National Park Service
U.S. Department of the Interior

Pinnacles National Monument (yellow outline) and the central California coast (Landsat April 17, 2010, data U.S. Geological Survey, analysis P. Gonzalez)

Climate Change Trends and Impacts at Pinnacles National Monument, California

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Historical Climate Trends

From 1901 to 2002, temperature increased across most of California (Figure 1; Gonzalez et al. 2010) and showed a statistically significant increase in the 50 km x 50 km area that includes Pinnacles National Monument (NM) (Figure 2, Table 1; Gonzalez et al. 2010). From 1937 to 2007, however, temperature at the Pinnacles NM weather station has not shown a statistically significant trend, but has decreased slightly (Figure 2; data from National Oceanic and Atmospheric Administration).

Analyses of 1950-1999 temperatures from weather stations across the western U.S. detected statistically significant warming and analyses of causal factors attributed the warming to climate change due to emissions from motor vehicles, power plants, and other human activities (Bonfils et al. 2008). In addition, analyses of western U.S. weather station measurements have detected a shift of spring warmth to earlier in the year and attributed that shift to human-caused climate change (Ault et al. 2011).

From 1901 to 2002, precipitation increased across the southwestern U.S. (Figure 3), in the 50 km x 50 km area that includes Pinnacles NM (Figure 4, Table 1; Gonzalez et al. 2010), and at the Pinnacles NM weather station (Figure 4; data from National Oceanic and Atmospheric Administration). The trend for the 50 km x 50 km area is statistically significant, although the trend at the weather station is not (Figure 4). The observed increase in precipitation is consistent with human-caused climate change trends across the U.S. (Portmann et al. 2009).

Since 1950, the frequency of extreme temperatures and the length of the growing season have increased for the southwestern U.S. as a whole (Kunkel et al. in review) and for the area of Pinnacles NM (Davis et al. in review). For the southwestern U.S., the number of four-day periods of one-in-five year hot temperatures (or 80% extreme) increased approximately 90% (Kunkel et al. in review). No published scientific information is available for historical trends of wind, fog, or other climate variables in the area of Pinnacles NM.

Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007). The three main IPCC greenhouse gas emissions scenarios are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (Friedlingstein et al. 2010). IPCC has also developed methods to characterize uncertainty in climate projections, establishing a standard set of colloquial terms that correspond to quantified confidence levels (Table 2).

For the three main IPCC emissions scenarios, temperature could increase three to five times the warming already observed in the 50 km x 50 km area that includes Pinnacles NM (Table 1; Gonzalez et al. 2010). Precipitation could decrease in two out of three emissions scenarios in the 50 km x 50 km area that includes the park (Table 1; Gonzalez et al. 2010). These results are consistent for climate projections downscaled to 12 km x 12 km for California (Cayan et al. 2008).

Spatial analyses of the area within Pinnacles NM, using climate projections for IPCC emissions scenario A2 downscaled to 4 km x 4 km, show the spatial variation and the uncertainty of temperature and precipitation projections (data from Conservation International <http://futureclimates.conservation.org> using method of Tabor and Williams (2010)). Projected temperature changes increase with distance from the ocean (Figure 5). The temperature projections of the 18 GCMs are generally in close agreement, with a coefficient of variation (the standard deviation as a fraction of the mean) of 0.24, indicating that the temperature uncertainty is approximately one-fourth of the mean (Figure 6).

In contrast, the 18 GCMs project highly divergent changes in precipitation for the area within the park. While the average of the GCMs is a 1% increase in precipitation under IPCC emissions scenario A2 (Figure 7), half of the 18 General Circulation Models (GCMs) project decreases while half project increases (Figure 8). The coefficient of variation of the precipitation projections is 30, indicating that the precipitation uncertainty is approximately thirty times the mean.

Taken together, the temperature and precipitation projections from the 18 GCMs form a cloud of potential future climates (Figure 9). The ensemble mean reflects the central tendency of the projections, but the uncertainty for the precipitation projections is large.

Climate projections for IPCC emissions scenario A2 that were downscaled to 90 m x 90 m (Davis et al. in press) are consistent with the 4 km x 4 km results (Table 3). Future warmer conditions at the park could approach conditions currently found in the southern San Joaquin

Valley (Davis et al. in review). The length of the growing season could increase 32-38% (11-13 days) (Davis et al. in review).

Projections indicate potential increases in the frequency of extreme temperature and precipitation events (Table 3, IPCC 2012). Across Western North America, one-in-twenty year hot temperatures (or 95% extreme) may increase in frequency to once every year or once in two years (IPCC 2012). At the Pinnacles NM weather station, the one-in-twenty year average annual maximum temperature for the period 1981-2000 was 26ºC. One-in-twenty year storms may increase in frequency to one in 8 to 10 years (IPCC 2012). Northern California may see a 25 to 200% increase in one-in-100 year rainstorms (99% extreme) (Cayan et al. 2008).

In the area around Pinnacles NM, modeling under emissions scenario A2 projects 6-9 more consecutive days per year with maximum temperatures > 35ºC, 1-2 more days per year with rainfall > 25 mm in a day, and 6-10 more consecutive days per year with rainfall < 3 mm per day (Kunkel et al. in review). No published scientific information is available for future projections of wind, fog, or other climate variables in the area of Pinnacles NM.

Historical Climate Change Impacts

A systematic search of the central database of scientific literature, the Thomson Reuters Web of Knowledge <http://wokinfo.com>, did not find any published climate change information that used field data from Pinnacles NM.

Nevertheless, scientific publications have examined field data from California and the western U.S., detected ecological changes outside the historical range of variation, examined possible causal factors, and attributed the changes to human-caused climate change. Climate change increased tree mortality from 1955 to 2007 in old-growth conifer forests in California, Colorado, Utah, and the Northwest (van Mantgem et al. 2009). Climate change has contributed to bark beetle outbreaks have caused the most extensive tree death across western North America in the last 125 years (Raffa et al. 2008). Climate change has caused a northward shift of the winter ranges of numerous bird species by an average of 0.5 ± 2.4 km y^{-1} from 1975 to 2004 across the U.S. (La Sorte and Thompson 2007).

Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 shows that climate was the dominant factor controlling burned area, even during periods of human fire suppression (Littell et al. 2009). Reconstruction of fires of the past 400 to 3000 years in the western U.S. (Marlon et al. 2012, Trouet et al. 2010) and in Yosemite and Sequoia National Parks, California (Swetnam 1993, Swetnam et al. 2009, Taylor and Scholl 2012) confirm that temperature and drought are the dominant factors explaining fire occurrence. Aggressive fire suppression during the 20th century depressed fire frequencies substantially below natural levels (Littell et al. 2009, Marlon et al. 2012), allowing small understory trees to multiple and fire fuels to accumulate. At Pinnacles NM, Davis et al. (in review) indicate that the fire return interval is 265 years, higher than the historical fire return intervals 10-25 years in oak woodland and 20-80 y in chaparral.

Biomes are major vegetation formations characterized by the same life form, such as temperate broadleaf forest or temperate grassland (Woodward et al. 2004). A biome shift is the conversion of an ecosystem from one major vegetation type to another. Field research has detected elevational and latitudinal shifts of biomes around the world (Gonzalez et al. 2010) attributable to climate change. In Southern California, drought and fire contributed to upslope shifts of temperate mixed forest into temperate conifer forest (Kelly and Goulden 2008). In San Diego County, California, wildfires in chaparral shrubland have led to conversion to grassland invaded by exotic plants (Keeley and Brennan, in press).

No long-term field data are available to examine historical biome changes at Pinnacles NM. A short-term analysis of the Landsat National Land Cover Database (NLCD) shows no land cover change at Pinnacles NM from 2001 to 2006 (Figures 10-11; Fry et al. 2011).

Future Projected Vulnerabilities

Modeling of fire due to climate and human ignitions in the wildland-urban interface indicates potential fire frequency increases of 20 to 70% in the two 12 km x 12 km square areas that include Pinnacles NM under the B1 and A2 emissions scenarios (Westerling et al. 2011). Modeling of the climate ranges of 60 bird species in California indicates no substantial change in bird species richness under at Pinnacles NM under the A2 emissions scenario (Wiens et al. 2009). Modeling of the climate ranges of California buckeye (*Aesculus californica*) and valley oak (*Quercus lobata*) indicates that the probablilty of occurrence of these two species may decrease to lease than 0.1 under emissions scenario A2 (Davis et al. in review). This is consistent with previous statewide projections (Kueppers et al. 2005). Spatial results from a dynamic global vegetation model (Gonzalez et al. 2010) that were downscaled to 8 km x 8 km indicate a potential shift of mixed forest to grassland at Pinnacles NM under emissions scenarios B1, A1B, and A2, with a medium confidence (0.30 ± 0.51) (Figures 12-15).

Summary Tables and Least Change Estimate for Scenario Planning

Table 3 summarizes the published scientific information on historical and projected climate change in and around Pinnacles NM. Table 4 summarizes published scientific information on historical and projected ecological impacts of climate change in and around Pinnacles NM. No published information was found for impacts of climate change on cultural resources, infrastructure, or visitor experience at Pinnacles NM.

