbance (fire, storms, pest-infestations etc.).

Manual interpretation was used to partition land cover into one of 11 land-cover classes, based on the Anderson Level I classification system (Anderson et al. 1976). Interpretation of Landsat imagery was facilitated with the use of ancillary data such as aerial photographs, topographic maps, and other spatially explicit sources of information. The 1992 NLCD (Vogelmann et al. 2001) was used as a land-cover reference point. While NLCD provides a decent starting point for LULCC mapping, it is not appropriate in its original form for use at the local scale. Due to the "speckled" nature of NLCD, interpreters commonly had to clean up the product or start with an entirely new land cover interpretation, which LULCC mapping was based upon. Image interpreters used the 1992 Landsat TM image, as well as other ancillary data sources such as aerial photographs, to derive a suitable land-cover product for the 1992 date. Once land cover was mapped for the 1992 period, interpreters forward- and backward-classified LULCC for the remaining four dates. This was accomplished by comparing Landsat images from successive dates and visually identifying areas of LULCC. Upon completion of mapping, change estimates were generated using post-classification comparison of LULC products from the multiple dates.

Sample block change products provide estimates of land-cover change with defined bounds of uncertainty in three different categories. *Net change* is the difference in area of a land-cover class between time *t* and *t-1*. *Gross change* is the total area that changed (i.e., gains plus losses) in a given land-cover class between time *t* and *t-1*. The third type of change is *conditional gross change*. For example, of the area that was classified as developed in time *t*, how much of that area was agriculture in time *t-1*, how much of that area was grasslands/shrublands in time *t-1*, etc.? Formulas to estimate net, gross, and conditional gross change and corresponding margins of error can be found in Stehman, Sohl, and Loveland (2003).

Results

Spatial Area Change

Gross spatial area change (or "footprint") for the Central California Valley ecoregion, meaning the percent of stratum area that changed land-cover type at least one time between 1973 and 2000, was estimated at 12.4% of stratum area (5,670km^2) with a margin of error of 3.0% (±1,351 km^2) for an 85% confidence interval (Table 2).

Table 2: Gross spatial area change, 85% confidence interval, standard error, and relative error for the Central California Valley ecoregion.

			MARGIN OF ERROR (85% CI)				
	FOOTPRINT OF CHANGE	% of ECOREGION	+/- (%)	LOWER BOUND	UPPER BOUND	STANDARD ERROR	RELATIVE ERROR
(1973–2000)	*ALL CHANGE*	*12.4%*	*3.0%*	*9.4%*	*15.3%*	*2.0%*	*16.3%*
	1 Change	9.3%	2.0%	7.3%	11.2%	1.3%	14.4%
	2 Changes	2.5%	1.3%	1.3%	3.8%	0.9%	34.5%
	3 Changes	0.6%	0.2%	0.3%	0.8%	0.2%	27.2%
	4 Changes	0.0%	0.0%	0.0%	0.0%	0.0%	36.2%

Most locations changed only once (74.8% of gross change; 4,241 km^2). Multiple changes (i.e., pixels changing two, three, or four times) accounted for the remaining 25.2% of gross change, or 1,429 km^2. Table 2 shows the breakdown of estimated spatial area change with associated margins of error, lower and upper bounds, and standard and relative error. Relatively low standard error indicates high levels of confidence in gross spatial area change estimates.

Gross Change by Interval

Gross change was also estimated for each temporal interval. The period 1973 to 1980 had the highest estimated change, with 5.7% of the stratum (2,615 km^2) changing from one land-cover type to another between the two dates. The 1980 to 1986 interval was estimated at 3.3% (1,498 km^2); the 1986 to 1992 interval at 3.0% (1,388 km^2); followed by the 1992 to 2000 period at 4.1% change (1,873 km^2). Net change estimates, margins of error, lower and upper bounds, standard error, and relative error can be found in Table 3.

Table 3: Estimated change by temporal period, 85% confidence interval, standard error, relative error, and estimated normalized average annual change given as both percent of stratum area and in square kilometers.

% stratum		85% CONFIDENCE INTERVAL					
	% of ECORE-GION	+/- (%)	LOWER BOUND	UPPER BOUND	STANDARD ERROR	RELA-TIVE ERROR	AVERAGE ANNUAL %
1973 to 1980	5.7%	1.4%	4.3%	7.1%	1.0%	17.1%	0.8%
1980 to 1986	3.3%	0.8%	2.4%	4.1%	0.6%	17.6%	0.5%
1986 to 1992	3.0%	1.2%	1.8%	4.3%	0.8%	27.5%	0.5%
1992 to 2000	4.1%	1.3%	2.8%	5.4%	0.9%	22.4%	0.5%

km^2		85% CONFIDENCE IN-TERVAL					
	ECORE-GION AREA	+/- (km^2)	LOWER BOUND	UPPER BOUND	STANDARD ERROR	RELA-TIVE ERROR	AVERAGE ANNUAL km^2
1973 to 1980	2615	655	1960	3266	1.0%	17.1%	376
1980 to 1986	1498	385	1113	1882	0.6%	17.6%	247
1986 to 1992	1388	559	829	1951	0.8%	27.5%	234
1992 to 2000	1873	614	1260	2482	0.9%	22.4%	234

Due to the varying lengths of temporal intervals, temporal comparison of change estimates was accomplished by calculating average annual estimates of change for each period. This is accomplished by simply dividing the estimated change rate by the length of the temporal interval. Average annual change was highest between 1973 and 1980, at an estimated 0.8% (376 km^2) per year, while the following three intervals remained relatively constant at 0.5% (247 km^2) per year for the 1980 to 1986 period and 0.5% for both the 1986 to 1992 and 1992 to 2000 intervals (231 km^2 and 231 km^2, respectively).

To determine whether there was a statistically significant difference between change estimates for the four temporal intervals, a Wilcoxon test (Wilcoxon 1945) was used to determine to what extent the difference in mean rank of change estimates is significant. Statistically significant differences were observed where $P<0.05$, that is, the probability that the observed difference could be the result of random fluctuations in the variables (i.e., estimates of change in two intervals), indicating that estimates of change for the 1973 to 1980 interval were in fact different from the other three intervals, while comparison of the last three intervals does not reveal any statistical difference. This indicates that the rate of gross change was relatively stable between 1980 and 2000, showing very little variability between temporal periods.

Net Change

Change in individual land-cover types, or net change, is measured at the stratum scale. The land-cover class with the largest change was the grasslands/shrublands class, with an estimated loss of 1,775 km^2. That is, 19.2% of the stratum was grasslands/shrublands in 1973 and decreased to 15.4% by 2000 (Table 4). The second largest net change was an estimated increase of 1,124 km^2 of developed lands (2.5% of stratum area) over the 27-year study period. Agriculture is estimated to have accounted for 71.6% of stratum area in 1973, increasing to 72.4% of stratum area in 2000. Net changes for each LULC class by temporal center point with associated margins of error can be found in Table 4. While net change is an important measure of change across the stratum, it is important to note that it does not reflect the dynamic nature of change over time. Only changes in the developed class followed a typical linear trend, increasing in area in each interval. The agricultural and grassland/shrubland classes experienced significant amounts of gains and losses within each interval and are masked by the net change values.

Testing for statistical significance of LULCC trends over the entire 27-year study period was done for two types of trends, linear and quadratic. A Wilcoxon test (Wilcoxon 1945) was applied to each LULC class to obtain probabilities of the trend being the result of random fluctuations of the percent land cover estimates. The developed, mechanical disturbed, and grassland/shrubland classes were statistically significant linear trends, with $P<0.05$. The grassland/shrubland class was also significant as a quadratic trend, at a significance level of $P<0.05$. The agriculture class was significant as a quadratic trend, at a significance level of $P<0.10$. Trends in LULCC over the study period were not significant in any of the other classes at the $P<0.10$ level, meaning trends in minor land-cover classes could not be measured with any statistical certainty, although those

Table 4: Land cover class estimates for each class in each date presented in percent of stratum and in absolute area (km²).

* Linear trend significance. P values less than 0.05 indicate significance at the alpha=0.05 level.
** Linear trend significance. P values less than 0.10 indicate significance at the alpha=0.10 level
[t] Quadratic trend significance. P values less than 0.05 indicate significance at the alpha=0.05 level.
[tt] Quadratic trend significance. P values less than 0.10 indicate significance at the alpha=0.10 level.

%	WATER		DEVELOPED*		MECH. DIST.*		MINING		BARREN		FOREST		GRASS/ SHRUB*[t]		AGRICUL-TURE[tt]		WETLAND	
	%	85% CI	%	85% CI	%	85% CI	%	85% CI	%	85% CI	%	85% CI	%	85% CI	%	85% CI	%	85% CI
1973	0.7%	0.3%	6.5%	3.1%	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.3%	0.1%	19.2%	5.1%	71.6%	5.8%	1.4%	1.0%
1980	0.7%	0.3%	7.2%	3.4%	0.1%	0.0%	0.2%	0.1%	0.0%	0.0%	0.3%	0.1%	17.7%	4.9%	72.3%	5.7%	1.6%	1.1%
1986	0.8%	0.5%	7.6%	3.5%	0.1%	0.0%	0.2%	0.2%	0.0%	0.0%	0.3%	0.1%	16.7%	4.7%	72.8%	5.6%	1.7%	1.2%
1992	0.7%	0.3%	8.2%	3.7%	0.1%	0.1%	0.2%	0.2%	0.0%	0.0%	0.3%	0.1%	17.3%	5.0%	71.5%	5.8%	1.7%	1.2%
2000	0.9%	0.5%	9.0%	3.8%	0.2%	0.1%	0.2%	0.2%	0.0%	0.0%	0.3%	0.1%	15.4%	4.4%	72.4%	5.6%	1.7%	1.2%
Change	0.2%		2.5%		0.1%		0.0%		0.0%		0.0%		-3.9%		0.8%		0.3%	

km²	WATER		DEVELOPED*		MECH. DIST.*		MINING		BARREN		FOREST		GRASS/ SHRUB*[t]		AGRICUL-TURE[tt]		WETLAND	
	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI	km²	85% CI
1973	299	142	2984	1438	17	9	79	64	2	0	156	60	8806	2345	32803	2666	655	458
1980	328	151	3280	1553	29	18	86	64	2	0	147	60	8097	2221	33116	2597	715	499
1986	358	206	3462	1603	24	14	86	69	2	0	146	55	7641	2148	33324	2546	758	536
1992	322	156	3740	1681	36	27	90	73	3	0	145	55	7933	2276	32764	2670	768	545
2000	411	215	4108	1740	74	37	95	78	2	0	142	55	7031	2034	33160	2551	777	559
Change	112		1124		57		16		0		-14		-1774		357		122	

minor classes combined accounted for less than 2.5% of the entire ecoregion area.

Common Conversions

An understanding of where changes in LULC are coming from and going to can be obtained by examining the most common land-cover conversions. The most common conversion was 3,334 km^2 of grasslands/shrublands converting to agriculture, followed by 1,965 km^2 of agriculture converting to grasslands/shrublands, 684 km^2 of agriculture changing to developed, and 366 km^2 of grasslands/shrublands converting to developed. Combined, these four changes accounted for 86.1% of all estimated change in the stratum. The most common conversions were also calculated for each temporal interval and are presented in Table 5.

In three of the four temporal intervals, grassland/shrublands converting to agriculture was the largest individual conversion, accounting for nearly 50% of all estimated change. While this particular conversion was common in all temporal intervals, it was less common between 1986 and 1992, when it was outpaced by agriculture converting to grassland/shrublands (Figure 5). During this interval, agriculture to grassland/shrublands accounted for an estimated 48.6% of all change (675 km^2), while grassland/shrubland converting to agriculture dropped to 19.5% of total estimated change (271 km^2) (Figure 6). Rainfall records from the same temporal interval indicate a period of long-term, below-average annual precipitation that is believed to have had significant impacts on land use.

During all temporal periods, change from agricultural to developed consistently ranked in the top three land-cover conversions. This conversion was closely followed by grassland/shrublands changing to developed. Over the course of the entire 27-year study period, we estimate 684 km^2 of pasture and/or cropland changed to developed uses, while an additional 366 km^2 converted from grassland/shrubland to developed. The intervals with the highest average annual increase in developed were 1986–1992 and 1992–2000, with an estimated 0.10% of the stratum area (45.8 km^2) changing to developed uses every year. Table 6 shows the total estimated area converted to developed uses from all other classes for each of the four temporal periods.

Table 5: Top five land cover conversions (area), margin of error, and standard error for each interval and overall.

Period	From class	To class	Area changed (km²)	Standard Error (km²)	85% CI +/- (km²)	% of ecoregion	% of all changes
1973–1980	Grass/Shrub	Agriculture	1305	316	462	2.8%	49.9%
	Agriculture	Grass/Shrub	748	240	351	1.6%	28.6%
	Agriculture	Developed	177	64	94	0.4%	6.8%
	Grass/Shrub	Developed	106	51	75	0.2%	4.1%
	Agriculture	Wetland	71	63	92	0.2%	2.7%
	Other classes	Other classes	208	n/a	n/a	0.5%	8.0%
			2615			5.7%	100.0%
1980–1986	Grass/Shrub	Agriculture	734	188	275	1.6%	49.0%
	Agriculture	Grass/Shrub	316	122	176	0.7%	21.1%
	Agriculture	Developed	98	35	52	0.2%	6.5%
	Grass/Shrub	Developed	71	29	43	0.2%	4.7%
	Agriculture	Water	57	47	68	0.1%	3.8%
	Other classes	Other classes	222	n/a	n/a	0.5%	14.8%
			1498			3.3%	100.0%
1986–1992	Agriculture	Grass/Shrubs	675	314	460	1.5%	48.6%
	Grass/Shrub	Agriculture	271	81	119	0.6%	19.5%
	Agriculture	Developed	160	53	77	0.3%	11.5%
	Grass/Shrub	Developed	101	33	49	0.2%	7.3%
	Water	Agriculture	44	39	58	0.1%	3.2%
	Other classes	Other classes	137	n/a	n/a	0.3%	9.9%
			1388			3.0%	100.0%
1992–2000	Grass/Shrub	Agriculture	1024	366	536	2.2%	54.7%
	Agriculture	Developed	249	99	146	0.5%	13.3%
	Agriculture	Grass/Shrub	225	69	101	0.5%	12.0%
	Grass/Shrub	Developed	89	32	46	0.2%	4.8%
	Agriculture	Mech. Disturbed	62	26	37	0.1%	3.3%
	Other classes	Other classes	224	n/a	n/a	0.5%	12.0%
			1873			4.1%	100.0%
Overall:							
1973–2000	Grass/Shrub	Agriculture	3334	792	1160	7.3%	45.2%
	Agriculture	Grass/Shrub	1965	656	960	4.3%	26.6%
	Agriculture	Developed	684	198	289	1.5%	9.3%
	Grass/Shrub	Developed	366	123	181	0.8%	5.0%
	Agriculture	Wetland	165	145	213	0.4%	2.2%
	Agriculture	Water	136	88	129	0.3%	1.8%
	Agriculture	Mech. Disturbed	112	45	65	0.2%	1.5%
	Grass/Shrub	Water	99	41	61	0.2%	1.3%
	Water	Agriculture	77	33	49	0.2%	1.0%
	Water	Grass/Shrub	59	40	59	0.1%	0.8%
	Other classes	Other classes	377	n/a	n/a	0.8%	5.1%
			7374			16.1%	100.0%

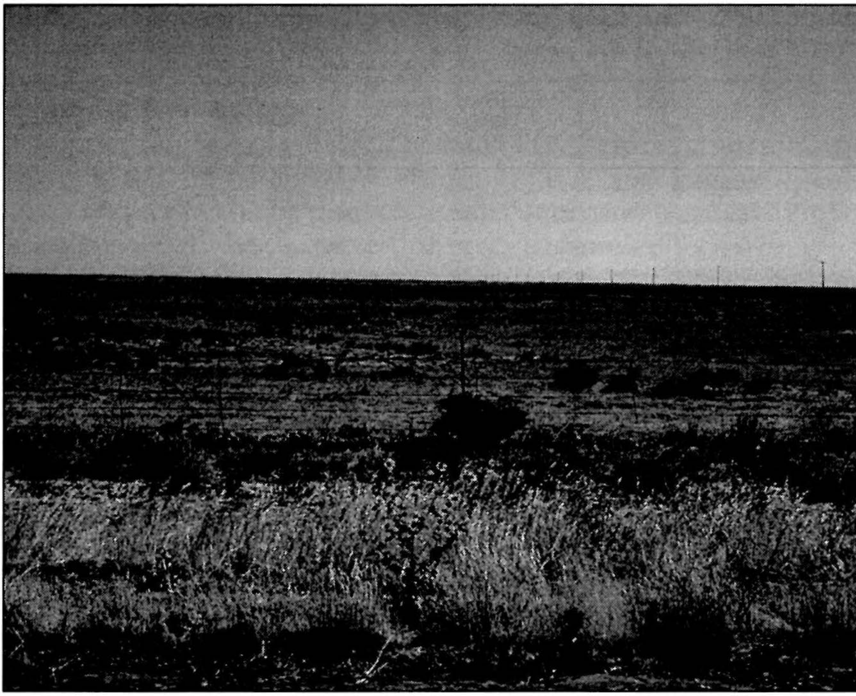


Figure 5.—Large area of natural grassland/shrubland just north of Kern National Wildlife Refuge in northern Kern County. It was common for parcels in this area to change between natural covers and irrigated agriculture during our study period. (Photograph by Benjamin Sleeter, 18 September 2004.)