To develop management options under scenario planning, NPS staff will start with a scenario that considers the least amount of future climate change. From Table 3, this least change scenario for the year 2100 would involve a temperature increase of ~1.4ºC, a precipitation change of ~0, 6 more consecutive days per year with temperatures > 35ºC, 1 more day per year with rainfall > 25 mm, 6 more consecutive days per year with rainfall < 3 mm, and a growing season 11 days longer.

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Table 1. Historical and projected climate (mean ± standard deviation (SD)) trends for the 50 km x 50 km square area that includes Pinnacles NM (Mitchell and Jones 2005, IPCC 2007, Gonzalez et al. 2010). Historical trends also given for the weather station at the park. The climate projection under IPCC emissions scenario A2 for the 50 km x 50 km square area matches the climate projection downscaled to 4 km x 4 km for the area within the park (data from Conservation International using method of Tabor and Williams (2010)). Note "century^{-1}" is the fractional change per century, so that 0.11 century^{-1} is an increase of 11% in a century.

	mean	SD	units
Historical			
temperature 1901-2002 annual average	13.2	0.5	ºC
temperature 1901-2002 linear trend	0.5	0.2	ºC century^{-1}
temperature 1937-2007 annual average (station)	15.1	0.6	ºC
temperature 1937-2007 linear trend (station)	-0.6	2.8	ºC century^{-1}
precipitation 1901-2002 annual average	550	180	mm y^{-1}
precipitation 1901-2002 linear trend	0.11	0.11	century^{-1}
precipitation 1942-2010 annual average (station)	410	140	mm y^{-1}
precipitation 1942-2010 linear trend (station)	0.30	0.17	century^{-1}
Projected			
IPCC B1 scenario (lower emissions)			
temperature 1990-2100 annual average	2.2	0.8	ºC century^{-1}
precipitation 1990-2100 annual average	-0.13	0.26	century^{-1}
IPCC A1B scenario (medium emissions)			
temperature 1990-2100 annual average	2.9	0.8	ºC century^{-1}
precipitation 1990-2100 annual average	-0.08	0.26	century^{-1}
IPCC A2 scenario (higher emissions)			
temperature 1990-2100 annual average	3.4	0.8	ºC century^{-1}
precipitation 1990-2100 annual average	0.01	0.26	century^{-1}

Table 2. Intergovernmental Panel on Climate Change (IPCC 2007) treatment of uncertainty.

Confidence	Degree of confidence in being correct
Very high	At least 9 out of 10 chance
High	About 8 out of 10 chance
Medium	About 5 out of 10 chance
Low	About 2 out of 10 chance
Very low	Less than 1 out of 10 chance

Table 3. Historic and Projected Climate Trends at Pinnacles National Monument

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May 31, 2012

Variable	Trend	Historical 20th Century Change	Projected 21st Century Change			Confidence in Scientific Understanding (IPCC Terms)
			Lower Emissions Scenario (IPCC B1)	Central Emissions Scenario (IPCC A1B)	Higher Emissions Scenario (IPCC A2)	
Temperature	↑	50 km x 50 km area: +0.5 ± 0.2°C (Gonzalez et al. 2010); Central Coast: Spring has warmed more than other seasons (Cordero et al. 2011)	50 km x 50 km area: +2.2 ± 0.8°C (3 GCMs, Gonzalez et al. 2010)	50 km x 50 km area: +2.9 ± 0.8°C (3 GCMs, Gonzalez et al. 2010)	Pinnacles NM: +3.4 ± 0.8°C (18 GCMs, data Conservation International <http://futureclimates.conservation.org>, method of Tabor and Williams (2010)); minimum winter temp. +2-2.7°C, maximum summer temp. +3.7-4°C (2 GCMs, Davis et al. in review)	Very High (IPCC 2007)
Precipitation	↔	50 km x 50 km area: +11% ± 11% (Gonzalez et al. 2010)	50 km x 50 km area: -13% ± 26% (3 GCMs, Gonzalez et al. 2010); Northern California: -4% (2 GCMs, Cayan et al. 2008)	50 km x 50 km area: -11% ± 26% (3 GCMs, Gonzalez et al. 2010)	Pinnacles NM: +1% ± 26% (18 GCMs, data Cons. Int. <http://futureclimates.conservation.org>, method of Tabor and Williams (2010)); Northern California: more drying in summer (Cayan et al. 2008)	Very Low (IPCC 2007)
Extreme temperature events	↑	Southwestern U.S.: Increase of approximately 90% of four-day periods of one-in-five year hot temperatures (or 80% extreme (Kunkel et al. in review)	Western North America: one-in-twenty year hot temperatures (average annual maximum 26°C, 95% extreme) might occur every other year (12 GCMs, IPCC 2012)	Western North America: one-in-twenty year hot temperatures (average annual maximum 26°C, 95% extreme) might occur every one and a half years (12 GCMs, IPCC 2012)	Western North America: 10-20% increase days >30°C, one-in-twenty year hot temperatures (average annual maximum 26°C, 95% extreme) might occur every year (12 GCMs, IPCC 2012); 6-9 more days per year of consecutive days > 35°C (4 GCMs, Kunkel et al. in review)	High (IPCC 2012)

Table 3. Historic and Projected Climate Trends at Pinnacles National Monument

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National Park Service

May 31, 2012

Variable	Trend	Historical 20th Century Change	Projected 21st Century Change			Confidence in Scientific Understanding (IPCC Terms)
			Lower Emissions Scenario (IPCC B1)	Central Emissions Scenario (IPCC A1B)	Higher Emissions Scenario (IPCC A2)	
Extreme precipitation events	↑	Southwestern U.S.: No statistically significant change (Kunkel et al. in review)	Western North America: one-in-twenty year storms may increase in frequency to one in 10 years (14 GCMs, IPCC 2012)	Western North America: one-in-twenty year storms may increase in frequency to one in nine years (14 GCMs, IPCC 2012)	Western North America: one-in-twenty year storms may increase in frequency to one in eight years (14 GCMs, IPCC 2012); Northern California: 25-200% increase in 99% extreme storms (2 GCMs, Cayan et al. 2008); Pinnacles NM area: 1-2 more days per year with rainfall > 25 mm per day, 6-10 more consecutive days per year with rainfall < 3 mm per day (4 GCMs, Kunkel et al. in review)	Low (IPCC 2012)
Growing season length	↑	Southwestern U.S.: Increase of approximately one month (Kunkel et al. in review); Pinnacles NM: no significant trend (Davis et al. in review)			Southwestern U.S.: Increase of 35-40 days (4 GCMs, Kunkel et al. in review); Pinnacles NM: increase 32-38% or 11 - 13 days (Davis et al. in review)	High

Table 4. Historical and Projected Ecological Impacts of Climate Change around Pinnacles National Monument

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May 30, 2012

	Historical 20th Century Change	Projected 21st Century Impacts	Confidence in Scientific Understanding (IPCC Terms)
Vegetation distribution	• Santa Rosa Mountains, Southern California: upslope shift of temperate mixed forest into temperate conifer forest, 1977-2007 (Kelly and Goulden 2008) • Chaparral, San Diego County: wildfires led to conversion to grassland invaded by exotic plants (Keeley and Brennan, in press) • Western U.S. old-growth conifer forests: climate change increased tree mortality from 1955 to 2007 (van Mantgem et al. 2009) • Western North America: climate change contributed to bark beetle outbreaks, most extensive tree death across western North America in the last 125 years (Raffa et al. 2008) • Pinnacles NM: Landsat National Land Cover Database - no land cover change 2001 to 2006 (Fry et al. 2011)	• Pinnacles NM: California buckeye (*Aesculus californica*) and valley oak (*Quercus lobata*) probablilty of occurrence may decrease to <0.1 (emissions scenario A2, 2 GCMs, Davis et al. in review). • Pinnacles NM: Downscaled output from a dynamic global vegetation model (Gonzalez et al. 2010) indicates a potential shift of mixed forest to grassland with a medium confidence (0.30 ± 0.51) (emissions scenarios B1, A1B, and A2, 3 GCMs)	Medium
Wildfire	• Western U.S.: climate dominant factor controlling burned area 1916 to 2003, even during periods of human fire suppression (Littell et al. 2009) • Pinnacles NM: fire return interval ~265 years, 1950-2008, higher than natural 10-25 years (oak woodland), 20-80 y (chaparral) (Davis et al. in review)	Pinnacles NM: potential fire frequency increases 20-70% (B1 and A2 emissions scenarios, 3 GCMs, Westerling et al. 2011)	Medium
Birds	U.S.: Climate change has caused a northward shift of the winter ranges of numerous bird species by an average of 0.5 ± 2.4 km y^{-1}, 1975-2004 (La Sorte and Thompson 2007).	Pinnacles NM: Modeling of climate ranges of 60 bird species indicates no substantial change in bird species richness (A2 scenario, 2 GCMs, Wiens et al. 2009)	Low

Figure 1.