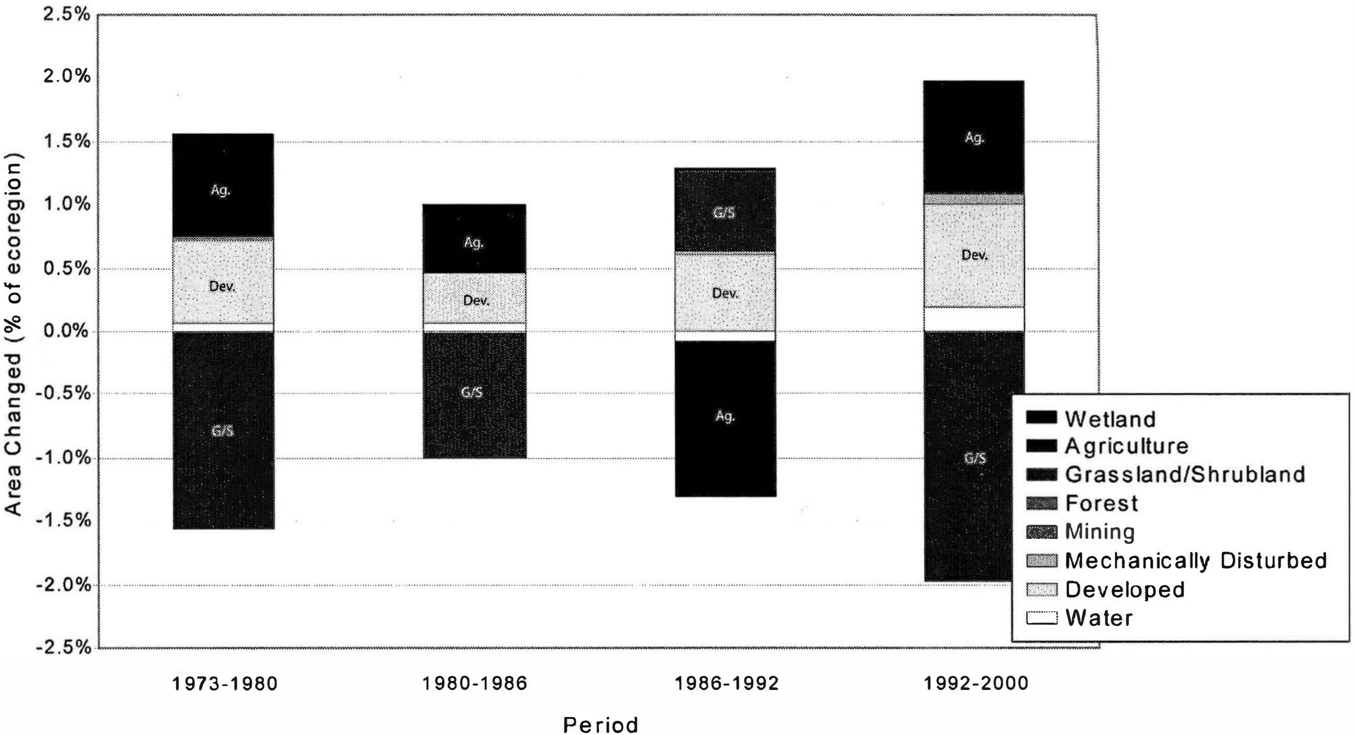


Figure 6.—Net changes in selected land-cover classes for the four temporal intervals. Agriculture had a net increase in each of the four intervals, with the exception of 1986–1992, where losses in agricultural lands outpaced gains. Trends in the grassland/shrubs class followed an inverse relationship and between 1986 and 1992 gains outpaced losses. Significant increases in development were estimated for each of the four intervals.

Table 6: Estimates of change to developed uses.

INTERVAL	% CHANGE	km²	STANDARD ERROR	RELATIVE ERROR	+/- 85% CI	LOWER BOUND	UPPER BOUND
1973–1980	0.65%	296.0	0.22%	34.36%	0.33%	0.32%	0.97%
1980–1986	0.40%	181.8	0.13%	32.64%	0.19%	0.21%	0.59%
1986–1992	0.61%	278.5	0.16%	26.57%	0.24%	0.37%	0.84%
1992–2000	0.80%	368.3	0.31%	38.01%	0.44%	0.36%	1.25%

Discussion

Changes in Agriculture

One hypothesis of this research was that land-cover change in the CCV_S was unidirectional, with most change taking the form of urbanization of agricultural lands. Urbanization in the Central Valley has long been considered the single greatest threat to the region (Moore 1998; Vink 1998; Sokolow 1998; Charbonneau and Kondolf 1993). Results from this research project support the hypothesis that agricultural lands are being converted to new development; however, this particular transition was not the most commonly observed change. Furthermore, we estimate a net increase in agricultural lands in the ecoregion between 1973 and 2000 (Table 4). This conclusion is supported by findings in Hart (2003) and Johnston and McCalla (2004). From a land-area perspective, the conversion of agricultural lands to developed uses is secondary to the changes occurring between grassland/shrublands (rangelands) and agricultural landscapes (Figure 7).

Four scenarios generally explain the observed conversions between grassland/shrublands and agriculture. They are:

- Cycling of agricultural lands in and out of production
- Loss of agricultural productivity due to environmental conditions (e.g., drought, desertification, increased salinazation, water availability, etc.)
- Removing parcels from agricultural production in advance of development (results in a multi-step process)
- Development of traditional agricultural lands and relocation of agriculture to ecoregion periphery

Planned and unplanned rotation of fields can result in mapped conversion between these two land-cover sectors, while seasonal and annual idling of cropland may also result in "false-positive"

Figure 7.—Large expanse of grape vines located just east of Montpelier, California, and 17 km east of Turloch, California, in Stanislaus County. Since 1970 the region has seen a large increase in land used for viniculture. (Photograph by Benjamin Sleeter, 19 September 2004.)

detections of land conversion. However, these changes are believed to account for a very small amount of the total agriculture change, considering a patch would have to have the time to develop a robust vegetative cover that was spectrally similar to naturally occurring vegetation. Idle lands with no vegetative cover are always classified as agriculture. Degradation of marginal agricultural lands due to a lack of fresh water, lack of drainage, the presence of a high water table, and salinization of soil and ground water resources can also result in loss of agricultural production (Schoups et al. 2005) and are often expressed as a change from agriculture to grassland/shrubland covers. Research by Schoups et al. (2005) has shown that, for some lands in the San Joaquin Valley, irrigated agriculture may not be sustainable due to salinization of soils.

At a much smaller scale, urbanization was also responsible for converting agricultural lands to grassland/shrublands. Often occurring at the periphery of existing urban areas, urbanization not only converts agricultural lands to developed uses but also resulted in the transitional conversion of agricultural lands to grasslands/ shrublands, which in subsequent years would eventually transition to developed uses.

Perhaps the most obvious explanation of the fluctuations between agriculture and grassland/shrublands is the dynamic nature of farming in the ecoregion. As development continues to convert farm lands to new urban uses, agriculture is relocating to the periphery of the ecoregion and into the Central and Southern Chaparral and Oak Woodlands ecoregion, bringing large amounts of marginal lands into agricultural production (Charbonneau and Kondolf 1993). This represents a major shift for the ecoregion and the State of California in general, as farmers continue the transition away from traditional field crops such as alfalfa and grains and invest in higher-risk and higher-value crops such as fruits and nuts (USDA 2008; Johnston and McCalla 2004; Blank 2000) (Figure 8).

Irrigation of marginal lands at the ecoregion periphery carries some amount of concern regarding the attenuation of non-point source water-quality impacts (Charbonneau and Kondolf 1993), although the increased use and technological advancement of drip irrigation systems has the potential to limit impacts to water quality. Drip irrigation use has increased from less than half of 1% of all irrigated land in 1972 to nearly 33% in 2001 (Orang, Snyder, and Matyac 2005). This corresponds to a shift away from field crops to a substantial increase in orchards and vineyards. Orang, Snyder, and Maytac (2005) estimated that irrigated orchards increased from about 15% to 31% of all irrigated land in California since 1972; vineyards increased from about 6% to 16% over the same time period; and field crops decreased from about 67% to 42% (Figure 9). Additionally, the transfer from field crops to perennial crops also has the potential benefit of increasing carbon sequestration in California. Kroodsma and Field (2006) estimate that between 1980 and 2000, California agriculture sequestered 0.7 Tg C/yr with perennial crops accounting for more than 50% of the total, mostly due to the production of woody biomass and the low-till nature of their soils. The authors conclude that adopting low-till and improved pruning techniques has the potential to nearly double the amount of carbon sequestered by California agriculture.

An intriguing result of our research was the temporal nature of change between agricultural and grassland/shrubland land-

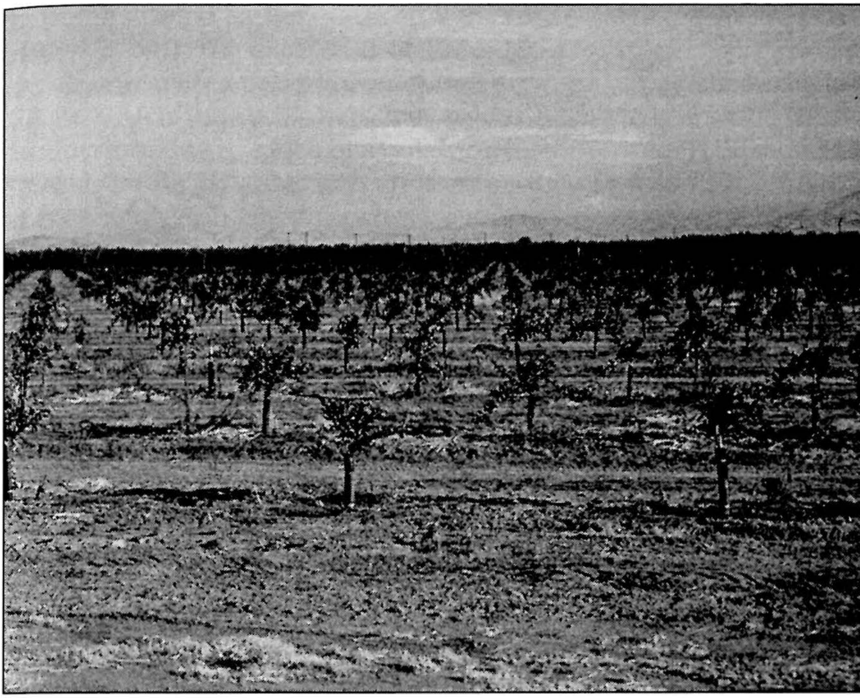
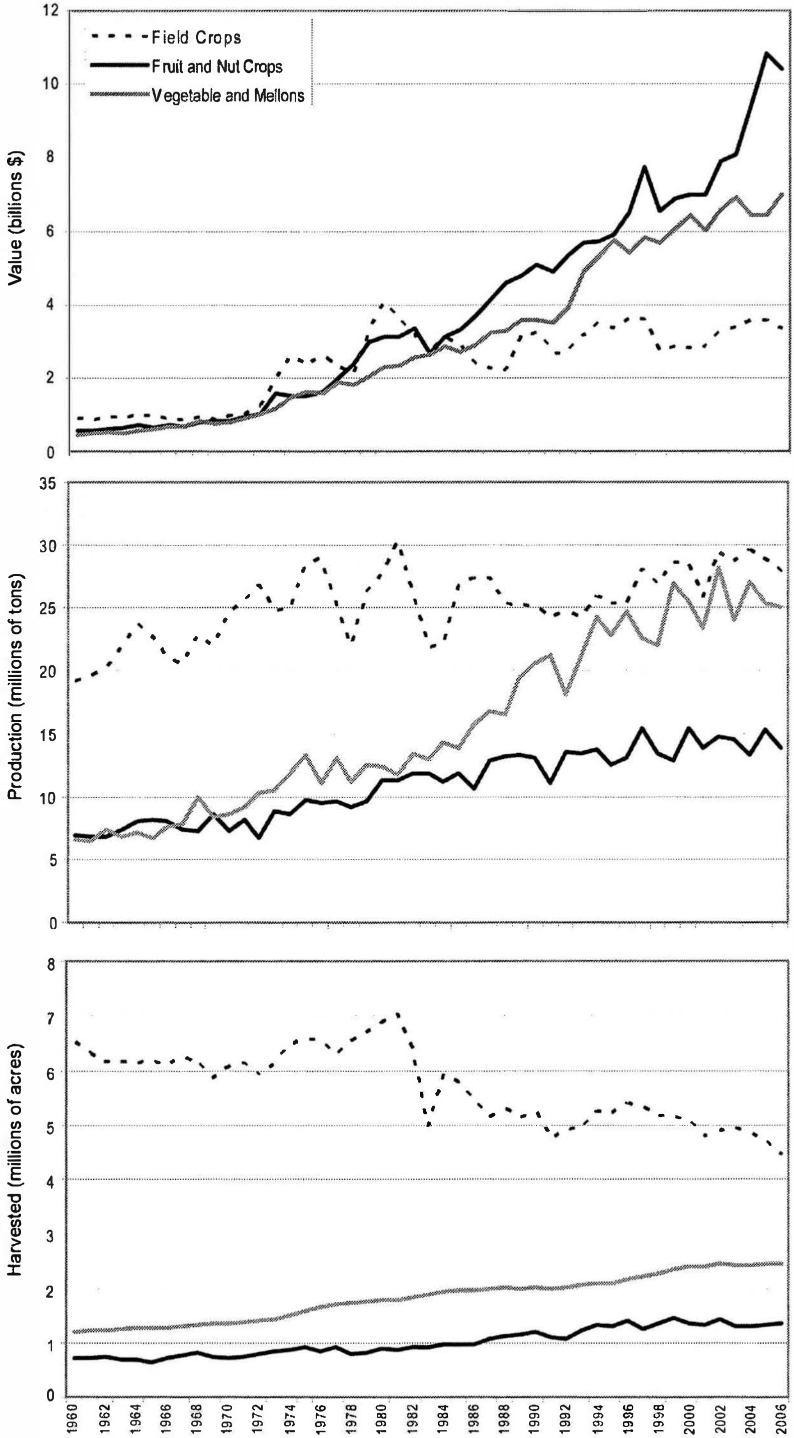


Figure 8.—Young citrus orchard in the foreground, contrasted by an older orchard in the background, 11 km north of Visalia, California, in Tulare County. Citrus is a major crop type found near Visalia. The boundary between the CCV and SCCCOW ecoregions is located approximately 10 km to the east. (Photograph by Benjamin Sleeter, 19 September 2004.)

Figure 9 (next page).—Three major crop types in California agriculture with area (acres), amount harvested (tons), and value ($) plotted since 1960. From 1960 to 1980, field crops accounted for the greatest amount of harvest land, the highest amount of production, and even the highest value. Between 1980 and 2006, field crops have remained relatively stable in value while production has increased on a declining amount of harvested land. Fruit and nut crops and vegetables and melons have gradually increased in the amount of land harvested, while production and value have both shown substantial increases. This amounts to increased efficiency across all crop types, while specialty and high value crops continue to occupy a greater share of the landscape.


Field Crops
Fruit and Nut Crops
Vegetable and Mellons
Value (billions $)
Production (millions of tons)
Harvested (millions of acres)
0
2
4
6
8
10
12
5
15
20
25
30
35
1
3
7
1960
1962
1964
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2004
2006

scapes. As noted earlier, gains in agriculture outpaced losses in all intervals, with the exception of 1986–1992. This interval happens to coincide with a period of extended drought in California (Figure 10) in which many farmers had to cut back their acreage under production, due to a lack of available irrigation water (USDA 1991). Should California enter into another period of prolonged drought, as is evidenced in the paleoclimate record (Stine 1994), significant areas of arid farmland currently being irrigated could potentially be converted to grassland/shrubland, due to a scarcity of water resources. Impacts of long-term climate could potentially result in high costs to California agriculture, although there is significant uncertainty associated with future projections and their associated impacts in the Central California Valley (Cash and Zilberman 2003). More research is needed to further quantify the relationship between LULCC in the ecoregion, the presence of persistent drought, and regional climate variability.

Urbanization and Development

Urbanization and impervious cover increased significantly in the ecoregion and serve as catalysts for change in other sectors, even though these changes are not the most significant in terms of area converted. Between 1973 and 2000 we estimate an additional 1,124 km^2 of new developed lands were added to the ecoregion, with most new conversions occurring near cities and at the periphery of existing infrastructure. It is estimated that between 1970 and 2001, California's population increased by 42% to 34.0 million people (U.S. Census Bureau 2008). During the same time, the population of Central California Valley counties[1] increased by nearly 51% to 5.58 million people, or approximately 16% of the state's total population (U.S. Census Bureau 2008). Sacramento, Fresno, Kern, and San Joaquin counties each accounted for at least 10% of the ecoregion's population in 2001, with Sacramento the highest at 22.7% (1.27 million people) (Figure 4).

The majority of new developed lands take the form of suburban subdivisions, new commercial and industrial development, and to a more limited extent, exurban growth such as ranchettes. Housing

[1] Central Valley counties were interpreted to include all counties that have their centroid within the stratum and other counties that have a large portion of their population located within the ecoregion stratum. Counties include Butte, Colusa, Fresno, Glenn, Kern, Kings, Merced, Sacramento, San Joaquin, Solano, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba.

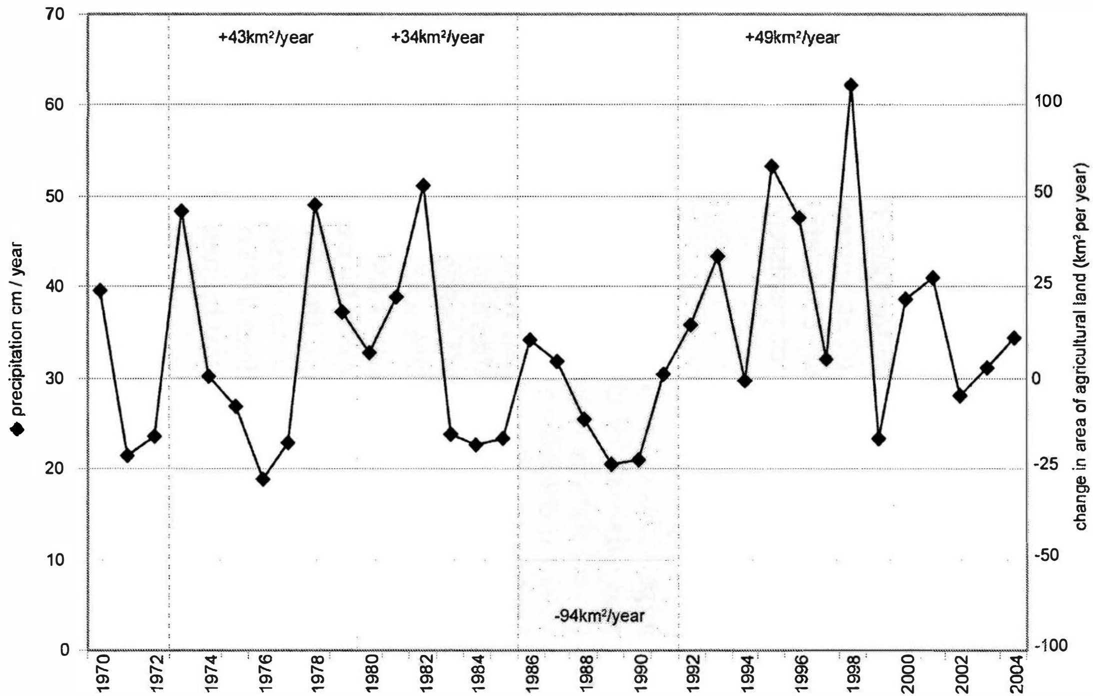

Figure 10.—Average annual precipitation (PRISM Group) and net changes in the agricultural class since 1970 for the CCV ecoregion. Net increases in agriculture were realized in three of the four temporal intervals. Only the 1986 to 1992 period resulted in a net loss of agricultural lands (-94 km2/yr). This period coincides with a period of extended drought in California, with a dry period extending back to 1983.

for the region's rapidly increasing population is the primary driver of new development. Sites where growth in suburban development was found include samples near Bakersfield, Fresno, Stockton, Modesto, and Sacramento, among others (Figure 11). Typically, these samples experienced relatively high rates of change to "developed," while other, more rural samples experienced little to no change in this sector. Occasionally, exurban development was captured and was generally confined to more rural settings. With respect to land-area conversions, exurban development was not a major land-use change observed in this region.

Growth in the developed landscape is occurring for a number of different reasons, although it continues to be heavily influenced by the major urban areas found just outside the ecoregion. The San Francisco Bay Area and Los Angeles, both part of the Southern and Central California Chaparral and Oak Woodlands ecoregion, continue to influence the landscape in the Central California Valley as people leave the urban centers in search of more affordable hous-

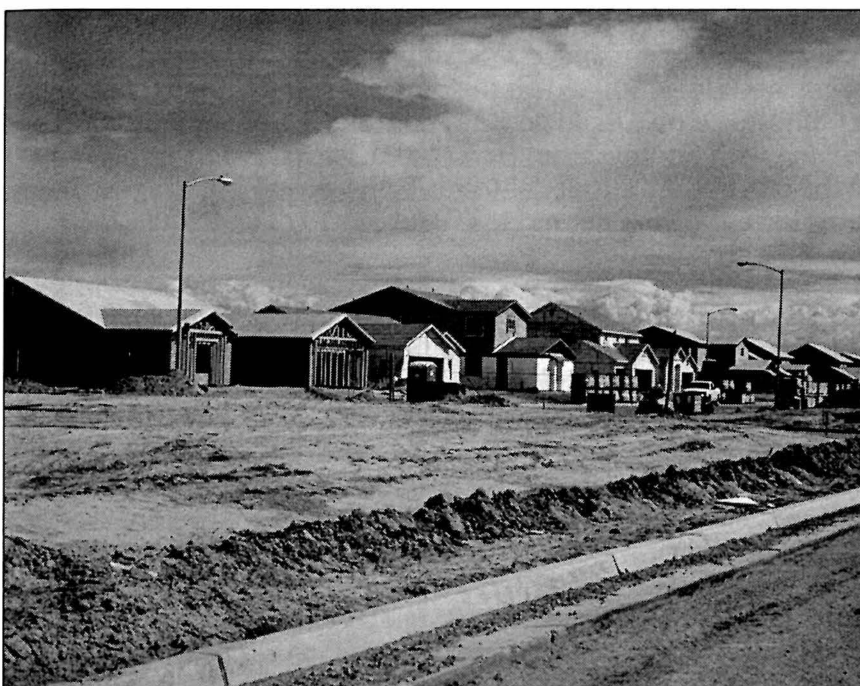

Figure 11.—Construction of a new suburban development just outside Fowler, California, in Fresno County. (Photograph by Benjamin Sleeter, 19 September 2004.)

ing. Cities such as Bakersfield, Tracy, Stockton, and Modesto often serve as commuter cities for those working in major metropolitan regions. California has also realized a surge in population due in part to in-migration from other states and Mexico. The large increase in population has resulted in a high demand for housing throughout the state. The Central Valley was particularly well suited to absorb a large share of this growth, due to the availability of relatively inexpensive land and its proximity to jobs and services. Gersmehl (1997) illustrates how realized capital gains alone in 1988 were estimated at $28 billion—the same magnitude as all agriculture in California.

In the future, the balance between agriculture and urban (developed) needs is sure to be high on the list of issues facing policy makers. The use of conservation easements is one tool that has already been employed in California to preserve farmland from urbanization (Sokolow and Lemp 2002; Johnston and Carter 2000). As more and more farmland is replaced by urban and developed uses in some portions of the ecoregion, and the boundary (edge) between the two competing land uses changes, conflicts between residential uses and agriculture have the potential to become an increasing problem for local and regional managers (Sokolow 2003). However, the use of easements is largely based on the general assumption that farmland in California is on a rapid decline and is at risk from urbanization. In keeping with findings from Hart (2003), we have shown this not to be the case in the Central California Valley ecoregion, as agricultural lands have shown a net increase between 1973 and 2000.

The underlying question begs asking: Why are people coming to California in such large numbers? To truly understand what drives LULCC, we must understand the linkages between socioeconomic systems and local to regional land-use decision-making. Lambin et al. (2004) indicate that the primary drivers of LULCC are local responses to economic opportunities and constraints. These same economic and policy-driven opportunities and constraints for new land uses are created by local to national markets and are increasingly influenced by globalization (Lambin et al. 2004). Additional research is needed to connect the remotely sensed observations presented in this paper with shifting market forces presumed to be driving local to regional land-use decisions in the Central California Valley ecoregion.

Conclusion

Since 1973 the Central California Valley has experienced a modest amount of change. We estimate that between 1973 and 2000, 12.4% of the ecoregion changed from one cover type to another. Over the same period, the amount of developed lands in the ecoregion increased from 6.5% to 9.0% of the ecoregion stratum, or 1,122 km^2. Results also reveal that contrary to popular belief, agriculture increased in area from 71.6% to 72.4%, mostly in the form of irrigated orchards and vineyards at the ecoregion periphery. The 1986 to 1992 interval was the only period where agriculture had a net decline and corresponds to a period of prolonged drought in California. Given the establishment of a historical context of LULCC, more research can now begin to quantitatively link drivers and consequences of change with these results, with the objective of providing accurate projections of land cover under varying management and environmental conditions. Identification of linkages between the human and environmental systems and remotely sensed observations represents a critical gap in knowledge of land-change science—a gap that will require significant resources to overcome (Rindfuss et al. 2004). The creation of a regional database of the rates, types, and dynamics of LULCC is a first start at bridging this information gap. As linkages are demonstrated, future projections of LULC could have significant usefulness for global and regional climate modeling, biogeochemical cycling, natural resource management, and urban/suburban land-use planning.

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Influences of Stand Structure and Fuel Treatments on Wildfire Severity at Blacks Mountain Experimental Forest, Northeastern California

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Abstract

This study utilizes forest stand structures and fuel profiles to evaluate the influence of different types of silvicultural treatments on fire severity in the Blacks Mountain Experimental Forest (BMEF), located within Lassen National Forest of northeastern California. We compare the severity of fire, assessed based on tree crown and bole scorch on 100 ha experimental treatment plots, following a wildfire started on adjacent national forest lands. Non-parametric statistical testing showed that selective thinning combined with prescribed surface fuel burning is the most effective method for preventing crown fire and minimizing fire severity in an interior *Pinus ponderosa* forest. These results also suggest that various combinations of the silvicultural treatments assessed can be effective at reducing the potential for severe fire spreading into wildland-urban interface (WUI) areas (supporting defensible space CA law PRC 4291), while suggesting approaches for U.S. Forest Service lands that can result in more resilient ecosystems in similar western U.S. forests treated with similar silvicultural methods.

Key words: Fire ecology, fuels management, California forests, wildland-urban interface (WUI)

Introduction

In most summer-dry forests of California, frequent fires have long been an important ecosystem process (Whitlock 2001). Historically, the fire return intervals, or number of years between successive fires, have been short in the interior ponderosa pine (*Pinus* *ponderosa* Laws.) forests (1- to 25-year return intervals) (Agee 1993; Taylor 2000; Norman and Taylor 2003). The majority of these fires were mostly of low intensity; however, intense fires, especially in patches, could occur after fuel buildup resulting from longer-than usual-return intervals or other factors such as (drought and) insect outbreaks (Agee 1993).

Recent studies indicate that northeastern Californian mixed-conifer forests have undergone major structural and compositional changes since the exclusion of fire (Taylor 2000; Norman and Taylor 2005). Needle litter and native grasses have been replaced by needle and branch fuels with more vertical continuity, in the form of both live saplings and dead fuel. This contributes to a greater possibility of increased fire intensity and severe crown fire (Mutch 1994). A low-intensity fire regime has been replaced by a moderate- to high-intensity fire regime that is essentially the result of change in fuel load and stand structure (Agee 1994; Agee and Skinner 2005).

A result of the structural change in these forests is the development of ladder fuels that contribute to high-intensity crown fires. Van Wagner (1977) described ladder fuels as "bridge fuels," combustible matter in the understory serving as an intermediary between the surface fuels and the main canopy, which allows fires to move into the canopy. Crown fire potential is dependent on the quantity and arrangement of these fuels (Kilgore and Sando 1975). Kilgore and Sando (1975) state that the probability of a surface fire moving into the crowns is greatly increased by an understory of saplings that provide continuous fuels from the ground to the dominant tree crowns. This continuous fuel supply was absent during a mostly low- to moderate-intensity fire regime (Kilgore and Sando 1975). This increase in ladder fuels has led to increased levels of crown scorch and bark char, indicators of fire severity (Davis and Cooper 1963) and tree mortality (Stephens and Finney 2002). The suppression of fire has also allowed a shift in species composition from dominance of fire-tolerant ponderosa pine to a greater proportion of less fire-tolerant species in the understory—primarily white fir (*Abies concolor* [Gordon & Glend] Lindley) and incense cedar (*Calocedrus decurrens* [Torrey] Florin). The seedlings of these less-tolerant species are no longer eliminated by low- to moderate-intensity surface fires as they were under a pre-suppression fire regime. The result is a less resilient forest condition than one under a pre-suppression fire regime (Agee et al. 1978).

California is a region noted for its high-intensity fires assisted by annual summer drought and long-term drought cycles. The uniqueness of this study allowed for us to assess California law PRC 4291 (California law, 2005), which requires property owners in wildland areas and along wildand-urban interfaces (WUI) to create 100 feet of defensible space for fire protection around their homes and buildings in the following manner: (1) by removing all flammable vegetation within 30 feet immediately surrounding a structure (i.e., lean, clean and green zone), and (2) by creating a fuel-reduction zone in the remaining 70 feet by focusing on removing lower-level vegetation components (i.e., shrub layer) and removing lower tree branches at least six feet from the ground. These are important considerations to test, as the WUI area covers 20.7% of the state of California, and 5.1 million homes in California are in the WUI area (highest nationally) (Radeloff et al. 2005).

Purpose of Forest Fuel Management

Forest fuel management may help to reverse human induced changes that have "produced successional changes in wildland vegetation and fuels" (Arno and Brown 1991). There are many different strategies and techniques available for fuels treatment, depending on management goals and the characteristics of the forest ecosystem. Selective thinning, mechanical fuel removal (Arno and Brown 1991), and/or prescribed fire (Arno and Brown 1991) are potential ways of altering a forest structure from its original state to a state that might decrease the probability of a severe wildfire. In essence, fuel reduction strategies are viable options for managing areas that have been subjected to fire exclusion or suppression (Agee and Skinner 2005).

Selective harvesting of smaller trees, for example, may help to create old growth-like vegetation structures while lowering the potential severity of a fire in a forest, or preventing a fire from moving into the managed area at all by reducing the amount of consumable fuels in the understory (Arno and Brown 1991). Crown fires depend on the vertical profile of fuels, starting from the ground surface and continuing into the canopy (Agee and Skinner 2005; Cruz et al. 2003; Cruz et al. 2004). Studies have shown that the probability of a crown fire can be reduced by manipulating ladder fuels (Graham et al. 2004).

Thinning alone may not achieve as significant a reduction in fire intensity as when the thinning is followed by surface fuels treatment. Thinning may add fuel to the surface by contributing parts of cut trees and small trees damaged by the thinning operation (Weatherspoon 1996). At the least, the existing surface fuels are not reduced. This slash, if not treated appropriately, can contribute to greater fire intensity. Thinning also influences the regeneration of small trees, changes the overall levels of competition, and affects the microclimate by increasing solar radiation and winds (Weatherspoon 1996). Thinning can be a viable alternative in areas with dense understory, however (Arno and Brown 1991). Additionally, the effects on fire behavior from increases in solar drying and wind movement in the stand are usually more than offset by the overall reduction in potential for crown fire and resulting fire intensity (Weatherspoon 1996; Agee and Skinner 2005).

Prescribed fire can enhance the effects of thinning by further reducing fire intensity. Prescribed fire can help to achieve a desired composition and structure, such as reducing stand density (Mutch 1994), controlling undesirable species (Arno and Brown 1989), or reducing dead-fuel accumulation (Mutch 1994). By focusing on reducing surface fuels and horizontal and vertical fuel continuity, especially removing smaller trees, intense crown fires may be reduced (Agee and Skinner 2005).

In forests that have excluded fire for long periods, thinning and burning can be combined for maximum results (Graham et al. 2004). Many studies have examined post-fire results of fire exclusion (Martinson and Omi 2004; Omi and Martinson 2004; Finney et al. 2005; Strom and Fulé 2007; Schmidt et al. 2008). In a study conducted by Omi and Martinson (2002), wildfire severity indicators (scorch height, crown volume scorch, stand damage) were greater in untreated areas than treated areas. Pollet and Omi (2002) found that in ponderosa pine forests having either treatment by prescribed fire only, thinning, or a combination of thinning and prescribed fire, crown fire severity was less in areas that had been treated compared with areas that had not been treated.

This study utilizes stand structural and fuel profiles to evaluate the influence of different silvicultural treatments on wildfire severity in interior ponderosa pine forests of the Blacks Mountain Experimental Forest (BMEF) in northeastern California. The fortuitous movement of the Cone Fire (an accidental fire started during a logging operation on adjacent National Forest land in September 2002) into the Blacks Mountain Experimental Forest has allowed the effect of different silvicultural treatments to be evaluated in an experimental manner. We compare the levels of fire severity following the Cone Fire, which impacted several existing 100 ha experimental treatment plots, utilizing crown and bole scorch damage present after the fire (sensu Omi and Martinson 2002). Treatments implemented before the fire included creation of two stand structures through mechanical thinning with and without follow-up prescribed fire. All treatments were accomplished between two and five years prior to the wildfire occurrence.

Methods

Study Area

The study area was in the Blacks Mountain Experimental Forest (BMEF), located within Lassen National Forest in the southern Cascade Range of northeastern California (Figure 1). The U.S. Forest Service's Pacific Southwest Research Station has established a research project in which they have created experimental treatment plots of contrasting stand structures and silvicultural management (Oliver 2000). BMEF lies on a volcanic plateau with predominant plant communities of the Jeffrey pine (*Pinus jefferyi* Grev. & Balf.) ponderosa pine series, with white fir and incense cedar as associates (Oliver 2000). Temperatures range from a minimum of –6°C to a maximum of 30°C, with mean annual precipitation ranging from 51 to 115 centimeters (Miles and Goudey 1997). Half of BMEF lies in a basin surrounded by moderate slopes (predominantly 0–10°, with few 10–20° slopes), with an elevation range from 1,600 to 2,300 meters (Hallin 1959). BMEF consists of ±4,172 ha, of which ±1,200 ha were set aside as 12 100-ha study plots and subjected to four specific structural silvicultural treatments. A high-diversity (HiD) treatment included retaining large old trees, big snags, multiple canopy layers with clusters of small trees, gaps, and canopy openings. This was contrasted with a low-diversity (LoD) treatment that created a single layer of intermediate-size trees with a continuous but open canopy, few snags, few canopy gaps, and few forest openings by removing the large, old trees and thinning the smaller poles and saplings (Oliver 2000). Some areas of BMEF outside the treatment plots had been previously treated at least 20 years prior to the Cone Fire as either partially cut under sanitation/salvage prescriptions or commercially thinned (Skinner et al. 2004; Ritchie et al. 2007) and were not part of any ongoing study (Oliver 2000). Each BMEF plot was then split to allow prescribed fire in one half,

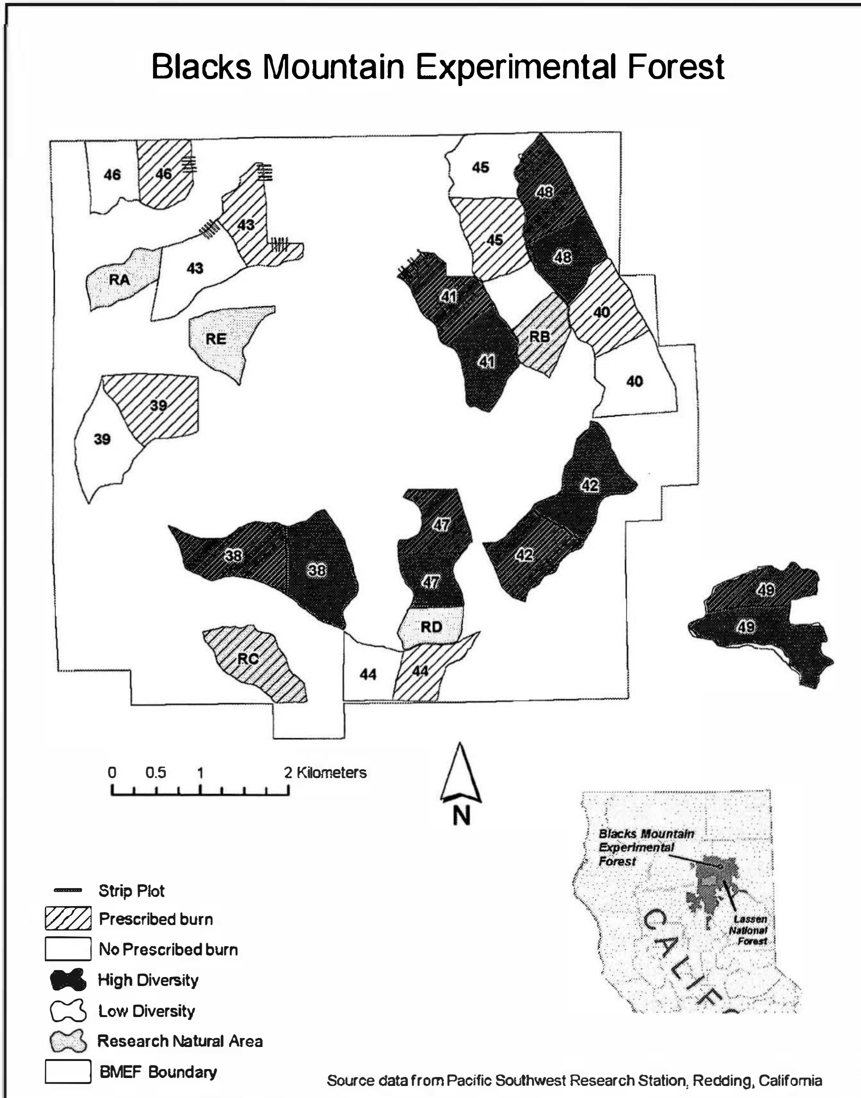

Figure 1.

and no fire in the other. Each of the two structural treatments was replicated six times in 100-ha treatment plots. Due to changes in elevation, species composition varied among units, with lower areas (1,600–1,850 meters) dominated by almost pure ponderosa pine or Jeffrey pine, while higher areas (1,850–2,300 meters) had a substantial amount of white fir and incense cedar. The historic fire regime of this ecosystem was of the frequent/low-moderate intensity type, typical of interior ponderosa pine in the southern Cascade Range of northeastern California (Skinner and Taylor 2006).