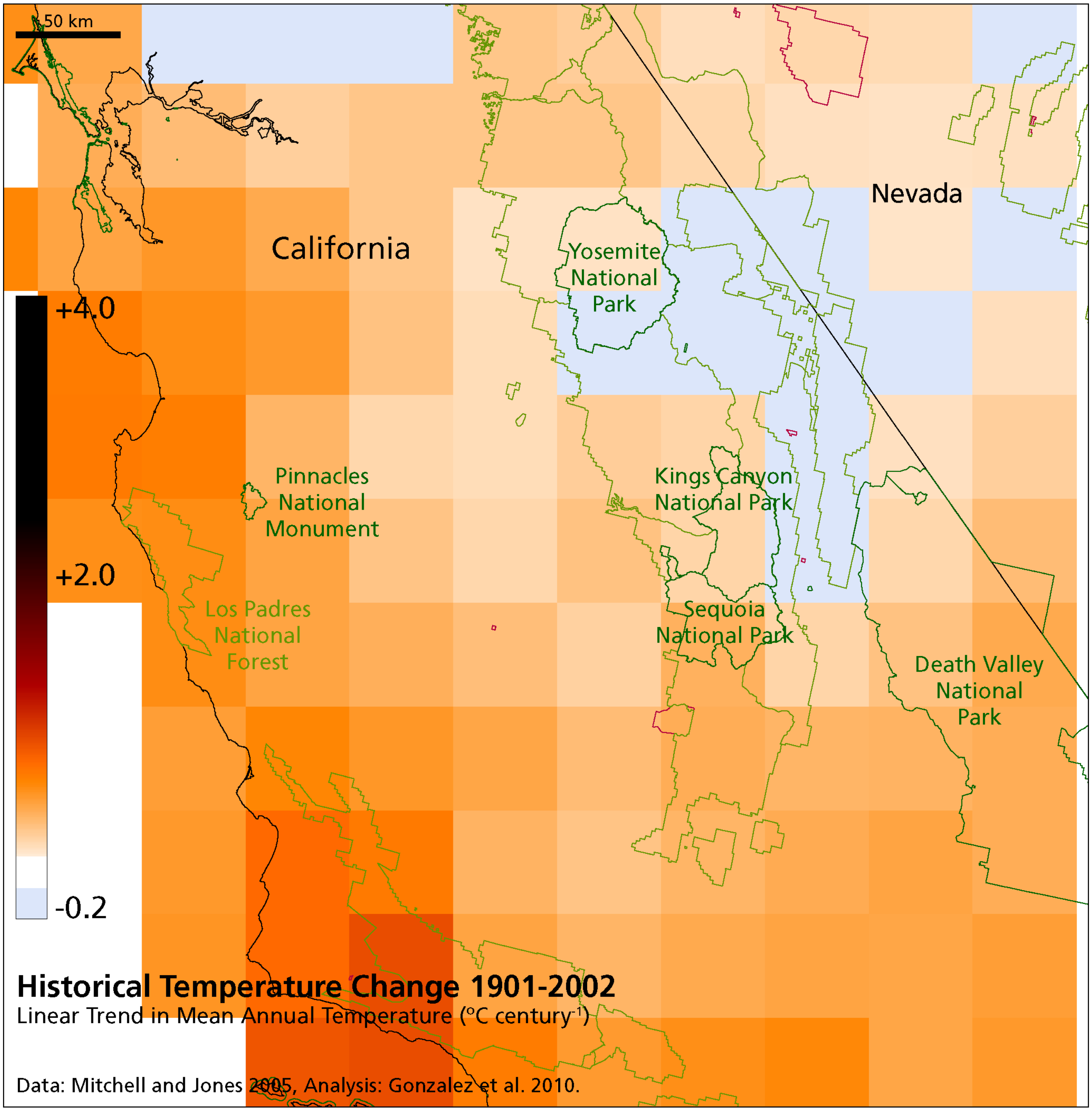

50 km
California
Nevada
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Sequoia National Park
Los Padres National Forest
Death Valley National Park
+4.0
+2.0
-0.2
Historical Temperature Change 1901-2002
Linear Trend in Mean Annual Temperature (°C century-1)
Data: Mitchell and Jones 2005, Analysis: Gonzalez et al. 2010.

Figure 2.

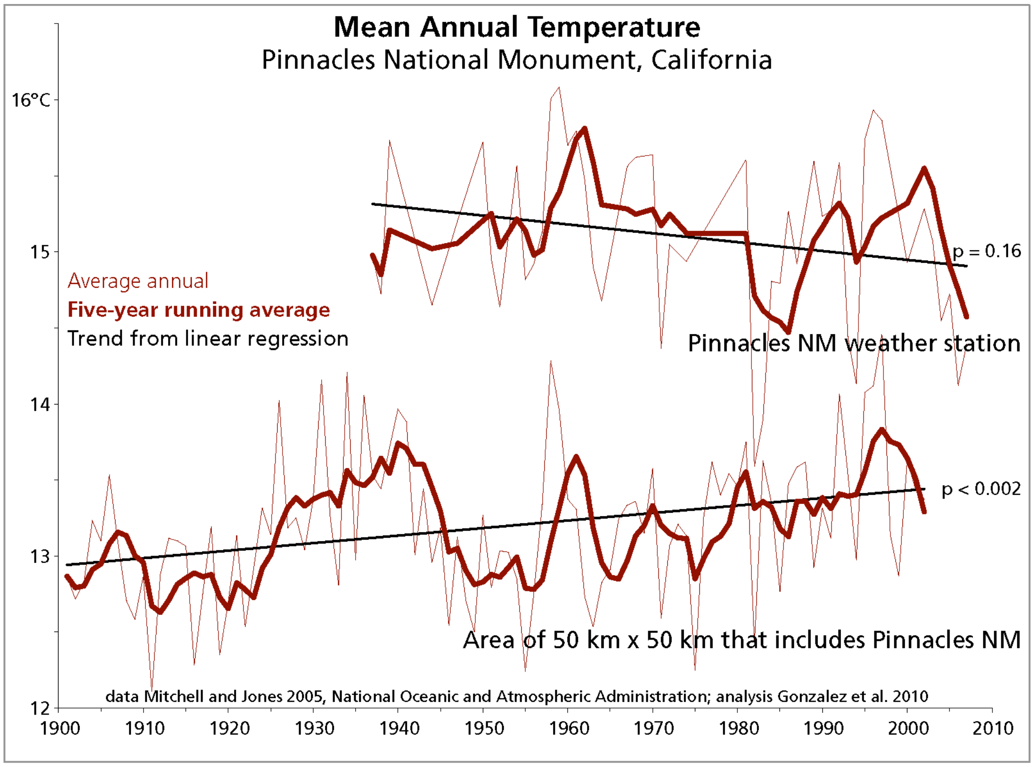

Mean Annual Temperature
Pinnacles National Monument, California
16°C
15
14
13
12
Average annual
Five-year running average
Trend from linear regression
p = 0.16
Pinnacles NM weather station
p < 0.002
Area of 50 km x 50 km that includes Pinnacles NM
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 3.