Field Methods

Data were collected on each of three silvicultural treatment types, as well as in the adjacent areas that had not recently had silvicultural treatments, to describe wildfire severity and compare the effects of the Cone fire in the different silvicultural treatment plots. In this paper, we refer to the areas not recently treated (> 20 years since treatments) as being untreated, since they were not treated as part of the ongoing BMEF study. Three treatment units and treatment types were affected by the fire. Fire behavior and resulting severity varied throughout the BMEF (Figure 2), with much of the area outside the treatment units being burned by a high-intensity, mostly passive crown fire. Within the treatment units, the fire burned as a surface fire with varying intensity and effects depending on type of treatment. The nature of the terrain at the BMEF is quite gentle; weather conditions during the Cone Fire overwhelmed any

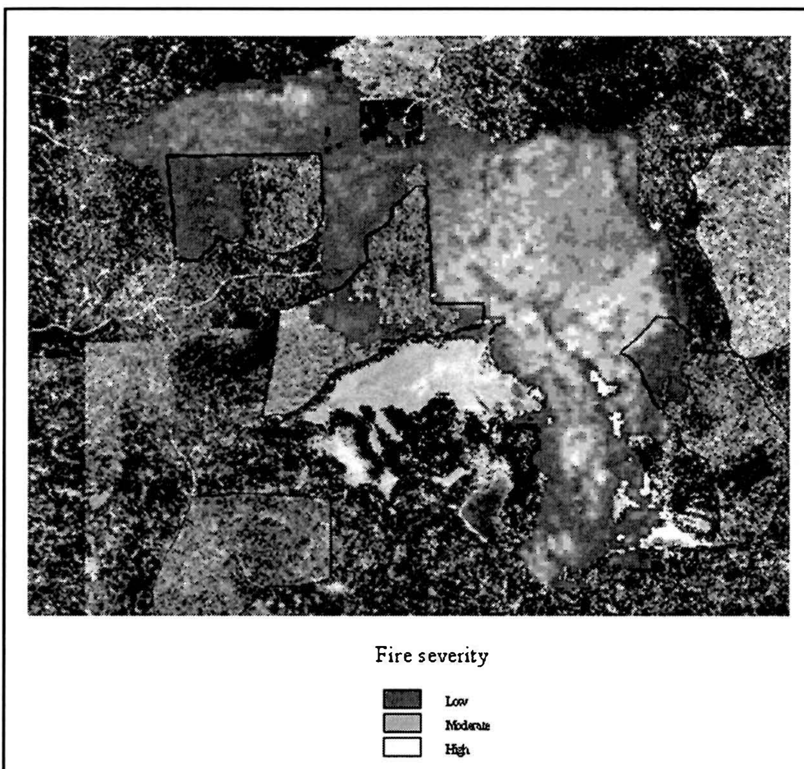

Figure 2.

potential effects of topography. Details on fire behavior in the different stand conditions and tree mortality patterns can be found in Ritchie et al. (2007). For this study, data were collected to describe how fire severity indicators changed as the fire burned from outside to inside the treated plots using sets of treatment-type replicates (sample) that could be laid out based on the Cone Fire's path. Each tree (sub-sample) found within the spatially defined replicates was specifically measured for crown scorch and bole scorch. Twenty-five 10 m x 150 m strip plots were placed in three groupings in order to represent the effects of the fire approaching and entering the treated areas (Figure 1). Five strips were located in Unit 46, a LoD unit, on the eastern edge of the half that had been prescribe-burned (LoDF). Fifteen strips were located in Unit 43; also a LoD unit, five on the northern edge of the half without prescribed fire (LoDNF), five on the northeastern edge of the half with prescribed fire (LoDF), and five on the southeastern edge of the half with prescribed fire (LoDF). Five strips were located in Unit 41, a HiD unit, on the northern edge of the half that had been prescribe burned (HiDF).

The strip plots were systematically established using a fiberglass measuring tape oriented perpendicular to treatment plot boundaries affected by the Cone Fire. The strip transects extended 100 meters into treated areas and 50 meters into untreated areas. All trees greater than 10 cm DBH had the following data recorded: species, distance from treatment boundary (m), diameter at breast height (cm), mortality, indicator of scorched or torched, total height (m), height of bole scorch for all cardinal directions (m), height of crown scorch for all cardinal directions (m), and height to base of live crown before wildfire (m). We were unable to sample thinning without prescribed fire in Unit 41, as the adjacent area was salvaged before we were able to establish measurement plots.

Data Analysis

We used paired statistical tests to make comparisons among the variables for the silvicultural treatments and by spatial distance increments (Table 1). The specific variables examined were the percentage of bole scorch and the percentage of crown scorch for each tree, based on total tree height. The percentages were calculated by taking an average of the scorch measurements in each of the four cardinal directions. We use the non-parametric Mann-Whitney U-test for analysis involving two factors; treatment, or lack thereof, and silvicultural structure. We used the Kruskal-Wallis One Way Analysis of Variance tests for analysis involving three or more factors; treatment, distance increment, and treatment and distance increment (Table 1). Each grouping included several distance increment and/or silvicultural treatment parameters, as shown in Table 1.

Table 1. Data structure for statistical analysis of Cone Fire behavior.

Data Type	Parameters	Test used
Treatment Presence/Absence	Treated Untreated	Mann-Whitney U-test
Silvicultural Treatment Stand Structure	High diversity (HiD) Low diversity (LoD)	Mann-Whitney U-test
Silvicultural Treatment	High Diversity w/fire (HiDF) Low Diversity w/fire (LoDF) Low Diversity w/o fire (LoDNF) Untreated (UT)	Kruskal-Wallis One Way Analysis of Variance
Distance Increments (aggregated data)	0–50 meters 50–100 meters 100–150 meters	Kruskal-Wallis One Way Analysis of Variance
Silvicultural Treatment and Distance Increment	High Diversity w/fire (HiDF) • 0–50 meters • 50–100 meters • 100–150 meters Low Diversity w/fire (LoDF) • 0–50 meters • 50–100 meters • 100–150 meters Low Diversity w/o fire (LoDNF) • 0–50 meters • 50–100 meters • 100–150 meters	Kruskal-Wallis One Way Analysis of Variance

Non-parametric tests were used to preserve the integrity of the data while recognizing its non-normal skewness. While individual tree data were recorded (i.e., hundreds of trees), this data has been summarized to averages per strip-plot, from which the number of statistical cases varied from 5 to 15 depending on the structural and treatment type. This was done to avoid the error of pseudo-replication (Hurlbert 1984) in the statistical analysis. The probability being tested against was $p < 0.05$, or an alpha of 95% confidence. *Post-hoc* testing with the Bonferroni method was done after preliminary test-

Table 3. Kruskal-Wallis One-Way Analysis of Variance for percentage bole scorch and percentage crown scorch comparing parameters by data type (Table 1).

Data Type Silvicultural Treatment Variable	Parameter	Mean (%)	Standard Deviation (%)
Bole Scorch			
	HiDF n= 5 $p < 0.00001$	18.54	9.82
	LoDF n= 15 $p < 0.00001$	2.29	3.86
	LoDNF n= 5 $p < 0.116$	13.38	5.76
Crown Scorch			
	HiDF n= 5 $p < 0.001$	66.50	8.54
	LoDF n= 15 $p < 0.001$	25.93	8.52
	LoDNF n= 5 $p < 0.064$	47.23	15.63

Distance Increments (aggregated data) Variable	Distance (m)	Mean (%)	Standard Deviation (%)
Bole Scorch n= 25 $p < 0.0001$			
	0–50	62.62	24.94
	50–100	12.07	16.13
	100-150	2.99	6.10
Crown Scorch n= 25 $p < 0.0001$			
	0–50	88.54	18.36
	50–100	34.22	34.00
	100–150	9.04	17.41

Fire Effects Transition with Distance into Silviculturally Treated Plots

To further analyze the transition of the fire effects as the fire moved into silviculturally treated areas, Kruskal-Wallis One-Way Analysis of Variance testing was performed for both percentage bole scorch and percentage crown scorch (Table 3) in 50-meter increments. This determined whether or not there was an area of transition between the adjacent, not treated, areas (0–50 meters) and the silviculturally treated plots (50–150 meters). There was a significant difference ($p < 0.0001$) between each 50-meter increment with regard to percentage bole scorch and percentage crown scorch. For most strip plots, the 50–100 meter area acted as a transition zone in which the Cone Fire transitioned from a crown fire to a surface fire. In 13 out of 25 plots, the fire went out before reaching 100 meters into a treatment area.

The 50-meter increments were further analyzed with a Bonferroni *Post-hoc* adjustment to isolate the increment contributing to the significant difference between increments. There was a significant difference ($p < 0.0001$) between all three 50-meter increments, with regard to percentage bole scorch and percentage crown scorch.

Fire Transition into Treatment Plots, Grouped by Treatment Type and Distance

High diversity with prescribed fire treatment. There was a significant difference between all distance increments with regard to percentage bole scorch ($p < 0.006$) and percentage crown scorch ($p < 0.03$) (Table 4). The high variation within the 50–100 meter increment can be attributed to this being a transition zone for the Cone Fire, with some trees experiencing much more scorch than others.

A Bonferroni *Post-hoc* adjustment to isolate the increment contributing to the significant difference between increments indicated that there was a significant difference ($p < 0.0001$) between all three 50-meter increments for both percentage bole scorch and percentage crown scorch. The fire severity indicators were reduced as the fire moved farther into the treatment areas.

Low diversity with prescribed fire treatment. There was a significant difference ($p < 0.0001$) between all distance increments with regard to percent of both bole scorch and crown scorch (Table 4).

A Bonferroni *Post-hoc* adjustment indicated there was no significant difference between the 50–100 meter and 100–150 meter increment in percent of bole scorch. The change in severity of bole scorch occurred at the treatment plot boundary. There was a significant difference ($p < 0.0001$) between all three distance increments with regard to percentage crown scorch. The change in severity of crown scorch occurred over a longer transition area than bole scorch.

Table 4. Kruskal-Wallis One-Way Analysis of Variance by silvicultural treatment for percentage bole scorch and percentage crown scorch grouped by distance increment.

Silvicultural-Treatment	Variable	Distance (m)	Mean (%)	Standard Deviation (%)
HiDF n= 5				
	Bole Scorch $p < 0.006$			
		0–50	86.87	8.09
		50–100	34.41	22.46
		100–150	2.52	2.23
	Crown Scorch $p < 0.03$			
		0–50	99.96	0.08
		50–100	98.27	2.98
		100–150	20.20	19.72
LoDF n= 15	Bole Scorch $p < 0.0001$			
		0–50	52.13	26.07
		50–100	8.07	8.15
		100–150	4.14	7.59
	Crown Scorch $p < 0.0001$			
		0–50	81.87	21.35
		50–100	26.81	24.46
		100–150	8.33	18.28
LoDNF n= 5	Bole Scorch $p < 0.006$			
		0–50	69.87	8.68
		50–100	1.76	2.88
		100–150	0.00	0.00
	Crown Scorch $p < 0.0001$			
		0–50	97.11	2.53
		50–100	4.35	6.54
		100–150	0.00	0.00

Low diversity without prescribed fire treatment. While there was a significant difference between all distance increments with regard to percentage bole scorch ($p < 0.006$) and percentage crown scorch ($p < 0.0001$) (Table 4), there was less variation than for the high diversity with prescribed-fire silvicultural treatment and the low diversity with prescribed-fire silvicultural treatment.

The Bonferroni *Post-hoc* adjustment indicated that there was a significant difference with regard to percent of bole scorch between the silviculturally treated plot and the adjacent untreated area. Within the silviculturally treated plot, there was no significant difference with regard to bole scorch between the 50–100 meter and 100–150 meter increments, most likely due to an abundance of understory fuels that carried the Cone Fire throughout the strip plots. With regard to percentage crown scorch, there was no significant difference between the 0–50 meter increment and the 50–100 meter increment. There was a significant difference with regard to crown scorch between the 50–100 meter increment and the 100–150 meter increment. Thus, the low diversity without prescribed fire silvicultural treatment had a longer transition area than in the low-diversity with prescribed fire silvicultural treatment.

Semivariogram analysis of fire severity. The scale is defined by the range size, which represents the distance to where samples greater than the range are not spatially autocorrelated with samples less than the range values. The points less than the range distance are spatially autocorrelated and represent the scale of the fire severity variables. The following range averages were calculated by treatment type and effect measured: Bole scorch – LoDNF 175m, LoDF 35.8m, HiDF 69.1m; Crown scorch – LoDNF 32.8m, LoDF 43.5m, HiDF 106.1m

Discussion

Fire Transition Zone Comparing Silvicultural Treatment to Adjacent Untreated Areas

Though the Cone Fire ceased to burn as a crown fire immediately upon entering any of the silviculturally treated plots, there was variation in the subsequent proportion of bole and crown scorch in the different types of treatment plots. The large variations in both the percentage bole scorch and percentage crown scorch (Table 2) for the silviculturally treated plots can be explained by the differences in surface fuel beds encountered as the Cone Fire crossed from the adjacent untreated areas into the treated plots. This difference may be attributed to several reasons. For instance, ladder fuels in an understory can lead to crown fire (Van Wagner 1977). After the silvicultural treatments, the BMEF plots had insufficient seedlings and saplings to act as ladder fuels compared to the adjacent untreated areas. Additionally, silviculturally treated plots had fewer trees in general (Oliver 2000; Symons 2006), of which most were of a size class large enough (> 13 cm dbh) to not have low-hanging branches contributing to the ladder fuels structure and were spaced sufficiently far apart to not support active crown fire.

Fire Effects in Low-diversity Treatment Plots Versus High-diversity Treatment Plots

Both percentage bole scorch and percentage crown scorch were much lower for the LoD plots than the HiD plots, even though the fire ceased to burn as a crown fire immediately upon entering both plot types. This is most likely due to the more uniform removal of small trees in the low diversity silviculturally treated plots, leaving only widely-spaced trees in the 13–28 centimeter and 29–53 centimeter size classes. The larger numbers of small trees left in the HiD plots were susceptible to scorch from even low-intensity surface fire. The large variation in both the percentage bole scorch and percentage crown scorch (Table 2) in the high-diversity, silviculturally treated plots appears to be due to both (1) convective heat driven by wind into the plot from the intensely burning adjacent stands, and (2) scorching of smaller trees by the low-intensity surface fire that continued in the HiD stands. It appears that the denser stands with larger trees left in the HiD plots (Vaughn and Ritchie 2005) had produced sufficient needle cast in the five years since prescribed fire to carry a low-intensity surface fire. This was in contrast with the LoD stands, where even a low-intensity surface fire would not carry in the plots, even where it had been five years since prescribed fire. Generally, tree crowns in the high diversity strip plots closer to the treatment boundary experienced much higher levels of crown scorch than similar-sized trees located farther into the plot. In addition, the 50–100 m increment of the high-diversity silvicultural treatment plots (Plot 41) was influenced by wind speed and direction and the intensity of the fire in the adjacent untreated area (Ritchie et al. 2007). Therefore, the percentage bole scorch and percentage crown scorch near the silviculturally treated/not recently silviculturally treated boundary was likely influenced by convective heat from adjacent areas.

Fire Effects Comparing Silvicultural Treatment

In all cases, with the exception of bole scorch in the LoDNF treatment, there was a significant difference ($p < 0.05$) between silvicultural treatments for both percentage bole scorch and percentage crown scorch (Table 3). There was a very large difference between the low diversity with prescribed fire treatment and all other treatments. In the low diversity with prescribed fire treatment, removing the small trees (i.e., trees < 12 cm dbh) eliminated the low-hanging branches that act as ladder fuels into the canopy. This is in contrast to the high-diversity structural treatment, which left trees of many size classes and occasional thickets, some of which could act locally as ladder fuels. The reduction of surface fuels in the LoD structural treatment with prescribed burning contributed to the significant reduction in bole and crown scorch compared to the low diversity without prescribed fire treatment, as the Cone Fire was unable to burn even as a low-intensity surface fire in the former.

The Cone Fire dropped from a passive crown fire to a surface fire almost immediately upon hitting a thinned treatment plot, regardless of the specific type of treatment (Skinner et al. 2004; Ritchie et al. 2007). As predicted by fire behavior simulations, there was a gradient of change in fire severity that followed the intensity of the treatments (Ritchie et al. 2007). The absence of understory fuels to act as ladders to the canopy, combined with reduced surface fuels in the low diversity with prescribed fire treatment, caused the Cone Fire to immediately drop from the crowns and become a low-intensity surface fire, usually extinguishing itself without outside influence. There was no significant difference between the high diversity with prescribed fire and the low diversity without prescribed fire treatments for bole and crown scorch. There are likely different reasons, however, for the higher levels of scorch in the two treatments. Ritchie et al. (2007) determined the likelihood for considerable differences in tree mortality between the two treatments. They found a significantly higher level of tree mortality in the low diversity without fire than in the high diversity with prescribed fire. The high diversity with fire treatment included a higher degree of structural stratification, with more small clustered trees, and low-hanging branches that were susceptible to scorch from the surface fire. Thus, the more small trees there were in a stand, the higher the percent scorch was, even if the fire behavior was the same—whereas the low diversity without prescribed fire silvicultural treatment had a greater abundance of surface fuels (i.e., duff and woody fuels) to generate greater heat for higher scorch levels.

Fire Transition Comparing Distance into Treated Plots

Data was grouped by distance increments in order to determine if there was an area of transition as the fire moved into the silviculturally treated plots. There was a significant difference between all three increments (Table 4). The Cone Fire transitioned from a crown fire to a surface fire almost immediately upon entering any of the treatment areas. Crown scorch and bole scorch were reduced, compared to outside the treatment areas in the first 50–100 meter increment upon entering the stand. Only in the areas that did not receive prescribed fire following thinning did the fire continue to burn through the units beyond the 100–150 m increment distance from the edge of the treatment area. Some units experienced a greater range of the fire than others, based on the silvicultural treatment, as was discussed in a previous section.

California law PRC 4291 specifies at least 100 feet of fuels reduction around a structure to provide for defensible space. In this regard, defensible space is area where fuels have been modified to reduce fire behavior sufficiently to not rapidly spread fire and to allow fire suppression forces the opportunity to safely defend the property. Thus, defensible space is not necessarily expected to stop a fire, but to slow its spread and reduce its intensity, similar to the concept of a fuelbreak (Agee et al. 2000). Notably, all of the treatments assessed in this study were effective at bringing the fire out of the crowns and to the surface almost immediately as the fire encountered the treatment. The differences between treatments were primarily in a gradient of how the fire was subsequently able to burn through each of the treatment areas. As noted by the semi-variance analysis, the scale of the fire effects into a treated area tended to range between 35.8 and 175 m for bole scorch and 32.8 to 106.1 m for crown scorch. The longer penetrations of the Cone Fire into the HiDF as crown scorch tended to be due to more low-hanging fuels and small trees that were more susceptible to crown scorch. The large range of percentage crown scorch for HiDF and LoDF can also be attributed to convective heat and intensity of the Cone Fire being pushed strongly by wind as it reached the planned treatment boundaries. Overall, all treatments were effective in halting the crown fire almost immediately, with the low diversity with fire structural treatment the more effective, as it essentially stopped the fire from burning into the treatment area. Since California law PRC 4291 represents an average of various flammable vegetation types found in the state, i.e., chaparral, oak woodland, conifer forest, etc., a homeowner should consider from these results that 100 feet is the minimum defensible space for ponderosa pine-dominated forest areas with similar silvicultural treatments.

Conclusion

The analysis of fire effects in ponderosa pine-dominated forests based on different combinations of silvicultural treatments provides an insight into more-effective wildland-urban interface (WUI) area fire hazard-management techniques in the 21st century for California's drought-prone conifer forest regions. Since the turn of the 20th century, wildfires have often become severe events, largely as a result of built-up fuels due to active fire exclusion (Arno and Brown 1991). Recent studies reinforce that northeastern Californian mixed-conifer forests have undergone a major structural and compositional change since beginning the exclusion of fire (Taylor 2000; Norman 2002; Norman and Taylor 2005). This can contribute to higher probability of increased fire intensity, fewer fire-tolerant forest stands, and more-severe crown fire (Mutch 1994). A low-severity fire regime has been replaced by a moderate- to high-severity fire regime that is largely the result of the changes in fuel loading and stand structure (Agee 1994).

The results of this study show that a combination of selective thinning with prescribed fire can significantly reduce the severity of wildfire effects in an interior ponderosa pine forest. Percentages of bole scorch and crown scorch were lower in areas that had been selectively thinned followed by prescribed fire than in areas that had not had similar silvicultural treatments (Table 4). A low-diversity structural treatment combined with prescribed fire resulted in less bole scorch and crown scorch than a low-diversity structural treatment without prescribed fire, or a high-diversity structural treatment with prescribed fire.

Forest managers are now faced with up to a century of built-up fuels and dense understories. A complete return to historical regimes is not likely, as forest composition, structure, and function have been drastically affected by a century of fire exclusion. These results suggest that a combination of silvicultural treatments can spatially reduce the potential for severe fire damage in WUI areas (supporting CAL FIRE's defensible space policy/CA law PRC 4291), while suggesting active vegetation management approaches for the broader forested landscape. Active management approaches will likely result in more-resilient forest ecosystems in western U.S. ponderosa pine forests.

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Geographic Education

Graduate Degrees in Geographic Education: Exploring an Online Model

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Abstract

The national demand for online teacher graduate degrees has led to a national explosion of pedagogically oriented curriculum and instruction master's degrees in private and public universities. Subject-matter-rich online graduate degrees for teachers have been slow to follow. This paper describes the design and implementation of the only online geography master's degree in geographic education in the United States. The collectively rich national bank of K–12 geography education materials makes this type of degree possible. In a partnership with College of Education faculty, the program of study combines 24 semester credits in geography and 6 credits in education leading to a capstone project.

Key words: Geography education, online education, learner-centered education, virtual learning environments, Blackboard™

Introduction

Michael Libbee (2006) at the National Council of Geographic Education meetings presented results of 500 surveyed teachers around the nation; nearly 60% responded that they had little or no preparation in geography. Just less than 35% of the same group responded as having "several courses," with the remaining split between "College minor," "Graduate work," and "College major." These data reveal clearly that many K–12 educators who teach geography lack formal coursework training.

Currently, Texas State University offers an accelerated Ph.D. in geographic education, blending on-campus doctoral courses during summer sessions and online coursework during fall and spring semesters. After two years of coursework, students complete off-site dissertation research, working with top-caliber faculty and the Grosvenor Center for Geographic Education. Texas State University formerly offered an online master's degree with a specialization in geographic education. The degree consisted of courses in research design, quantitative methods, contemporary issues in geographic education, a seminar on theory and methods of geographic education, directed research, and electives including Geography for Teachers and innovative "Step Up to Geography Modules" in different world regions. The program blended courses intended to improve knowledge of world regional geography content, strengthen instructional skills, and complete requirements for a master's degree.

The only other distance-learning master's program in geographic education that we are aware of is offered by the Institute of Education at the University of London, England. The degree takes one year to complete as a full-time student, or two to four years for part-timers. Students take two-thirds of their course modules in a focused subject area, and the last third in either a research "dissertation" or a report plus a further module in the subject area.

Surveys of 455 K–12 teachers attending workshops of the Arizona Geographic Alliance in 2004 and 2005 revealed that a third of them desired online graduate teacher-education focusing on geography content. Almost one-fifth said that they would like to enroll in a master's program in geographic education if it could be completed online. Given this demand, we coordinated the construction of a very different online graduate program to fulfill this need.

The Program

The Master of Advanced Study in Geographic Education (MAS-GE)[1] program, offered by the School of Geographical Sciences at Arizona State University (ASU), is a non-thesis, discipline-specific master's degree designed expressly for working K–12 educators. All MAS-GE courses are taught online and on a nontraditional, K–12 school-year-friendly quarter schedule embedded within the semester framework of ASU. Although designed to be completed in 18 months, the program remains flexible, allowing students to finish in as few as 12 months or up to 24 months or longer. The program also allows K–12 teachers to become highly qualified in geography by completing 24 graduate hours in geography. All student assessments are individually focused on concepts, techniques, and applications of geography identified by the teacher for their respective educational context. The MAS-GE program consists of 30 semester-equivalent hours taken online, with two day-long sessions required at ASU Tempe Campus: an orientation session at the start of the program and presentation of an applied project at the end of the program.

[1]The program Web site can be accessed at http://geography.asu.edu/masge.

The MAS-GE program attempts to rectify the setbacks Libbee (2006) identified by focusing on core geography themes: the physical and human environments, geo-techniques, and regional geography. Each geography content course (GCU 672–GCU 676, Table 1) was created with the idea that teachers need basic geography, but at a graduate level blending in geographic knowledge through the spectacles of pedagogy. Thus, while geography content courses cover basic associated elements, the course assessments require teachers to move beyond simple knowledge exercises, asking them to analyze and synthesize the lectures into meaningful and useful products.

Table 1. Current required courses for the MAS-GE program and their associated catalog description. Credit hours are listed in parentheses after course title.

Courses (semester credits)	Catalog Description
GCU 671 Introduction to Geographic Teaching (4)	An intensive course on history of geographic education; scientific method in research on geography education; research trends; resources for teaching; best practices.
GCU 672 Physical Geography for Teachers (3)	Transfer of matter and energy exhibited in Earth's climate, hydrology, soils, biogeography, and landforms; case studies; virtual field trips.
GCU 673 Human Geography for Teachers (3)	Analysis of cultural, economic, urban, historical, transportation, population, political, and development geography; case studies; virtual field trips.
GCU 674 Geographic Techniques for Teachers (4)	Introduction to geographic techniques, including GPS, GIS, remote sensing, cartography, qualitative and field methods.
GCU 675 World Geography for Teachers (3)	Systematic overview of geographic knowledge about different world regions.
GCU 676 North American Geography for Teachers (3)	Systematic overview of geographic knowledge about different North American regions.
GCU 677 Geography Across the Curriculum (4)	Intensive course on integrating reading, writing and mathematics standards with geography content; selected case studies; best practices.
COE 501 Introduction to Research (3)	Overview of educational inquiry from controlled, quantitative to qualitative, naturalistic. Emphasizes locating and critically interpreting published research.
SED 593 Applied Project (3)	Hands-on dialogue with College of Education faculty on the integration of geographic knowledge in a student's educational context.

From the very first class (GCU 671, Table 1), teachers are exposed to research, compiling a minimum of four, two- to four-page critical article summaries per geography course (Figure 1). Each summary must be from a "professional" source (e.g., peer-reviewed journal), follow specific guidelines developed by College of Education partners, and relate to the teacher's "burning passion." A course focusing on teaching geography across the curriculum (GCU 677, Table 1) rounds-out the geography content.

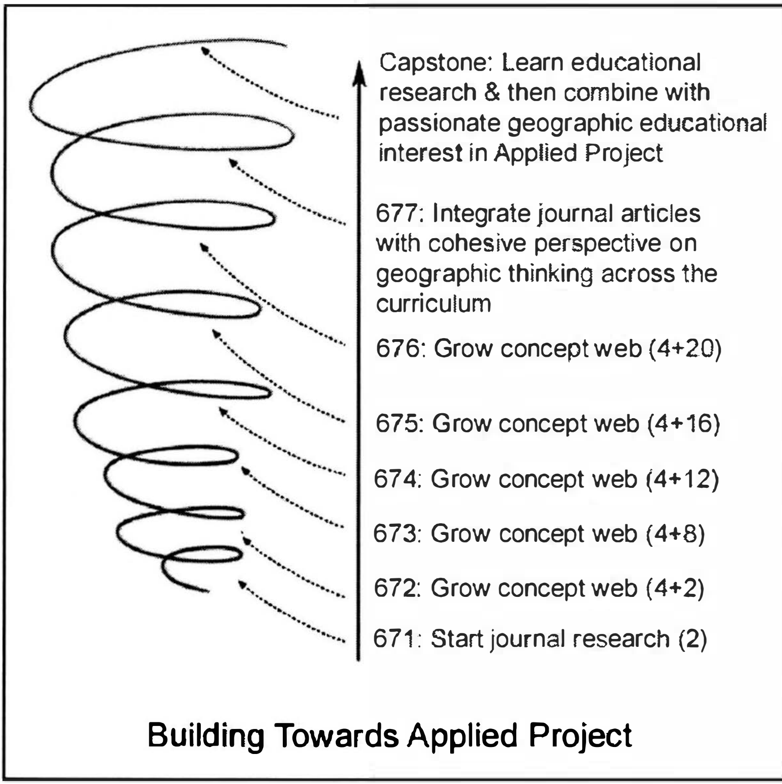


Figure 1.—MAS-GE students build a solid base of scholarly knowledge around their capstone project throughout the program, allowing their thoughts time to mature through building knowledge through 25 scholarly source reviews.

In addition to critical article summaries, each course requires formal course assessments. These focus entirely on teachers' perceived needs, while integrating information gained throughout the course. For example, as an assessment for the medical geography unit in GCU 673, one teacher created a lesson focused on the Spanish Flu pandemic of 1918–1920, and how understanding the geography of that outbreak can lead to an understanding of disease diffusion today. The Binko-style lesson (a structure used by geographic alliances nationally; see Neubert and Binko 1991 and Binko and Neubert 1996) designed by this teacher came replete with a photo-rich PowerPoint, student assessment, and map project to track disease vectors—all useful tools easily integrated into their classroom.

The general structure of the geography coursework starts and ends with courses that blend geography content and pedagogy. Courses between provide teachers with a thorough base of knowledge in the core areas of physical geography, human geography, and geotechniques. In order to stimulate intellectual growth in regional geography, teachers develop a course in world regional geography at the community college level and explore a familiar subject (North America) at a much higher level. Figure 2 explains the program's strategy at enriching depth in geography education.

Each course also builds toward the "Capstone Experience" that includes courses taught by Education College colleagues. In this two-part series, teachers learn the basics of research in education (COE 501, Table 1) and create a formal written project (SED 593, Table 1), presented at a year-end academic function attended by fellow students, family members, friends, and faculty—one of only two required face-to-face meetings. This two-course culminating experience replaces a traditional thesis, with the goal being development of a detailed, sophisticated, and innovative project based on a real or potential issue of interest to the teacher—a "burning passion." The capstone experience aims to create a framework whereby students discuss pertinent geographical issues, ideas for solutions, evaluate the feasibility of potential solutions, apply those solutions, and ultimately evaluate a project's success. Teachers receive continual guidance from instructors along the way to develop and enrich their capstone experience.

Pedagogical Interface

Although Blackboard™ was chosen as the initial platform because most students are familiar with its interface, the geography content courses (GCU 672–677) also have individual password-protected URLs. These Web sites consist of a syllabus with links to course lectures, assignment structure, course modules, extra readings, and other online resources. Although GCU 671 has a dedicated URL, it is run almost exclusively from Blackboard. The intent of the first

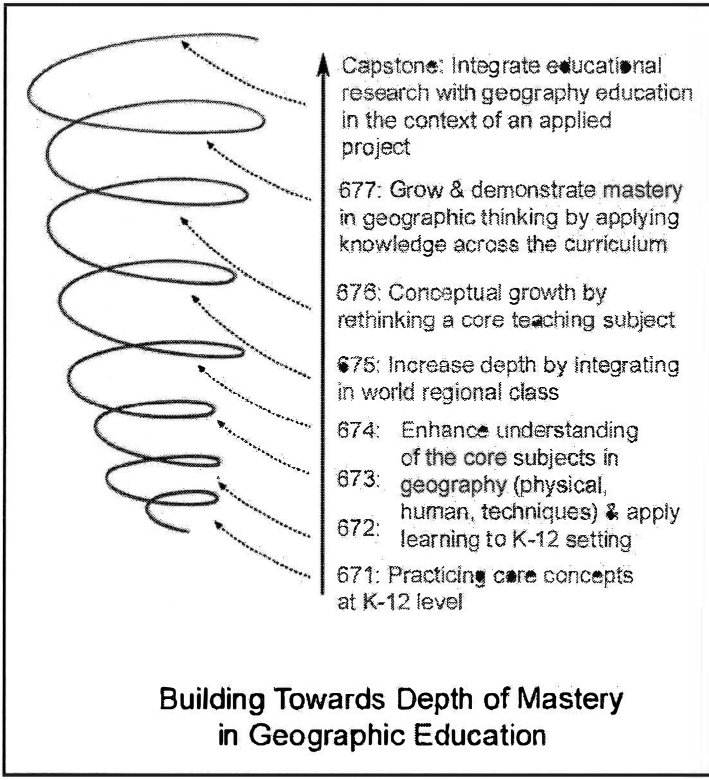
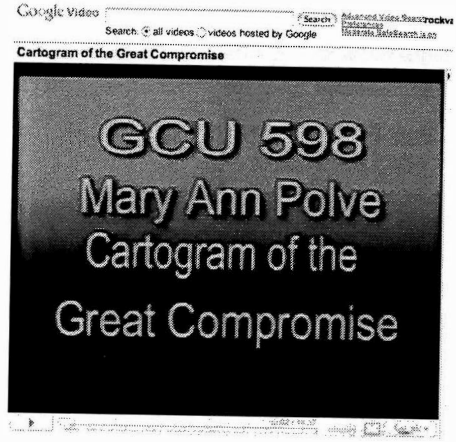


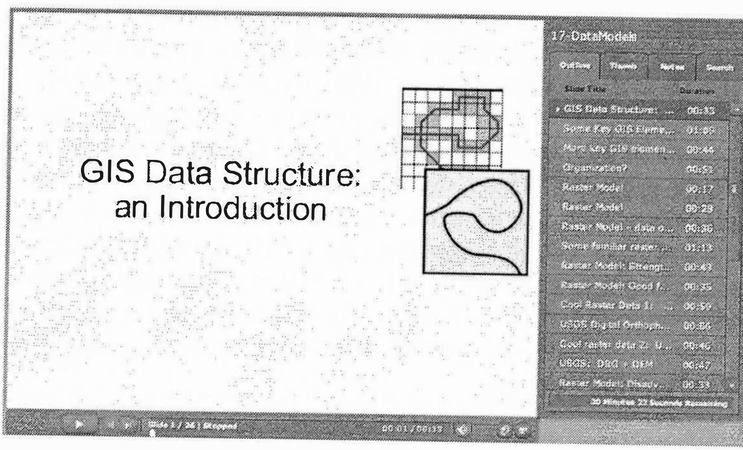
Figure 2.—Progression of courses intended to start by enriching the familiar of basic geography pedagogy and end by analyzing ways to integrate rich geography content across the entire K–12 curriculum.

GCU 671 course rests in introducing students to both the program structure and what will be expected of them. It focuses on learning why and how K–12 teachers teach geography. This course uses a bank of dozens of videotapings, conducted by the Arizona Geographic Alliance, of teachers from different grade levels explaining their lessons. These videos were then edited for content and time, converted to streaming quality, and uploaded as "non-public" to GoogleVideo (Figure 3a). This video bank also includes a few classroom tapings narrated by a pedagogical content expert—similar to a "Director's Cut" edition DVD. Using Google as an interface, then, teachers watch the different presentations at their leisure and analyze and critique each "set" of lessons.

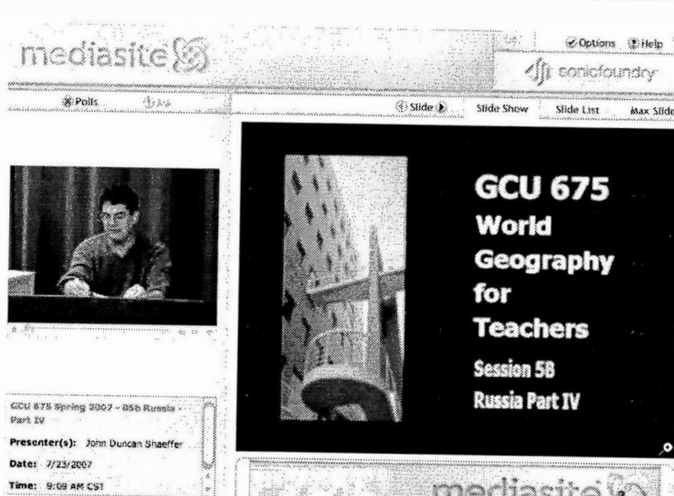
Figure 3.—The program uses different modes of delivery of material, including (a), streaming of videotaped presentations, (b), voiced over PowerPoint presentations, and (c), the media site mixed format.



a.



b.



c.