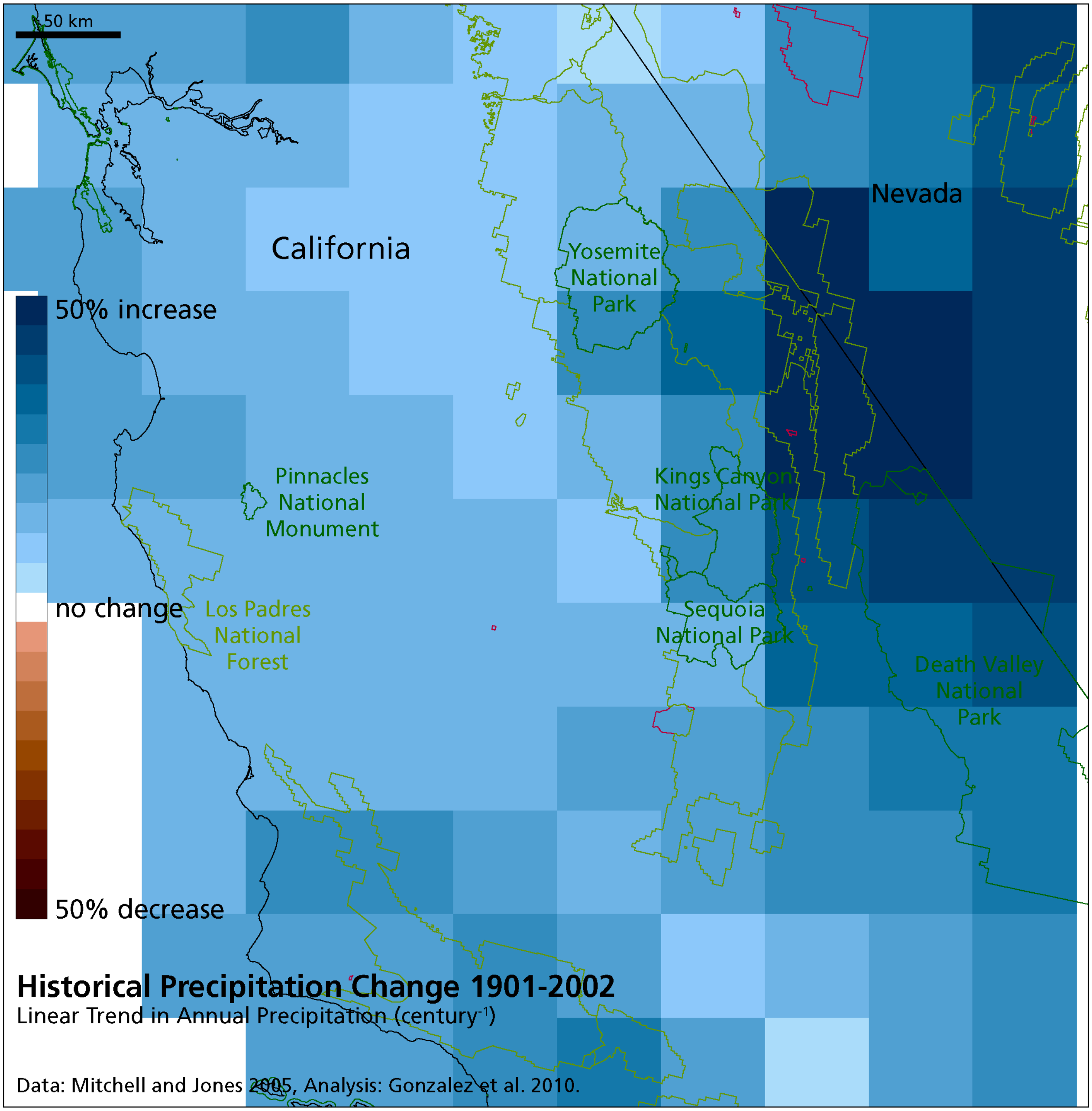

50 km
California
Nevada
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Sequoia National Park
Los Padres National Forest
Death Valley National Park
50% increase
no change
50% decrease
Historical Precipitation Change 1901-2002
Linear Trend in Annual Precipitation (century^{-1})
Data: Mitchell and Jones 2005, Analysis: Gonzalez et al. 2010.

Figure 4.

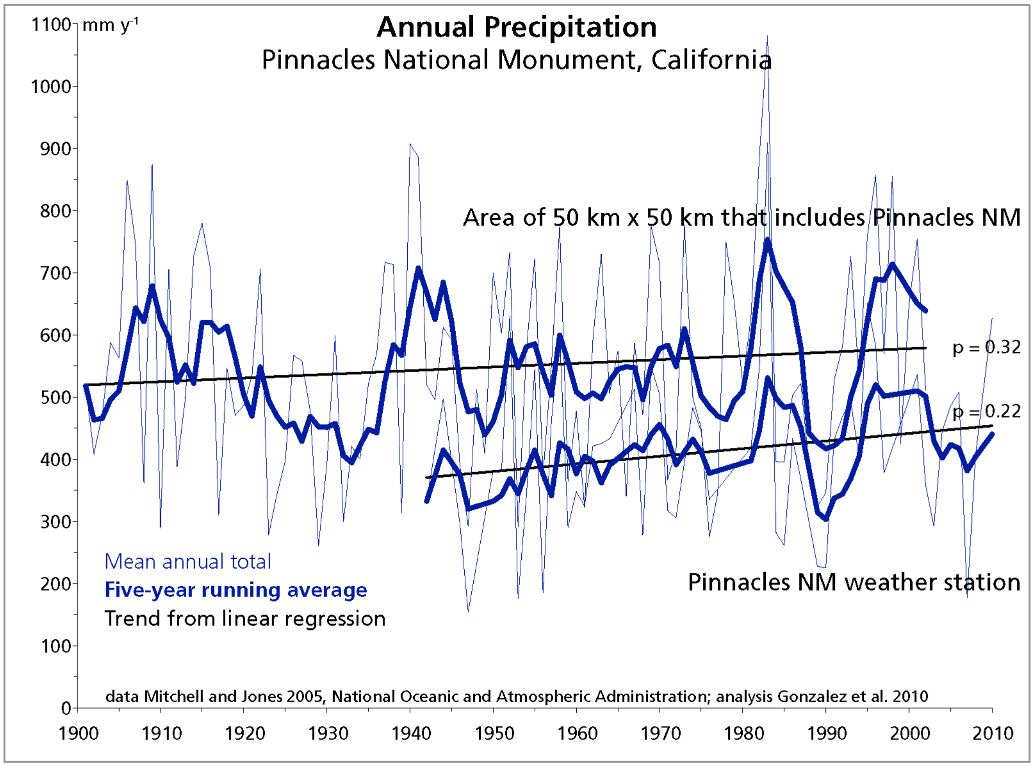

Annual Precipitation
Pinnacles National Monument, California
mm y-1
1100
1000
900
800
700
600
500
400
300
200
100
0
Area of 50 km x 50 km that includes Pinnacles NM
p = 0.32
p = 0.22
Mean annual total
Five-year running average
Trend from linear regression
Pinnacles NM weather station
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 5.

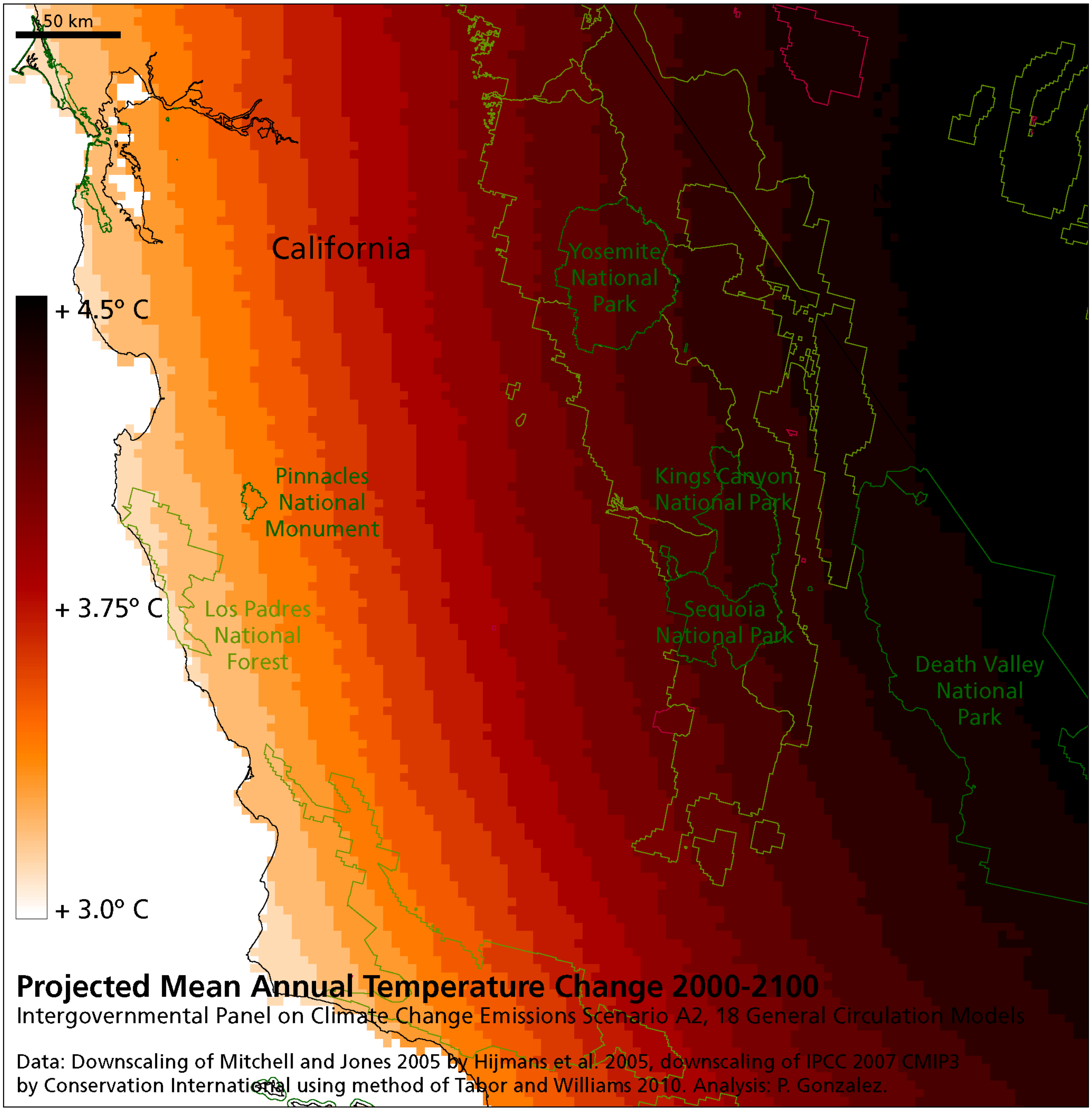

50 km
California
+ 4.5° C
+ 3.75° C
+ 3.0° C
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Los Padres National Forest
Sequoia National Park
Death Valley National Park
Projected Mean Annual Temperature Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3 by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 6.