Owing to their focus on content specifically, the geography content courses boast a different delivery mode: Adobe Breeze Presenter (Figure 3b).

Presenter is, at its simplest, a voiced-over PowerPoint presentation. But it also allows instructors to embed multiple images/animations, hyperlinks, and even video alongside the voiced-over text. This delivery system was chosen for its ease-of-use, cross-platform ability (works on Macs and PCs), and lack of any extra end-user equipment ("plug-in"). Students merely "click" on the link provided in the online syllabus, and immediately the lecture plays on their computer.

While it also has an individual URL, GCU 675 (World Regional) uses mediasite for its pedagogical interface (Figure 3c). The point of this course focuses on teachers observing, studying, and critiquing an entire college-level world regional course (via mediasite). Using the world regional model provided, teachers are required to create their own world regional course that could be taught at the community college level. For many teachers, this represents a challenge; they must communicate content beyond the K–12 level, forcing them to think like a college instructor. This seemingly simple task of creating a college-level course enhances their pedagogical content knowledge and forces them to think about future pedagogical content applications—all while internalizing how geographers think about world regions.

Alongside the Blackboard, Presenter, and mediasite interfaces are other resources. Several faculty members outside Arizona State contributed short video presentations of key concepts in geography. For example, in GCU 673, geographer J. P. Jones III (University of Arizona) contributed a short introduction to the socio-spatial dialectic—still a key concept in geographic thought. This inter-institutional cooperation not only results in a richer learning experience for teachers, but also exposes teachers to cutting-edge geography. Case in point: for the capstone experience, one student's focus rests on addressing the human-physical geography divide—a noble effort for a nontraditional student teaching full-time in a middle school K–12 classroom.

Most interactions between teacher and instructor occur via heavy one-on-one e-mail traffic (e.g., multiple e-mails per student, per quarter). While this can be frustrating for a geo-techniques course, the program was designed to be flexible and fit into a K–12 teacher's lifestyle. If problems cannot be remedied via e-mail, the instructor may opt for a site visit. These meetings can be individual or in a small group, and take place wherever is convenient for the teacher, such as at a school site, in a park to accommodate a teacher's children, or at a coffee shop. Throughout the first cohort, two *optional* face-to-face meetings were scheduled to address teachers' specific needs. These were both well attended and held at teachers' requests. One disadvantage to these meetings was that they mostly excluded non-local teachers. Yet teachers recognize that this *is* an online program, and as such, they do not expect face-to-face time, though the instructors make every effort to accommodate such requests.

Geography content courses are sandwiched between an in-person orientation at the beginning of the program and capstone presentations at the end. These bookends represent the only regularly scheduled on-campus events. While attendance at orientation is strongly suggested, non-local students are not required to be there. Likewise, the program's flexibility even extends to the capstone experience, as non-local students may submit their presentations via a virtual Web conference, or even a Breeze presentation of their own. The program's bottom line rests in flexibility and accommodation of the K–12 teacher lifestyle.

Assessment

Four main components frame our assessment: individual assessment *during* courses, a course-culminating "capstone" project, assessment of the courses themselves, and assessment of the program. Since the program is designed with the K–12 teacher in mind, many choices are possible for each class's units. Unit assessments for GCU 671, 674, 675, and 677 are slightly different, owing to the specific content in each. For GCU 672, 673, and 676, however, teachers can take three "take-home" essay exams (an option that no student has yet explored), or choose six options from a list (Table 2). In addition to these options for each geography content course, and to help prepare for the capstone experience, teachers are tasked with completing two connections to the capstone experience: critical article summaries (discussed above) and creation of a concept map that displays their evolving burning passion.

An integral part of the degree experience, capstone projects exhibit a wide-ranging (and tasty) geography-laden buffet. For example, first cohort capstone projects include a plethora of subjects, such as:

- Addressing the human-physical geography divide in K–12 education
- A geography of breast cancer (locational analysis of breast cancer occurrences)
- The impact of field experiences on K–12 classrooms (how teachers use personal field experiences and how technology can help encourage geographic thinking)
- A "City-First" approach to the study of regional geography in North America
- Battlefield preservation and reconstruction
- The diametrical opposition of environmental impact and romanticizing of tumbleweeds in the American West
- Incorporating travel study experiences into the classroom

While only a sample of the first cohort's burning passions, these topics exemplify teachers' willingness to complete work at the graduate level, moving from the role of consumer of knowledge to producer. This transformation is monitored through the various formative and summative assessments for the program.

In addition to summative end-of-course surveys, the program values formative teacher feedback. For example, the "Discussion Thread Leader" course assessment option (Table 2) resulted when a teacher wanted to discuss pertinent issues with colleagues. While it can be overlooked, Blackboard has proven effective as a learning community in graduate-level geography courses (Lukinbeal and Allen 2007). For this program specifically, Blackboard provides a complementary interface that enhances critical thinking (cf. Deloach and Greenlaw 2005; Francescato et al. 2005), inquiry, and collegial communication (cf. Gokhale 1995; Bradshaw 2002; Francescato et al. 2005; and Frederickson et al. 2005). Yet aside from the course survey (below), the discussion-thread leader option represents the only other use of Blackboard's assessment features.

Table 2. The six assessment options available for GCU 672, 673, and 676. Teachers are instructed to select the six assessments that best improve their teaching. In this table, "Limit" represents how many times an option may be selected for a single course.

Option	Limit	Description
Bulletin Board for Classroom (or Hallway Display)	2	Prepare a hallway display or classroom bulletin board that incorporates most of the elements from the lessons in this module. You will send in (e-mail, if you have a digital camera) photographs of the display.
Design your own assessment	1	Your assessment must involve synthesizing the information presented. There must be criteria for grading this performance assessment. It must link to the standards that you teach, and it most important, it should involve an outcome that would improve your teaching.
Discussion Thread Leader	2	The blackboard web interface has a feature that allows students to discuss the material in a flowing thread. If you are greatly interested in a particular topic, this assessment encourages you to lead a discussion thread that goes into depth on that topic. The key to this assessment option is enthusiasm for a topic and working with the instructor.
Journal Article Analysis	2	Find a journal article from ASU's library on a topic that was covered in lecture. Summarize the article, and compare the article's content to the presentation that you watched. This summary should be in the following form: • 1/2 page of brainstorming how this material might be used in your educational setting. • 1/2 page of summary of journal article • 1 page of comparison
Lesson—Binko Style	6	Write a "Binko"-style lesson. Remember, the "Binko" style is the lesson format used by geographic alliances and illustrated extensively in the GCU 671 class. The only addition is that you would add a new section: "Background Information." In this background information section, you would provide your notes and research on the lesson. The notes and research might come from the class materials, the readings, independent sources, or a mixture. The Background Information might also be a reading that the students would use in order to complete the tasks in the lesson.
Online Lesson Analysis and Adaptation	2	There exists a plethora of lessons on the internet. Some present incorrect information on a topic, but have the core of a great student activity. Others have outstanding content but were designed by scientists with little real classroom experience. This assessment involves you taking an Internet lesson that relates to the unit being covered, doing the research to determine if the content is valid, and then modifying the lesson to improve deficiencies.

Continued

Table 2 continued

Option	Limit	Description
PowerPoint presentation	6	Make a PowerPoint presentation (or modify the presented PowerPoint) to fit your grade level. You must submit your performance objectives for the PowerPoint, and provide the materials for student assessment of your PowerPoint (quiz, notetaking sheet, worksheet, or other student activity) along with the answer key.
Student Readings	2	Find grade appropriate readings/literature on the subject matter. Then, develop the complete assignment that you would give your own students, including handouts, instructions, worksheets, keys, or other items that would make this "ready to use tomorrow."
Study Guide and Test	2	Develop a study guide and test for your own classroom for when you would teach the material in this module.

The end-of-course surveys use Blackboard's survey feature. Although initially time-consuming to create, these surveys have provided constructive comments from teachers regarding the course layouts, designs, and level of content. From these surveys, it is clear that while the courses are "Very Challenging" for a majority of teachers, they found the content and workload acceptable. Further, teacher responses about what they learned ran the gamut of positives, from "I think that this course helped me teach better this year and will help me in the years to come" to "I was challenged to see things in a different light and apply what I learned."

In addition, two other qualitative summative assessments should be mentioned. First, halfway through the program's first cohort (started in September 2007), we reached the point of deciding whether or not to continue the program and recruit a second cohort (starting in September 2008). Thus, we asked the harshest question possible to all teachers in the cohort: did they feel the program worthy of recruiting a second group? We made it clear that, no matter what, we were committed to helping them complete their degrees. However, we honestly wanted to know the ultimate summative assessment of a program. Table 3 provides representative responses of the feedback received, edited to reduce journal space, but presented in a way that retains the assessment's flavor.

We also undertook qualitative summative evaluations at two well-attended optional face-to-face meetings. We learned that there is an overwhelming preference for Adobe Breeze Presenter as the mode of instruction. Teachers cited several reasons for this inclination:

ability to review material, ability to stop and go whenever convenient, and ability to take notes while both seeing and listening to the presentation.

Table 3. Summative assessment of the MAS-GE program after its first year, undertaken by asking an honest question of "whether we should continue this program. In other words, do you think that it is worthwhile for other teachers?" If the answers were negative, we were fully prepared to close the program after the first cohort completed their degrees. This table compiles segments of their responses.

Teachers' Responses
• Absolutely! ...The content courses were my favorite and am sad that we will soon start turning from that.
• I've wanted a Masters for some time but had the greatest reluctance to subject myself to the typical masters programs that teachers usually do. This program has offered a real alternative to the mind numbing standards of typical masters programs, indeed, this would be a great advantage in recruitment as far as I'm concerned.
• I think it's very cool. I recommend keeping the program. Yes, it involves a lot of time and work, but it is online, so that helps so much with flexibility.
• It has gotten me thinking about what else I might want to do, now that I have a course almost prepared for an adult audience.
• I think it is a worthwhile program because I wanted a degree in geography and I waited forever (okay, 8 years) and there was never a program that suited in this area.
• The different assessments for each course got me excited! Requiring us to create our own world regional course and learning to create maps and simple GISs well, now, instead of just telling my AP students about GIS, they can make an easy map using it. That is worthwhile in itself.
• For me personally it has been a valuable experience. Some of my colleagues are doing master's in Curriculum and Instruction or Admin, and though they seem to have less of a work load than I do, I think I am receiving something more valuable: content training that can be used in the classroom.
• Not only will I be one of the few teachers Highly Qualified in Geography but I am being prepared to teach a course at the Community College level. My colleagues with their C & I degree will not be able to do that.

Continued

Table 3 continued

Teachers' Responses
• As a teacher, this program has not only inspired me and provided the tools to integrate geography into the subjects I teach the most (History and Civics), it has helped me evolve as an educator.
• My lesson plans are infinitely more structured and executable. My confidence in the classroom is much higher, because I possess the tools and now have practice delivering more three-dimensional lessons.
• The program has given me both a sense of specialization and has broadened me, at the same time. As a result of the program, so far, I see content and curriculum differently. Not only do I see geography in everything, I have learned how to "think" about geography standards not as something I have to do, but as an imperative to provide perspective for students.
• I feel illuminated and challenged, by the program. It's intoxicating. Now, when I look out of an airplane, leaving Albuquerque, I look for the "calcrete duri-crust" around the river valley and analyze the clouds building over Flagstaff.
• I would encourage you to persist. I believe you and your staff have created something special. If you were to offer a PhD sister program, I would be the first to sign up.
• I LOVE this program! I have no complaints at all (so far), and would "sell" this program to anyone! I'm learning so many new things, and I'm also inspired to discover more.
• I found all of the classes helpful. My overall impression is very positive.
• I have been telling many people about this program, recommending it to those who have an interest in geography.
• All grad programs place stress on the teachers enrolled in them. Stress from the MAS-GE program, however, comes from the work involved, not from the logistics of participating in and completing the program. That's a big difference.

Continued

Table 3 continued

Teachers' Responses
• I would highly recommend the MAS-GE program at ASU! It allows for a reasonable amount of flexibility into a teachers schedule, especially with breaks and summer without a rigorous commute for evening classes, weekends, etc.
• The degree is from ASU and not a little heard of or possibly questionable on-line school.
• The faculty is most attentive and I truly feel their desire for success to all those involved in the cohort.
• The workload is no pushover, but assignments are focused on materials you can create and use in any classroom.
• This program is completely worth it. I have used so much of what we have done for the classes in this program in my classroom this year.
• Please continue the program.
• This has not been a waste at all. I can use this in my classroom!
• Someone commented to me that it would be wonderful to see the history department do something similar.
• It would be a shame to not see others follow behind us in this program.

Future Plans

No graduate program properly assessing its learner objectives can truly predict its future. This program's future rests in continued assessment from each cohort and from the external evaluators examining formative and summative assessments. Still, based on existing feedback, we anticipate programmatic growth with at least three themes. First, we hope to establish a cycle of professional growth, employing recent graduates as course instructors and as individuals improving course content. Second, we hope to add history, political science, and economics courses to develop a concentration in social studies education. Third, we hope to add courses to develop a concentration in geographic techniques for teachers. One great hurdle to this program rests in keeping down costs. As ASU increases its tuition rates, the cost of the program rises. Of course, the greatest hurdle to any innovative program rests in the changing dynamics of academic administrations.

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The Geographer's Viewpoint

Geography from the Back of the 2008 AAG Program: Is Geography What We Say or What We Do?

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All tables in this paper may be viewed at:
http://www.csulb.edu/~rodrigue/cg08tables/

Introduction

Geography every once in a while waxes reflective about itself as a community, a practice, and an epistemology (e.g., Hartshorne 1939; Schaefer 1953; Pattison 1964; Robinson 1976; Boehm and Bednarz 1994; Johnston 1998; Turner 2002; McDougal 2003; Castree 2005). This cyclical urge to reflect recognizes that the breadth of geography makes its scope a far horizon for those in the discipline and a temptation to challenges from disciplines of narrower reach along that horizon. Usually, these self-examinations focus on what it is that (should) define(s) geography conceptually along a series of dualisms: regional or systematic, content or method, natural science or social science, spatial or ecological, analytical or integrative, regionally integrative or human-environmentally integrative, positivist or post-/anti-positivist. Some have rather dismissively said that "geography is what geographers do" (e.g., Parkins 1934, cited in Whitaker 1940; Jones cited in James 1952; and referenced in Johnston 1980), while others view such centrifugality with despair and try to bound the field in yet another round of introspection.

These discussions take on practical importance for academic geography departments, which face cyclical program review and assessment, may factionalize along these polarities, or face interrogations of their boundaries by competing departments and, sometimes, hostile administrative structures. "What is it you people DO?"

This paper compares and contrasts what California geographers say geography is and what geographers actually do, both in California and at our flagship national conference, the Association of American Geographers. The paper begins with an examination of definitions of geography placed on the Web pages of university departments of geography in the State of California. It then characterizes the distribution of tenured and probationary faculty interests, as listed on department Web pages. These 202 California geographers are then categorized into broad specialties (e.g., physical, environmental, human, GIScience, and regional geographers) and their proportions discussed. Lastly, the distribution of topics for sessions at the Association of American Geographers 2008 annual meeting is described. Quite a disparity emerges among what California geographers tell the public geography is, their own interests and specialties, and the foci of the national conference. Implications for the health of the discipline are disquieting.

Data and Methods

This paper proceeds by a mixture of quantitative and qualitative literature content analysis. The AAG session topics and the lists of California faculty interests entailed simple coding and frequency counts. The California departmental Web page definitions of geography required an iterative and emergent coding process, which eventually stabilized into codes that could be counted and compared with the AAG and faculty codes. Analysis then proceeded through the Chi-squared, Kruskall-Wallis, and median tests, using 0.05 as the cutoff for significance.

Classifying California Geography Department Definitions of Geography

I focused on California departments and geographers to yield a manageable number of sites to visit in a single region that is large, diverse, and, hopefully, representative of national trends. Furthermore, I can draw on "local knowledge," being a California geographer familiar with all 23 of the baccalaureate (9), master's (8), and doctoral (6) geography programs in the state (having attended two, taught at four, chaired one, directed three graduate programs at two, and reviewed two). These are distributed in the California State University system (18), the University of California system (5), and the private University of Southern California (1).

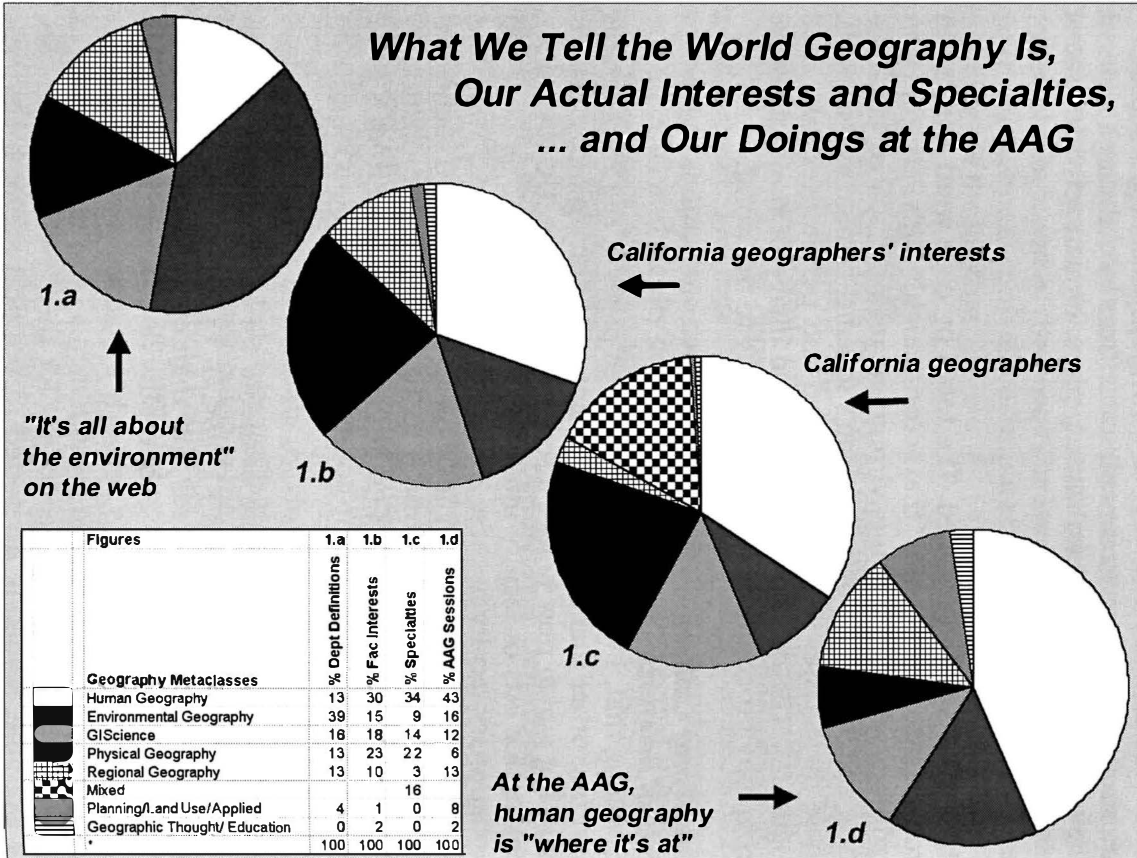
I located and downloaded the definitions of geography provided in 21 programs' Web pages (two, CSU Northridge and San Diego State University, had no such definitions anywhere on their Web pages during my June 2008 visits). These definitions were entered into a spreadsheet. Each definition was read several times, and words or phrases describing what they emphasized were coded during each pass-through until each item was consistently named from one pass to the next (Table 1). Some definitions were terse and others very thorough, yielding anywhere from one through nine coded elements. The mean number of codes per department was 4.95 and the median 4.88, the total adding up to 104 elements among the 21 programs. This iterative process aggregated the 104 into 16 codes: human-environment, integrative, systems, interdisciplinary, landscapes, natural environment, scales (from local through regional to global areal units), globalization, place, human activities, social science, spatial, map, natural science, earth as home of humanity, and planning/applied.

These 16 were then counted. The totals by code word were again grouped into "metaclasses" that accord roughly with Pattison's four traditions scheme: human-environment, regional, spatial, earth science, and, departing from Pattison's scheme, human and applied. These metaclasses were also summed and percentages calculated (Figure 1). The outcome is a collective image of how California geography programs represent geography to the world.

Classifying California Geographers' Lists of Interests

Following that, I went through the Web pages of the 23 programs (and one other that used to be a joint geography-geology department but which now houses a solitary geographer, UC Riverside), looking for lists of faculty interests. There were 202 tenured and probationary faculty in these 23, ranging from 3 at CSU Stanislaus and CSU San José to 23 each at UCLA and UCSB. The 10 bachelor's-granting programs range from 3 to 10 tenured and probationary faculty, while the 7 master's-granting programs have from 3 to 12 faculty and the 5 department-housed doctoral programs range from 9 to 23 geographers.[1]

Statements of interests were available for all of these 202 California university geographers (Table 2). I classified their interests into as many as six keywords and then coded each keyword by the six metaclasses listed above plus one other: geographical education or thought. This seventh metaclass would appear in AAG sessions and in individual statements of interest, but not in how departments define geography for their Web audiences. So, for example, someone interested in political ecology, environmental justice, or human-animal interactions would have these interests classified in the human-environment metaclass, while interests in riparian vegetation, marine terraces, or Holocene climate history would be classified in the physical geography group.



Figures	1.a	1.b	1.c	1.d
Geography Metaclasses	% Dept Definitions	% Fac Interests	% Specialties	% AAG Sessions
Human Geography	13	30	34	43
Environmental Geography	39	15	9	16
GIScience	16	18	14	12
Physical Geography	13	23	22	6
Regional Geography	13	10	3	13
Mixed			16	
Planning/Land Use/Applied	4	1	0	8
Geographic Thought/ Education	0	2	0	2
*	100	100	100	100

Work on migration, sociopolitical contestation of urban space, or media representations of subcultures, for instance, would be put in the human geography metaclass, while those interested in a particular region or in the interaction of a place with global or regional contexts would have their interests "placed" in the regional geography group. Geographers' interests in remote sensing, GIS, geostatistics, or cartography would wind up in GIScience, while foci in urban planning or market-area analysis would be classified in the applied-geography metaclass. Expressions of interest in geographic thought, theory, and history or in pædagogy were grouped together in the geographic thought and education metaclass. Again, the balance of stated faculty *interests* (Table 3a) are graphed to compare with the departmental definitions of geography and the distribution of interests in the AAG program (Figure 1).

Classifying the California Geographers Themselves

I then classified the 202 *individuals* as particular types of geographer on the basis of which of these metaclasses contained the most specific interests listed for each person. If no one metaclass dominated that person's interests but, rather, two or more of them equally shared dominance, I classified that individual into an eighth class, as "mixed," a category not used for the other items under comparison. Table 3b and Figure 1 display this information. The reason I considered both *individuals* as types of geographer and *interests* held by these individuals is that most individual geographers find themselves with a wider array of teaching interests than their often narrower research interests. Departments often need this widening of teaching repertoire in order to get their students through a balanced curriculum with the professorial resources available.

Most Recent Journal Publication Listed

As a further lens into individual geographers' interests, I searched for each person's *curriculum vitae* or other lists of publications on the departmental and campus Web site. This led into an examination of the publication behavior of different types of geographer. If no publication list was provided for an individual, I Googled him or her in Google Scholar and in Google Web in June 2008 and, if a journal publication came up on the first three screens, I used it instead (or, more accurately, the most recent one on the top three screens). For each person, I noted the most recent publication only if it was in the form of a refereed journal article (I did not use books, chapters, popular press pieces, conference presentations, or Web pages). I then used this "one snapshot sample" of a person's scholarly output to determine the balance of publication activities among geography journals and non-geography journals for the California university geography community as a whole.

Classifying the journals presented a few judgment calls, since all journals do publish pieces by people in a variety of disciplines and departments.[2] The list of journals is provided in Table 2 and how I classified them. I did try a run with more generously inclusive definitions of "geography" journals, but the results did not change materially (Table 4d).

I was able to track down 179 journal publications, most within the past several years. A few geographers' most recent journal publications came from back in the 1980s. The remaining 23 geographers did not provide an online reference to a journal article. Some of these may not have any publications; many more had different types of dissemination, including a few with books. I then cross-tabulated the publication venue (geography, non-geography, and no journal publications) against the eight kinds of geographers for further analysis using Chi-squared (Table 4a). The contingency table had many small cell counts among the 24 cells containing the eight types of geographer by the three journal publication classes (geography, non-geography, and none listed). Therefore I collapsed the eight types of geographers into four to meet the requirements of Chi-squared analysis. This is a conventional preprocessing stage commonly done in Chi-squared (cf., Burt and Barber 1996: 355–356).

To do the collapse, I first did pairwise comparisons of each type of geographer against each of the others (where there were at least six geographers in a category). I would not combine categories if the pairwise comparisons were significantly different at the 0.20 level. I arbitrarily assigned the single geographic thought and education geographer to the human category and the single applied geographer to the environmental geography and GIScience group, based on a sense of their secondary interests. The process is summarized in Table 4b. The four groups of geographers that emerged in this classification process were: (1) physical geographers; (2) environmental geographers, GIScientists, and the solitary applied geographer; (3) human geographers and the solitary thought and education geographer; and (4) regional geographers and those with mixed interests.

To get at what might be driving differences in publication behavior, I used Thompson's ISI Web of Knowledge *Journal Citation Reports* to extract Journal Impact Factors (JIFs) for all journals in which California geographers' most recent papers were published, which were also tracked by *JCR*. I calculated means and median JIFs for geography and non-geography journals. The distributions of JIFs were skewed by the few non-geography journals with extremely high JIFs (e.g., *Science*, with 26.372), so, to test the difference in central tendency, I did a median test based on Chi-squared (Table 5). I repeated the tests to include the many journals not tracked by ISI, assigning the arbitrary "JIF" of 0.05 for the journals not tracked by ISI (which was lower than the lowest JIF in this group of tracked journals, 0.075). I also repeated the tests using a more inclusive definition of "geography journal."

I went on to compare each of the four types of geographer in terms of the JIFs of the journals in which they had their most recent publications. Since some of the groups were distorted by the handful of geographers whose most recent publications were in non-geography journals with extremely high JIFs, Analysis of Variance was inappropriate for this four-group comparison, due to its vulnerability to outliers. I therefore performed a Kruskall-Wallis test to evaluate differences among physical, environmental/GIScience/applied, human/thought and education, and mixed/regional geographers in terms of the 2007 JIFs of the tracked journals in which they had their most recent journal publication. I repeated the test for those journals not tracked by ISI Web of Knowledge, again using the arbitrary 0.05 "JIF" (Table 6).

I also looked at the differences in propensity to seek out non-tracked journals in which to publish. I did a Chi-squared test of the frequencies with which the four types of geographers published in tracked and non-tracked journals (Table 7).

Classifying the AAG Program Session Topics

The AAG Program provided several means of locating presentations or sessions of interest to attendees: by presenter's name and time and by topic, for example. To help attendees topically, the back of the program included lists of all sessions, or formal groupings of papers or panel discussions, that addressed 60 different topics (e.g., geomorphology, resources, GIS, planning, cultural, regional, geographic education). The 60 topics listed 6,771 sessions among them, including spoken paper sessions, poster sessions, illustrated paper sessions, and panel discussion sessions. With nearly as many sessions listed as registrants (over 7,000, according to Richardson

2008), each particular session often was listed under more than one topic.

Many paper sessions are organized by the AAG Program Committee from abstracts submitted by authors directly to the AAG outside the specialty group structure, which is the most convenient way to get a paper into the program. Others are organized by individuals, who solicit papers on given topics and collect the abstracts for common submission to the Program Committee. Most of these individuals will seek the sponsorship of one or more specialty groups, hoping thereby to gain a larger audience for their sessions through specialty group announcements to their members. The allocation of sessions to topics in the back of the program is done by the AAG Program Committee, based on specialty group sponsorship and keywords submitted by session organizers or by paper authors. A given session could, thus, appear under several topics.

I classified the 60 topics into seven larger divisions corresponding to the metaclasses discussed above: physical geography, environmental geography, GIScience, applied geography/land use/planning, human geography, regional geography, and geographic thought and education (Table 8). I then counted the number of sessions listed under each topic, summed the counts by the larger divisions, and then graphed them (Figure 1). These sums include the potentially multiple appearances of any one session under various topics. The distribution of the numbers of cross-listings per session by subdiscipline is unknown, and it could conceivably affect the distribution of counts under each topic and the grouping of topics if there are systematic differences in the likelihood of cross-listing by the Program Committee.

Results

This section presents results on how California university geography programs represent geography to the public in their Web page definitions of the field. It then contrasts these definitions with the distribution of interests cited by geographers on their departmental Web page profile lists and with the specialties their interests imply. These definitions, interests, and specialties are then compared with the distribution of AAG sessions by topic. Lastly, the distribution of last-refereed-publication is considered by type of geographer and type of outlet.

What Departments Say Geography Is

The literature content analysis of the 21 geography definitions proferred by the 23 geography departments and programs in California's universities is summarized in Table 1. It presents the 16 codes ranked by the frequencies with which they were incorporated in the definitions (Table 1b). The classification of each code into the six metaclasses is presented as well (Table 1c).

Thirty-nine percent of these code counts fall in the human-environment or environmental geography metaclass. Spatial, or GIScience, accounted for 16% and regional for 13% of the code counts. Human geography amounted to 13%, and applied geography, including planning, comprised another 4%. The remaining 13% fell into the earth science or physical geography metaclass. *So, in presenting geography to outside audiences, geography departments imply that geography is "all about the environment," with roughly balanced contributions coming from physical, human, and regional geography and GIScience.*

Classifying Geographers' Stated Interests

Turning to the individual interests of 202 tenured and probationary faculty in geography programs at California universities (listed in Table 2), 797 were stated out of the 1,212 that could have been stated, had all 202 geographers used six keywords to describe their interests (Table 3a). Of these 797, 23% were in physical geography and 15% in environmental geography. Another 18% were in the geospatial techniques, and only 1% were in the applied or planning area. Thirty percent of the stated interests were in human geography, 10% were in regional geography, and 2% were in geographical education or geographical thought. *The interests of the California university geography faculty, then, appear to give more emphasis to the major topical and technical subfields of the discipline and less to the integrative environmental and regional subfields than the departments' Web page definitions of geography.* Topical, technical, and integrative interests swamp applied geography or the geographic thought and education areas, though.

Classifying the Geographers

Table 3b classifies each geographer by his or her most frequently mentioned interests. The predominant interests fall into the same seven classes (physical, environmental, GIScience, applied/planning, human, regional, and geographic thought and education). An additional class was created for those geographers whose stated interests mix two or more co-dominant concerns.

Of the 202 California university geographers in full-time tenured or tenure-track positions, 69 (34%) are human geographers, 45 (22%) are physical geographers, 29 (14%) are GIScientists, 19 (9%) are environmental geographers, 6 (3%) identify themselves as regional geographers, and 1 each (0.5%) are predominantly applied geographers or planners and specialists in geographic thought and education. An additional 32 (16%) do not have a single dominant specialty and were classed as mixed in interests and expertise. They are really quite mixed: 32 mixtures occurred in 19 different combinations of 2, 3, or 4 specialties, with every co-occurrence of physical, environmental, GIScience, and human about equally likely, except for the human and physical combination, which was the least likely pairing of specialties. *Again, the distribution of geographers among the metaclasses reinforces the impression that we are dominated by topical and technical specialties, rather than integrative perspectives. Even more strongly, human geographers emerge as the modal type of geographer.*

Geography from the Back of the Boston Program

Table 8 lists the 60 topics by the seven divisions, and Figure 1 represents their distribution in a pie chart. Far and away the dominant concern of contemporary geography is human geography, with 27 topics and 2,929 sessions (43% of the 6,771). The topics ranged from 419 sessions listed under urban geography to 5 listed under Bible geography. A distant second is environmental geography, with 1,077 sessions (16%) distributed among 8 topics, ranging from 379 for environment to 43 for energy.

Regional geography comes in third, with 852 sessions (13%) and 11 regions or region-related topics. GIScience is close behind regional geography, with 786 sessions (12%) distributed among 4 topics, ranging from GIS with 317 sessions to cartography with 86. Planning/land use/applied geography claimed 524 sessions. The two most sparsely represented divisions were physical geography, with only 434 sessions or 6% (ranging from climatology with 128 down to cryosphere with 28), and geographic thought and education, with only 169 sessions (2%). *In short, at the AAG, human geography is "where it's at."*

Who Publishes Where?

So, there is quite a discrepancy among the way departments define geography to the world, the distribution of interests among individual faculty, and the (self-)selection of interests (re)presented at the Association of American Geographers. It is possible that this may reflect regional disparities in interests, since the AAG program was compared only with the interests of the 23 geography programs in California.

On the off chance that California university geography departments are roughly representative of national trends, I explored whether different types of California geographers have different publication behaviors. I used the one snapshot sample of each individual's most recent journal publication to test the hypothesis that there is no significant difference in publication behavior among the various kinds of (California) geographers.

Geography and Non-Geography Journals...or No Journals at All

Table 4 shows the distribution of most-recent journal publication by venue (geography journal, non-geography journal, and no journal publication listed) and the eight types of geographer. As mentioned earlier, I collapsed the eight rows into four to get expected values to qualify for Chi-squared, after first doing pairwise Chi-squared tests to ensure that each row was made up of geographer types with similar publication behaviors.

Physical geographers are notable for publishing outside of geography journals (nearly 85%). Environmental and GIScience geographers, while dominated by non-geography journals (over 60%), direct a large minority (over 30%) of their publications to geography journals. Human geographers (including the one person who was predominantly concerned with geographic thought and education) put just over half their publications in geography outlets and a large minority of their publications (over 40%) in non-geography journals. Those with mixed interests or predominantly regional interests put just over half their publications in non-geography journals, but what sets them off as a separate category is the much larger percentage of such geographers (nearly 30%) compared with the other three groups, who either have no publications or whose publications are exclusively in book, chapter, or popular press outlets. That these are significant differences in publishing patterns is shown by the prob-value of the Chi-squared statistic, which was <0.001 (both in the preliminary 8 x 3 table and the final 4 x 3 table).

The differences in publishing patterns echo the disparity between the AAG session allocation and the distributions of interests among (California) geographers. Physical geographers focus on communicating their results to scientists in other disciplines rather than other geographers. In choosing conferences to attend with the perennially inadequate travel budgets provided them, they may not consider the AAG a cost-effective way to find a critical audience that can help them improve their analyses before publication submission, which may be a red flag for the AAG.

Journal Impact Factors

By publishing in outside journals, physical geographers and, to a lesser extent, mixed and regional geographers may also be interested in increasing citations of their work. The mean Journal Impact Factors ranking for the non-geography journals in which California geographers most recently published is nearly twice as large as for geography journals used by the California geographers (Table 5), but these disparities are affected by the outlier cases of publications in *Science* or *Nature.* The disparities in *median* JIFs are not significant, whether a stricter or more inclusive definition of "geography journal" is used (Table 5c). The differences become significant, however, if the effect of non-tracked journals is allowed, since most of the non-tracked journals used by these California geographers are geography journals.

Comparing the four groups of geographers in terms of JIFs through Kruskall-Wallis, however, the mean rank of the 117 most-recent-publication JIFs is significantly different (Table 6), with physical geographers enjoying the highest-ranked JIFs and human geographers/thought and education geographers having the lowest-ranked JIFs, with environmental/GIScience/applied geographers and mixed/regional almost indistinguishable in the middle ranks. The effect is much stronger if all non-tracked journals are included after being given the arbitrarily assigned JIF of 0.05. The ranking remains the same, but this time the human/thought and education groups are nearly tied at the bottom.

It would seem that physical geographers have good reason to write for an outside audience: it is bigger and, while willing to read geographers' work when it appears in these more inclusive venues, this audience may not be willing to seek their work out in geography journals. That being the case, it is hard to understand why human geographers focus so much more on geography journals. Perhaps geography in our journals really is human geography, and geography journals are the place for human geographers to go for an understanding audience and helpful criticism?

Publishing in Smaller Non-Tracked Journals

A converse way of looking at this question is to count the numbers of each kind of geographer whose most recent publication is in a smaller journal not tracked in ISI Web of Science Journal Citation Reports. Table 7 presents these counts. Physical geographers largely avoid such journals, while environmental/GIScience/applied geographers disproportionately seek them out (prob < 0.01).