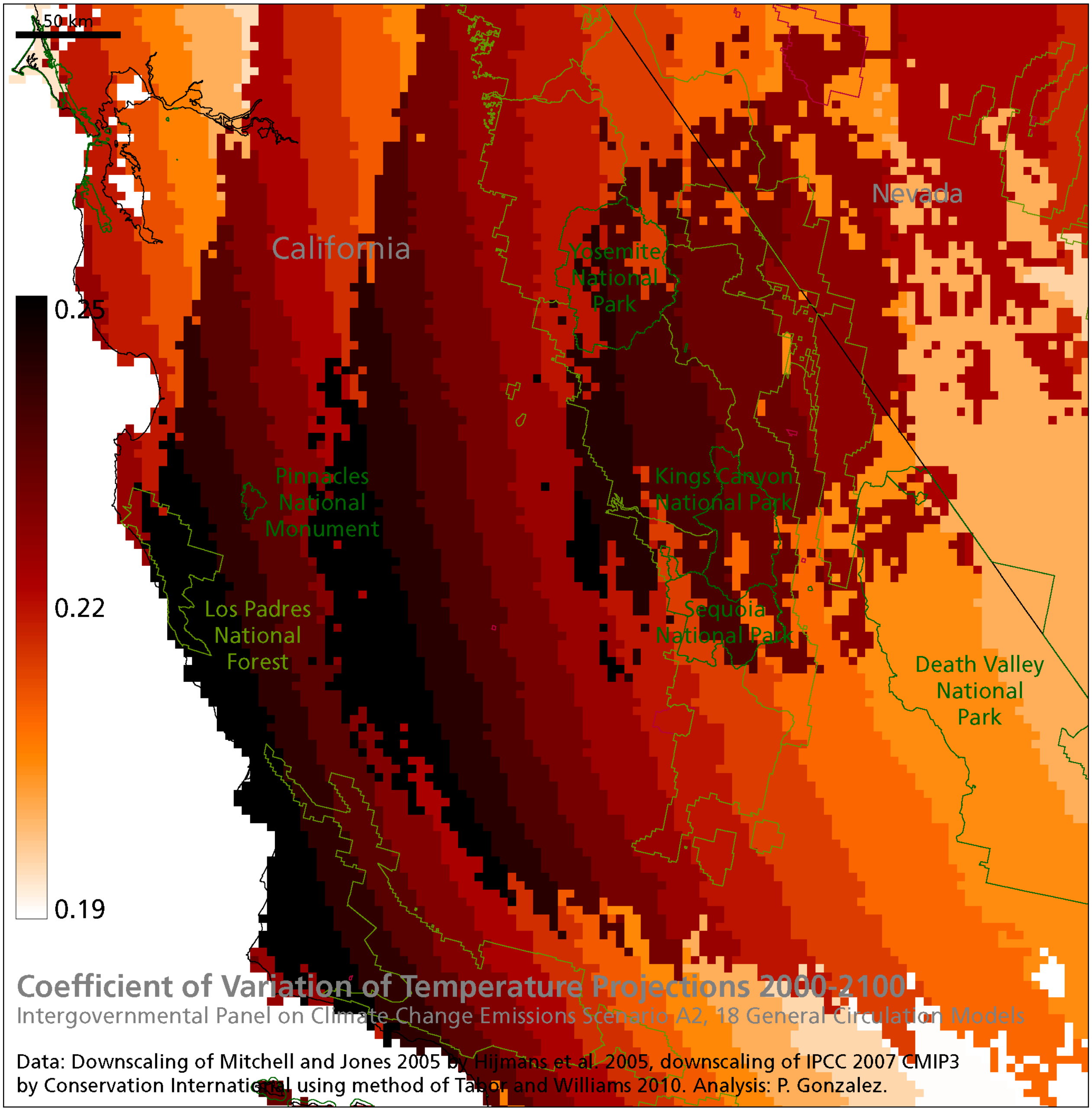

50 km
California
Nevada
Yosemite National Park
Kings Canyon National Park
Sequoia National Park
Pinnacles National Monument
Los Padres National Forest
Death Valley National Park
0.25
0.22
0.19
Coefficient of Variation of Temperature Projections 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 7.

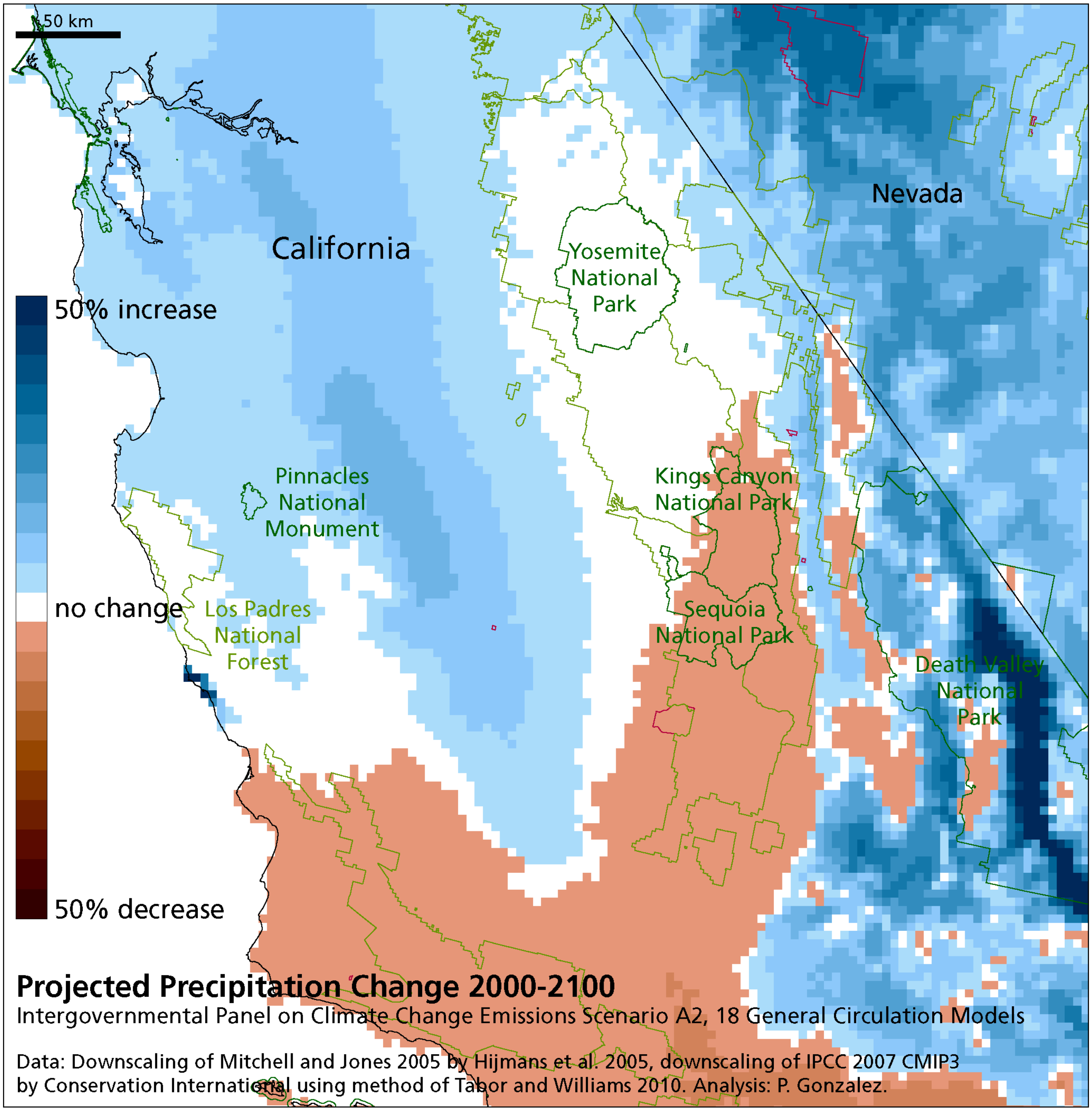

50 km
California
Nevada
Yosemite National Park
50% increase
no change
50% decrease
Pinnacles National Monument
Kings Canyon National Park
Los Padres National Forest
Sequoia National Park
Death Valley National Park
Projected Precipitation Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 8.

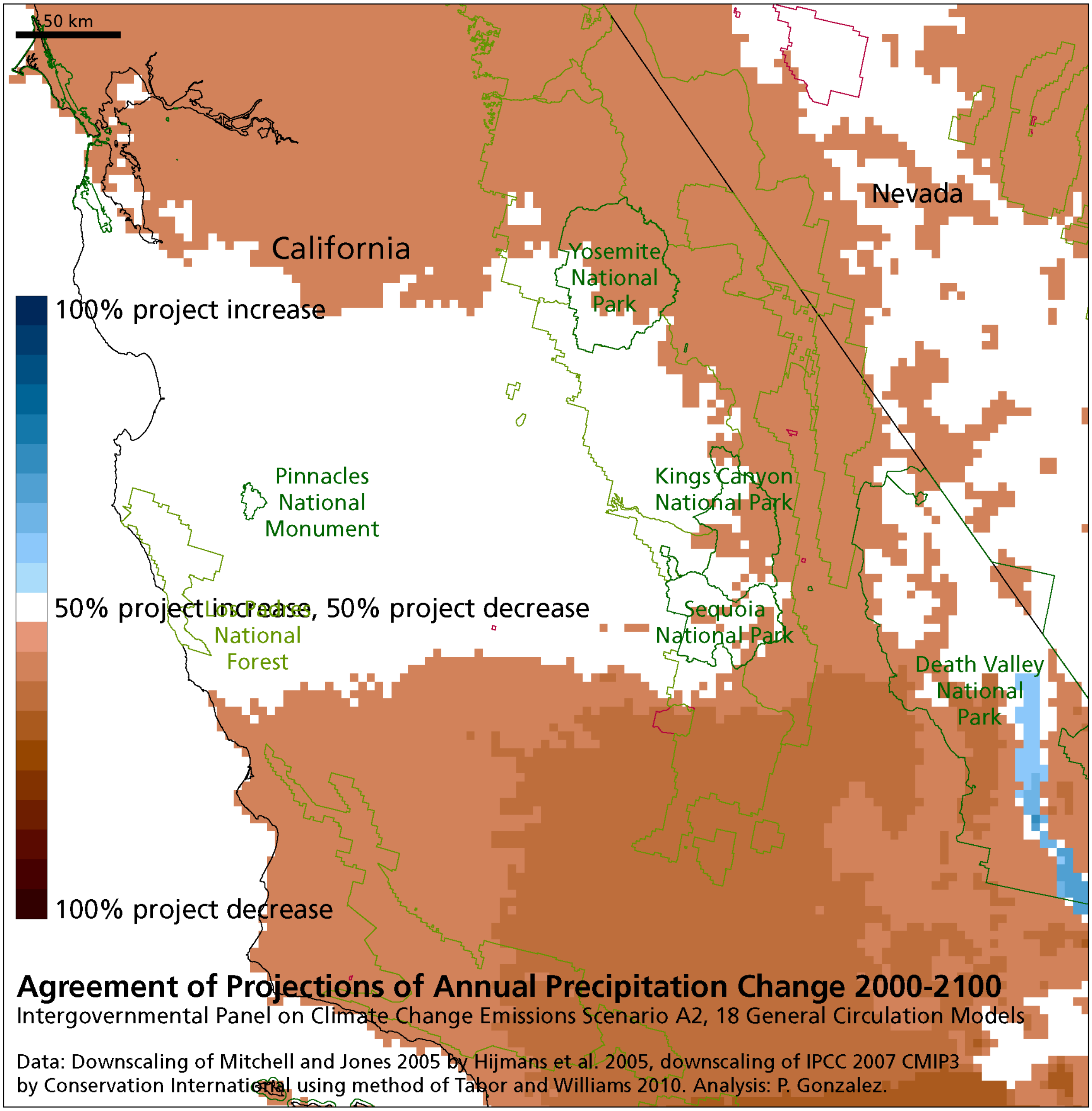

50 km
California
Nevada
Yosemite National Park
100% project increase
Pinnacles National Monument
Kings Canyon National Park
50% project increase, 50% project decrease
Los Padres National Forest
Sequoia National Park
Death Valley National Park
100% project decrease
Agreement of Projections of Annual Precipitation Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 9.

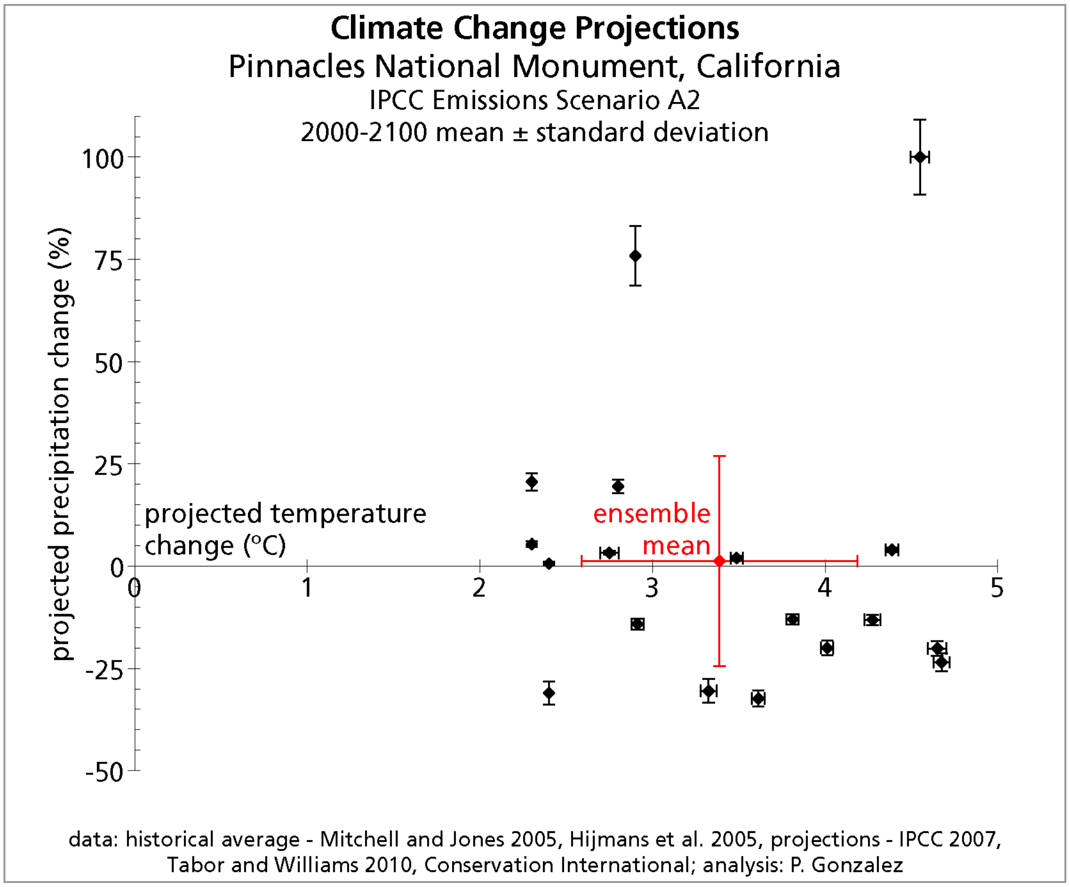

Climate Change Projections
Pinnacles National Monument, California
IPCC Emissions Scenario A2
2000-2100 mean ± standard deviation
projected precipitation change (%)
100
75
50
25
0
-25
-50
projected temperature change (°C)
0
1
2
3
4
5
ensemble mean
data: historical average - Mitchell and Jones 2005, Hijmans et al. 2005, projections - IPCC 2007, Tabor and Williams 2010, Conservation International; analysis: P. Gonzalez

Figure 10.