Publishing and the Missing Geographers at the AAG

Both the environmental/GIScience/applied geographers and the human geographers share a lot of their work with the general geography community, publishing in geography journals and in smaller, non-tracked journals, and attending the AAG. Indeed, the AAG seems to have become the haven of human geographers, particularly. It is possible that human geographers and, to a lesser extent, environmental/GIScience/applied geographers may be becoming too insular and self-referential for the good of the larger discipline. Alternatively, it is possible that scholars in cognate social sciences and humanities disciplines might seek out geography conferences and journals to a greater extent than those in cognate physical and biological sciences, thus obviating the need for human geographers to work as hard as physical geographers on outreach to people outside geography with similar interests.

Physical geographers are, apparently, not receiving the qualified professional criticism and sense of community they need at the AAG. They are disproportionately scarce there, but make up about 22% of the geography community, at least among California university tenured and probationary faculty. This impression is strengthened by the data on their proclivity to publish almost exclusively in non-geography journals and to seek out high-impact journals and eschew the smaller, non-tracked journals. This may be injurious to the discipline as a whole by not keeping other kinds of geographers abreast of work in physical geography that might inform other geographers' work as our discipline faces global environmental change and the political, economic, and social transformations and upheavals these imply.

Mixed and regional geographers publish predominantly in non-geography venues, perhaps for similar reasons as the physical geographers. I am not sure why such a relatively high percentage of them do not have journal publications. Possibly the kind of work they do does not lend itself to the shortness of the journal article format (though several of these did have book chapters, which are similar in size), making books or more popular outlets more appealing to them.

Discussion

There are huge disparities among what we claim geography is in public, what we are actually interested in doing, and where we find community as individual geographers. Human geographers find kindred spirits at the AAG and are disproportionately likely to seek out geography journals and smaller journals overlooked by ISI Web of Knowledge. To a lesser extent, environmental geographers and GIScientists seem to find it professionally rewarding to publish in geography journals and invest their travel monies in the AAG. Physical geographers, apparently, are having trouble meeting their professional needs for useful criticism and audience in geography journals and conferences, and are voting with their feet.

We tell the public that we are all about the environment, an important message in an era of accelerated environmental change that we have tools to track and concepts to analyze. Our definitions of our field imply a rough parity among human geographers, physical geographers, GIScientists, environmental geographers, and regional specialists, and a tacit appreciation for synthesis along human-environmental or regional axes, no matter our specialties. The implied parity would attract those students with integrative mental habit and would prove of utility in a world requiring "integrated Earth system science" (Schaefer et al. 2008), exactly the kinds of natural and social synthesis that geography has always meant to many geographers.

When we look at who we are and how we describe our individual interests, however, the picture shifts: now, the dominant interest is human geography, and physical geography is a close second, not the integration of the two implied in environmental geography (indeed, in considering the geographers of "mixed" specialties, physical and human were the two least likely to be paired in one person). In the aggregate, too, we proclaim a fairly strong interest in GIScience and in the environment, though these are shown not really to be our dominant concerns as individuals (we are more likely to be the urban geographer who "does" GIS or the hydrologist who "does" environmental pollution monitoring for a watershed conservancy). Additionally, we all seem to mention one or two regional interests, often the settings in which we do topical or technical research projects, no doubt partly because geography departments frequently provide a strong area studies or global studies function on most campuses, but it is not as though most of us citing regional interests are regional geographers.

When our dominant interests can be grouped in a specialty, in other words, when *we* are classified rather than our interests, the focus sharpens yet again. More than a third of us are human geographers, and more than a fifth are physical geographers. These two are far and away our dominant personæ. Much farther down now are the geospatial techniques, and further yet the environment! It becomes harder to classify people than lists of keywords, however, and fully 16% of us are mixed in interests. Almost no one claims that applied geography, regional geography, or thought and education dominate our professional passions.

When we take our show on the road to the AAG, the picture morphs yet again. It is practically the Association of Human Geographers! Physical geographers are almost missing, less frequently seen than even the applied geographers in this venue. The other subfields (except thought and education) form sessions twice as often as either physical or applied geography.

Do these shifts in presence and focus align with geographers' self-perception as a discipline? Are we really about the environment, or is this just good marketing and campus politics? Are we really as much of an Earth science as a social science, as our Web pages state or imply and our interests and specialties suggest? If so, are the AAG and geography journals really welcoming to physical geographers and worth their while to attend/read/write for? Why or why not?

Conclusions

No wonder geography has given rise to so many self-definition schemes: we really do not know what on Earth we are. Maybe we are but one legacy of the 19th-century German university administrative structure widely copied here and the struggles to establish new departments and differentiate disciplines in the emergent American university system from the Civil War to the post-WWII boom (Smith 1990; Castree 2005). Have we reified someone's long-ago administrative convenience? Is that why we have such disparities between what we say we are and what we actually do? Is this why we've had such difficulty getting geography, as we understand it, into K–12 curriculum *as* geography? It is interesting in this regard that so many attempts to codify the discipline grow out of struggles over the K–12 curriculum.

Pattison coded the disparate definitions of his day as human-environment, areal differentiation, spatial analysis, and Earth science. Designed to support geography in K–12 curriculum renovation, the 1984 *Guidelines for Geographic Education* came up with location, place, regions, movement, and human-environment interactions. *Geography for Life*'s formulation of 18 national standards for a geographically informed person is grouped around spatial knowledge, places and regions, physical systems, human systems, environment and society, and geographical applications. We still remain out of synch and out of phase with our attempts at codifying what we are and what we do. This lack of clarity, our small size as a discipline, and possibly our political naïveté might be how geography, though formally called out as part of California's K–12 education standards, is actually dismembered there: some of its interests are actually named "geography" in the History and Social Science Standards, other parts we recognize as part of us lie buried in the Science Standards under Earth science (a small part of the Science Standards, and our colleagues in geology share our sense of invisibility there), and a few other bits are scattered here and there in the Technology Standards.

Each department has a critical need to define itself pretty crisply to weather interdepartmental and administrative encroachments, attract majors, and position itself with regard to the great issues of the day. Our Web statements are, in this sense, propaganda in a war of ideas and posters in its recruitment offices. If they are no more than propaganda, though, we will be "found out," and we may be doing our students a disservice by saying we are one thing and doing another, perhaps not preparing our students to do the best work in what it is we say we are all about and which may have attracted them in the first place.

This paper raises more questions than it set out to answer. Are the results skewed by my focus on California as I try to answer a question about our major national conference? Others more familiar with other regions could gather similar data from their areas or critically re-perform this California analysis. Results could make for engaging sessions at the CGS and AAG, whether they support this project in California or not.

Qualitative research to get at the attitudes and feelings generating the numbers analyzed here is certainly in order. Do physical geographers feel alienated and, thus, stay away from the AAG? Or do they simply not think in such terms and just go about their work and publish to reach friends and colleagues they have met in other fields, so that the AAG has just fallen off their radar? Are those physical geographers who attend the AAG happy with the quality and quantity of the sessions targeted to them? Are human geographers becoming too introspective? What do they think about the paucity of physical geographers at the conferences they obviously value so highly, or do they simply not notice the missing? Are there more non-geographers who seek out and come to the AAG human geography sessions than the physical geography sections? Are the GIScientists in evidence at the AAG becoming insular in the safe confines of the AAG, even as forces gather to wrest GIS through certification from geographers (e.g., GIS Certification Institute, Management Association for Private Photogrammetric Surveyors)?

What about the environment? Are we or are we not a leading discipline in the study of environmental change and adaptation, the quintessential "integrated Earth system science"? Are our departments appropriately balanced to make meaningful contributions to these discourses and practices? Are we training students with depth of competence in these areas who can do outstanding work in environmental careers and thereby build societal demand for more geography and more geographers? To a certain extent, our GIScientists are building such competence and reputation, ironically to the point that others want control of our technologies and are building demand for certification processes that foreground their takes on GIScience and de-emphasize geography. Qualitative research utilizing focus groups, interviews, and surveys could help us understand who we are, why we are the way we are, and how to formulate what we want to become as a community.

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End Notes

1 I also included the lone geographer left in the once-joint geology and geography program at UC Riverside, but I did not include the 76 people listed as affiliated with the UC Davis Geography Graduate Group, most of whom are not geographers but may serve on geography dissertation committees. The members of the former Department of Geography there were scattered into

several departments during the 1990s, and they are not identified as such on the GGG Web site.

2 For example, the *Journal of Geophysical Research* (in all its many variants) publishes work not only by physical geographers but by geologists, geophysicists, geochemists, astronomers, physicists, biogeographers, ecologists, oceanographers, soils scientists, environmental scientists, and many more, the American Geophysical Union being an umbrella organization for all physical sciences having to do with the Earth or planets. I classified such journals as non-geographic. On the other side, there is the *Journal of Economic Geography,* not to be confused with *Economic Geography.* I classified it, like *Economic Geography,* as a geography journal, though many of the papers in it are by economists newly discovering the spatiality of the economy and classic spatial location theory.

Geographic Chronicles

2008 Conference Report: Chico

By Jacque Chase

Over 350 geographers came to the 62nd Annual California Geographical Society Meeting in Chico on May 2–4, counting as one of the largest attendance records in the organization's history. The conference also broke a record in the number of posters, maps, and papers (over 150 total submissions). A benefit of holding the conference a bit later this year was that participants were rewarded with delightful, dry spring weather that allowed them to maximize their enjoyment of the beautiful Chico State campus and surrounding areas.

Support for the conference exceeded expectations. More than 30 students volunteered their time. Faculty and community offered myriad field trips that included several aspects of the conference theme "Conservation and Planning for Sustainability," and campus officials came to welcome the crowd and learn more about geography.

Field trip participants enjoy rafting on the Sacramento River.

The conference began on Friday, with several field trips and a GIS workshop taught by Christine Lewis. The most sought-after trip was the Sacramento River float, headed by Chuck Nelson of the Geographic Information Center and the student-run Adventure Outings. Other trips included a tour of the Sierra Nevada Brewery's sustainable production facilities, led by the company's sustainability director, Cheri Chastain; a walking tour of historic downtown Chico, led by John Gallardo of the Chico Heritage Association; a tour to the area's wineries, with Scot Hoiland of Butte College; a trip to the University's Big Chico Creek Ecological Reserve, with graduate student Scott Gregory; and an introduction to innovations in planning, by local planner and teacher Pam Figge.

Upon arrival from their field trips, a thirsty and hungry crowd converged on the kick-off barbecue on the grounds of the lovely Julia

Morgan house (officially the Albert E. Warrens Center). In the shade of towering oak trees, participants mingled and got reacquainted. The Dean of Behavioral and Social Sciences, Gayle Hutchinson, and the President of Chico State, Paul Zingg, welcomed the crowd and acknowledged the impressive number of participants. Provost Sandra Flake was also in attendance, and she introduced the keynote speaker later that evening.

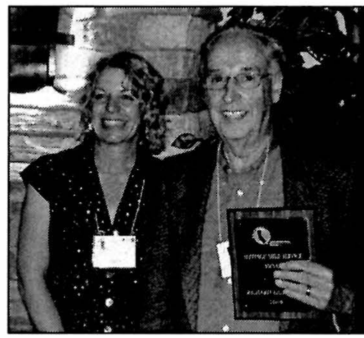
CGS fans barbecue on the beautiful Chico campus.

Jacque Chase and her great group of Chico geography students.

Following the barbecue, keynote speaker Jessica Lundberg traced the fascinating history of Lundberg Family Farms, for which she serves as Board Chair. This local farming family has been a leading force in sustainable methods of rice production in the Sacramento Valley since the 1930s. Jessica told the story of rice from global and local perspectives, and emphasized the ethical and environmental dimensions of food production.

On Saturday, Butte Hall was abuzz with hundreds of participants. (Our crowds were enhanced by a freshman debate team that had also been booked into Butte Hall, and in the confusion our Treasurer, Dan Walsh, may have managed to convince some debaters to join CGS!). Students and faculty spoke to overflow crowds about their research. A panel discussion on jobs in geography included practicing planners, GIS experts, and teachers. Across the courtyard, teachers and future educators gathered to learn about teaching geography in K–12 from the foremost expert in the field, Phil Gersmehl.

Presidential keynote speaker Ruth Mostern, from UC Merced, gave an impassioned talk on the use of GIS in historic research, presenting awe-inspiring visuals on her work on ancient China. Afterward, students and faculty continued the dialogue well into the evening with Dr. Mostern. As requested, the links to the Web sites highlighted in her talk can be found on the CGS homepage at: http://www.csun.edu/~calgeosoc/meetings/chico/mostern.html



CGS President Jennifer Helzer congratulates Richard Eigenheer on his Distinguished Service Award.

Over 200 people attended the Saturday banquet at the gorgeous Butte Creek Country Club, where graduate and undergraduate students received awards for their excellent maps, posters, papers, and academic achievements. The Friend of Geography award was presented to Pam Figge, and the Outstanding Educator award was given to Debra Sharkey of Cosumnes River College. Dick Eigenheer of CSU Stanislaus received this year's Distinguished Service Award. A raffle of distinctive gift baskets comprised of local products from all over the state and donated by many CGS members brought in nearly $500 for student scholarships. Thank you to everyone who helped with gift items, and please consider donating prizes for next year's Awards Banquet!

On Sunday, field trips included a visit to the Sacramento River National Wildlife Refuge, with Don Hankins of Chico State and Joe Silveira of U.S. Fish and Wildlife Service; a walking tour of public art, with local artist Paula Busch; a trip to Bidwell Park, with Chico State professor Guy King; a tour of the surrounding agricultural landscapes with Professors Mark Stemen and Scott Brady; and the popular Eco-Chico Bike Tour, designed by students of Professor LaDona Knigge of Chico State.

I appreciate all the positive and enthusiastic words I heard about the 62nd Annual CGS conference, and look forward to seeing you all in Santa Ynez!

California Geographical Society Award Winners 2008

DAVID LANTIS SCHOLARSHIPS
GRADUATE AWARD ($500):
Kim Pham, CSU Fullerton
UNDERGRADUATE AWARD ($500):
Diana Muncy, Humboldt State University

GEOSYSTEMS AWARD ($250)
Michael Commons, CSU Chico
Environmental Controls of Centaurea solstitialis

TOM MCKNIGHT PROFESSIONAL PAPERS
Undergraduate Papers
FIRST PLACE ($150):
Jennifer Reynolds-Kusler, CSU Sacramento
A Reconstruction of Late Holocene Vegetation Productivity and Composition from Meadow Sediments at Diamond Lake in the Klamath Mountains
SECOND PLACE ($125):
Megan Helms, Humboldt State University
The Ecological Importance of Fire: A Case Study Using Tree Ring Dating
THIRD PLACE ($100):
Michael Owens, Humboldt State University
Past, Present, and Future: Transitions in Resource Use and Landscape in Shelter Cove, California
Graduate Papers
FIRST PLACE ($150):
Cassandra Hansen, University of Nevada, Reno
Correlative Synoptic Scale Weather Patterns and Large Slab Avalanches on Mt. Shasta
SECOND PLACE ($125):
Michael Farrell, San Diego State University
Assessing Hydrologic Impacts of Global Climate Change at Fine Spatial Scales
THIRD PLACE ($100):
Amy McGrann, UC Davis
Floristic Resolution of Wildlife Habitat Relationships on the Pacific Crest Trail

JOE BEATON PROFESSIONAL POSTER

FIRST PLACE ($125):

Irene M. Seeley, University of Nevada, Reno
The Changing Footprints of Downtown Reno

SECOND PLACE ($100):

Mia Costa, University of Southern California
Indicators of Nutritional Affluence in Whittier, California

THIRD PLACE ($75):

Ngoc Ho, Orange Coast College
The Arctic Circle of Death: Suicides in Northern Canada, Scandinavia, and Siberia

Abbey Grimmer, University of Nevada, Reno
Conservation Planning: A Clark County Management Area Assessment

PROFESSIONAL PAPER CARTOGRAPHIC

FIRST PLACE ($125):

Janna Waligorski, CSU Chico
Shasta Valley Surface Geology

SECOND PLACE ($100):

Michael Commons, CSU Chico
Charles Darwin and Alfred Wallace: Race to the Theory of Evolution

THIRD PLACE ($75):

Sylvana Cares, CSU Chico
Invasion of the Tree of Heaven and the Historic Transcontinental Railroad

PROFESSIONAL COMPUTER DISPLAYED CARTOGRAPHIC

FIRST PLACE ($125):

Jared Wolf, Humboldt State University
Distribution of Neotropical Migrants in Response to the El Nino Southern Oscillation

SECOND PLACE ($100):

Mike Boruta, Humboldt State University
The Tourist Traps in Northwest California

THIRD PLACE ($75):

Willie Shubert, Humboldt State University
The Islamic World

STUDENT TRAVEL AWARDS ($150)

Marsha Bond, CSU Stanislaus
Gregory Greene, Cal Poly Pomona
Abbey Grimmer, University of Nevada, Reno
Cassandra Hansen, University of Nevada, Reno
Sarah Warnock, Humboldt State University

SPECIAL AWARDS

OUTSTANDING EDUCATOR AWARD:
Debra Sharkey, Cosumnes River College

FRIEND OF GEOGRAPHY AWARD:
Pam Figge, Professional Planner and Instructor

DISTINGUISHED SERVICE AWARD:
Dick Eigenheer, CSU Stanislaus

SPECIAL THANKS TO 2008 CONFERENCE ORGANIZER:
Jacque Chase, CSU Chico

Debra Sharkey receives recognition for her outstanding teaching.

The California Geographical Society

Founded in 1946 as the California Society of Teachers of Geography, the California Geographical Society (CGS) is the oldest statewide organization devoted to enhancing the understanding of geography. During the 1950s the organization became affiliated with the National Council for Geographic Education and changed its name to the California Council for Geographic Education. It acquired its present name during the 1980s as it sought, successfully, to become inclusive of all individuals interested in geography—academic and applied geographers, students, laypersons, and educators at every level. The CGS promotes interaction among its diverse members and holds an annual meeting in the spring at different venues around the state. Meetings include field trips and paper, poster, and map presentations, with cash awards for outstanding student presentations, and scholarships for graduate and undergraduate students. Teaching excellence and professional service are recognized with awards.

Members receive the Society's annual refereed journal, The California Geographer, as well as the periodic CGS Bulletin newsletter. Annual dues are $10 for students, $25 for regular members, and $20 for retired members. Applications for membership are available on the Society's Web site, http://www.csun.edu/~calgeosoc/.