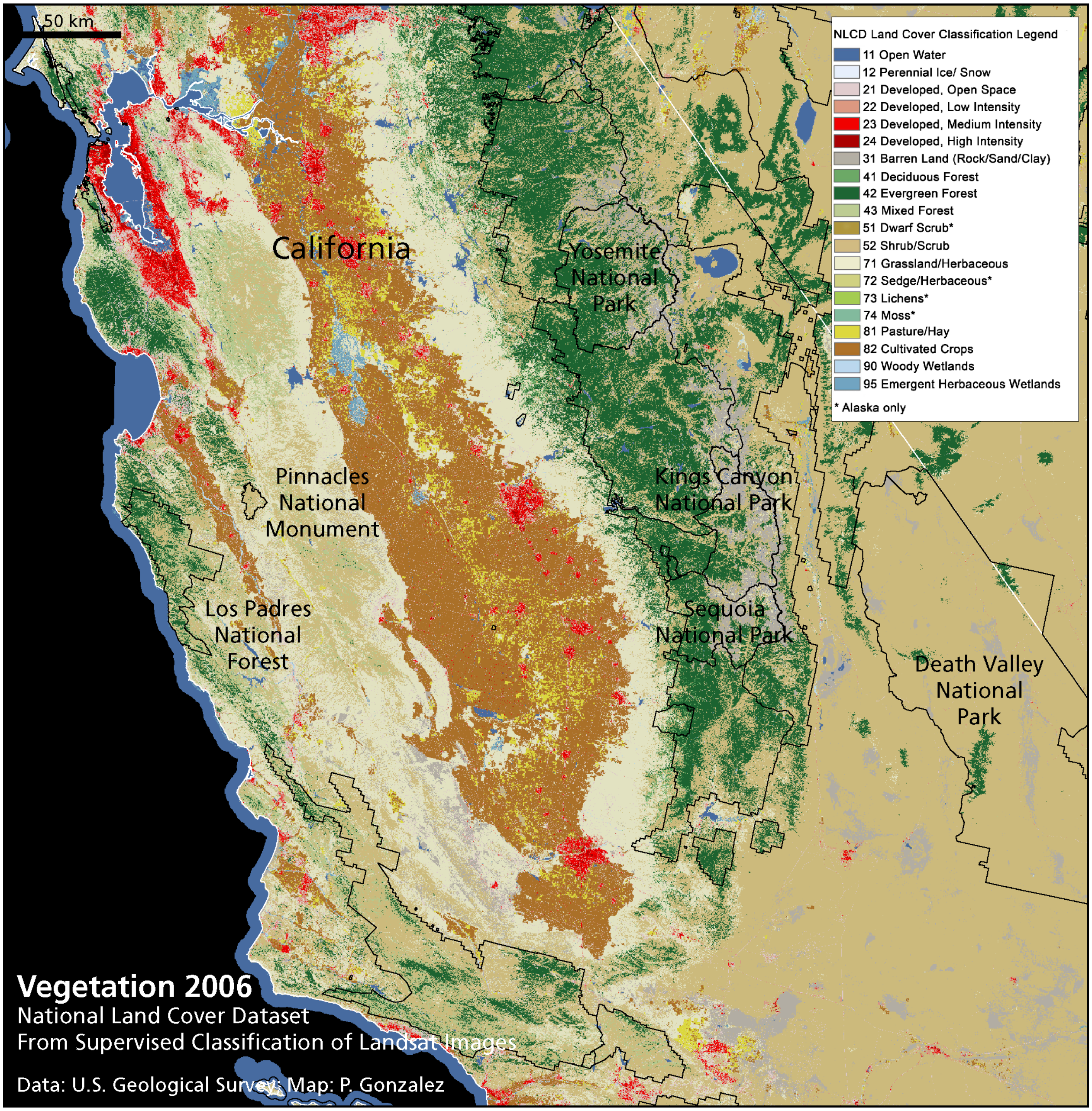

50 km
NLCD Land Cover Classification Legend
11 Open Water
12 Perennial Ice/ Snow
21 Developed, Open Space
22 Developed, Low Intensity
23 Developed, Medium Intensity
24 Developed, High Intensity
31 Barren Land (Rock/Sand/Clay)
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest
51 Dwarf Scrub*
52 Shrub/Scrub
71 Grassland/Herbaceous
72 Sedge/Herbaceous*
73 Lichens*
74 Moss*
81 Pasture/Hay
82 Cultivated Crops
90 Woody Wetlands
95 Emergent Herbaceous Wetlands
* Alaska only
California
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Los Padres National Forest
Sequoia National Park
Death Valley National Park
Vegetation 2006
National Land Cover Dataset
From Supervised Classification of Landsat Images
Data: U.S. Geological Survey; Map: P. Gonzalez

Figure 11.

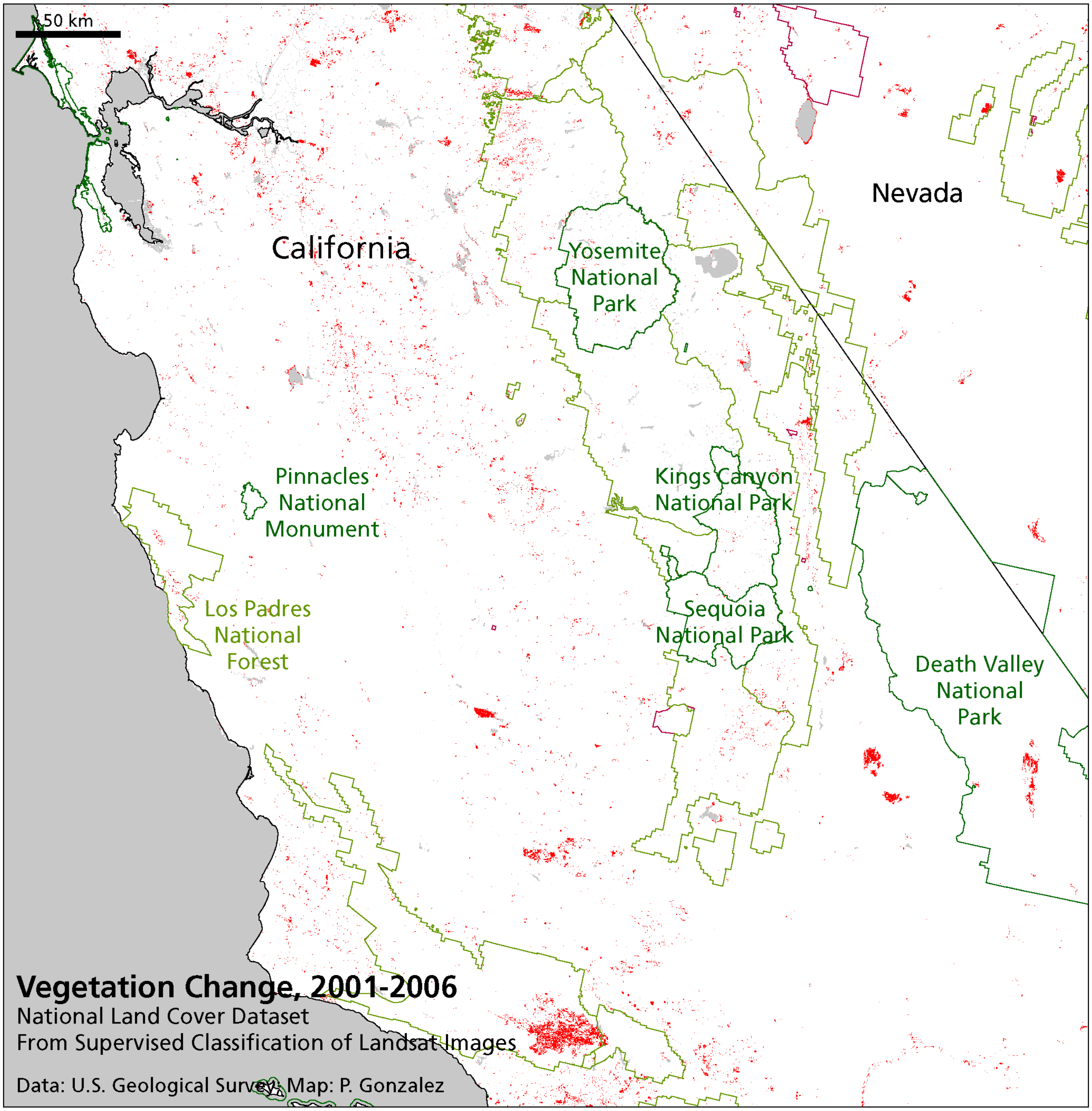

50 km
California
Nevada
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Sequoia National Park
Los Padres National Forest
Death Valley National Park
Vegetation Change, 2001-2006
National Land Cover Dataset
From Supervised Classification of Landsat Images
Data: U.S. Geological Survey, Map: P. Gonzalez

Figure 12.

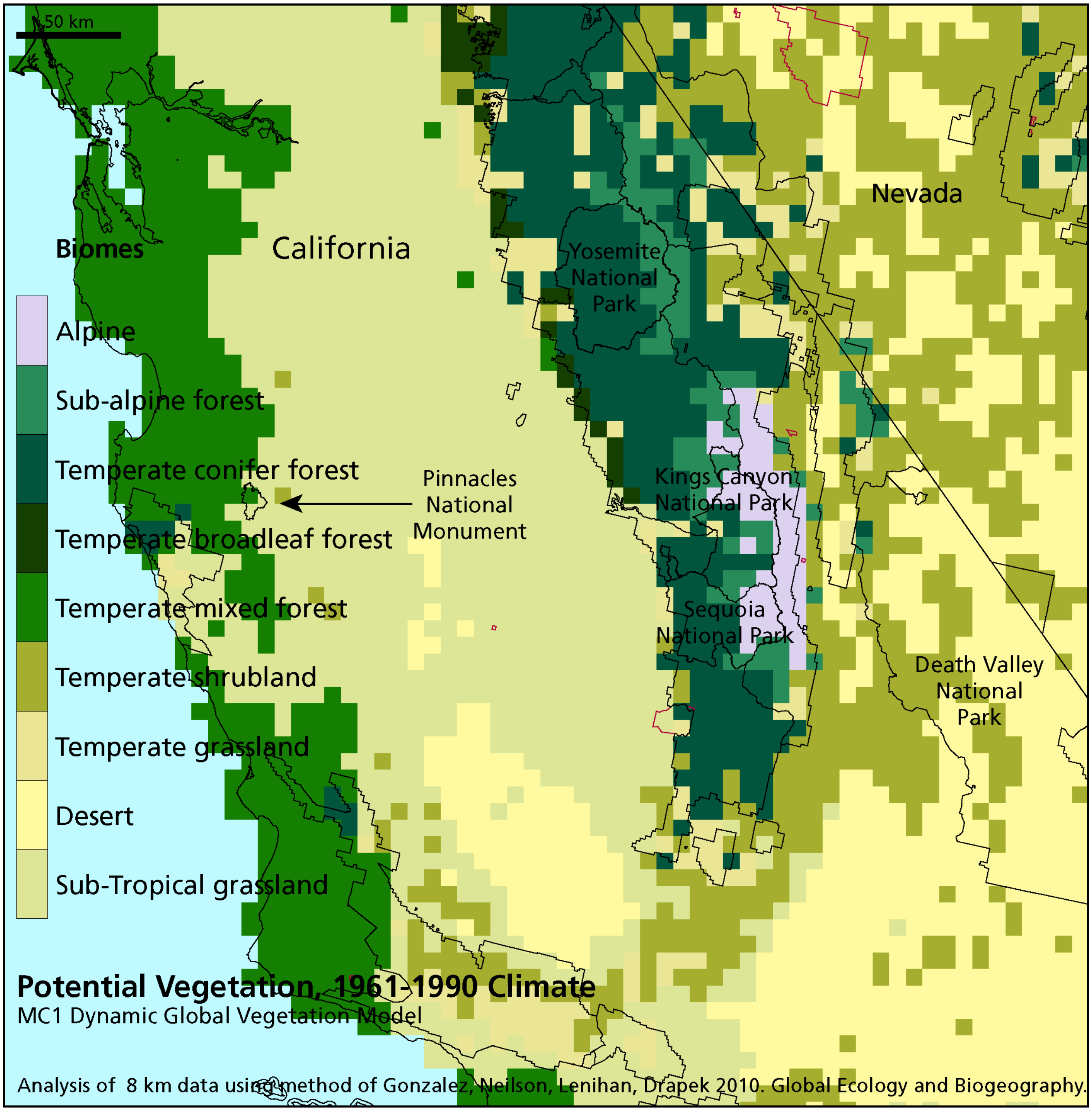

50 km
Biomes
California
Nevada
Alpine
Sub-alpine forest
Temperate conifer forest
Temperate broadleaf forest
Temperate mixed forest
Temperate shrubland
Temperate grassland
Desert
Sub-Tropical grassland
Pinnacles National Monument
Yosemite National Park
Kings Canyon National Park
Sequoia National Park
Death Valley National Park
Potential Vegetation, 1961-1990 Climate
MC1 Dynamic Global Vegetation Model
Analysis of 8 km data using method of Gonzalez, Neilson, Lenihan, Drapek 2010. Global Ecology and Biogeography.

Figure 13.

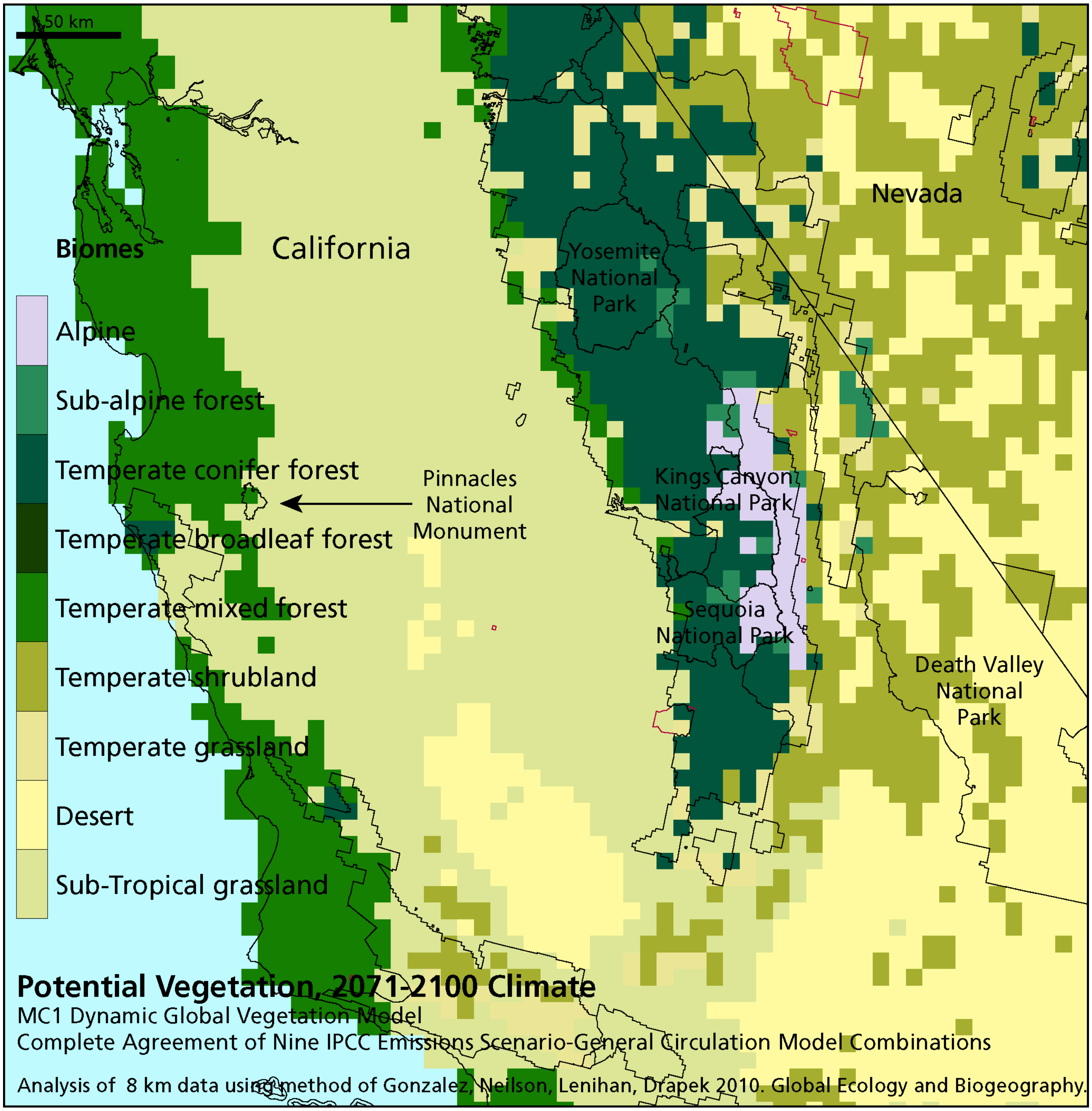

50 km
Biomes
California
Nevada
Alpine
Sub-alpine forest
Temperate conifer forest
Temperate broadleaf forest
Temperate mixed forest
Temperate shrubland
Temperate grassland
Desert
Sub-Tropical grassland
Pinnacles National Monument
Yosemite National Park
Kings Canyon National Park
Sequoia National Park
Death Valley National Park
Potential Vegetation, 2071-2100 Climate
MC1 Dynamic Global Vegetation Model
Complete Agreement of Nine IPCC Emissions Scenario-General Circulation Model Combinations
Analysis of 8 km data using method of Gonzalez, Neilson, Lenihan, Drapek 2010. Global Ecology and Biogeography.

Figure 14.

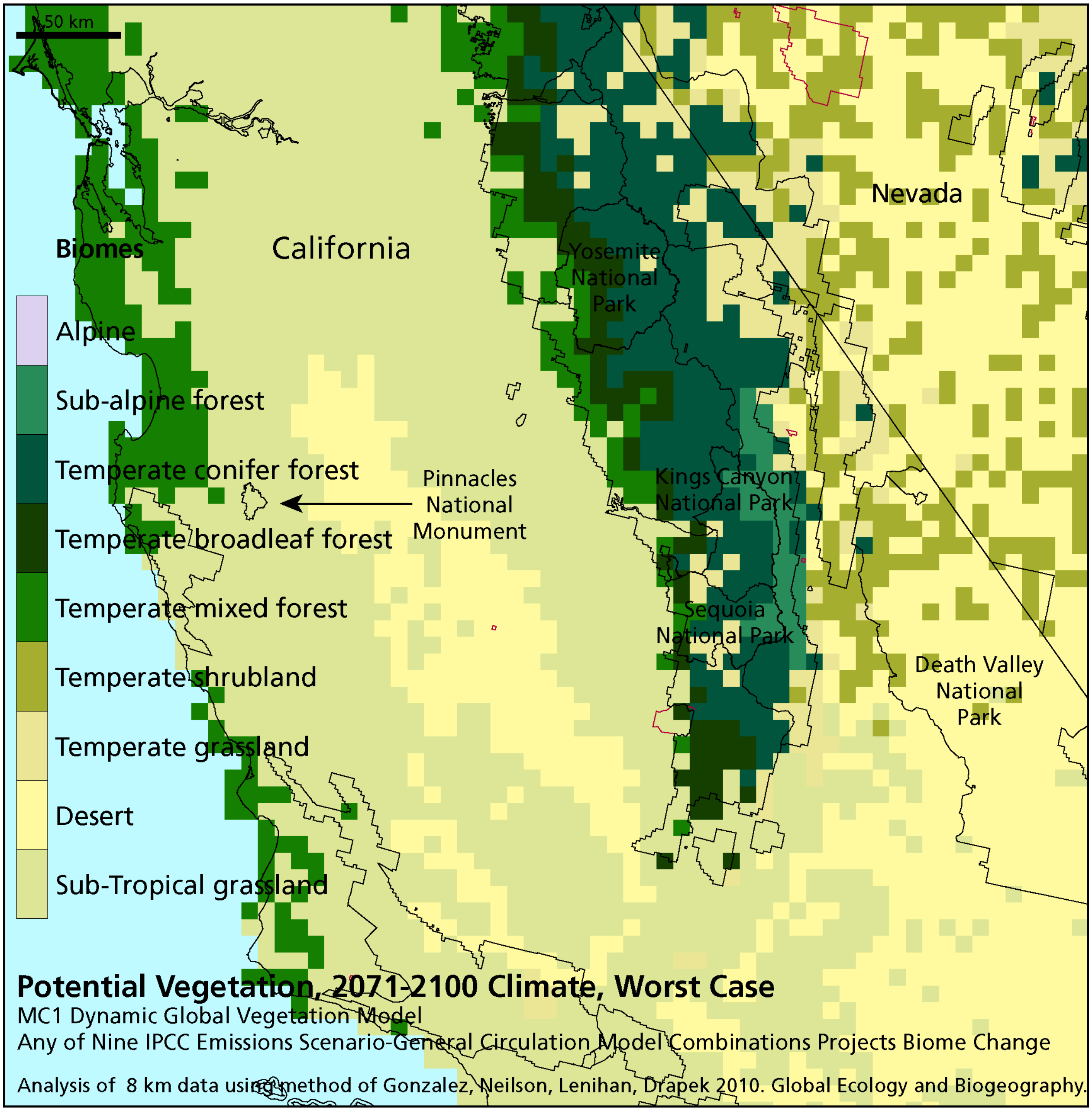
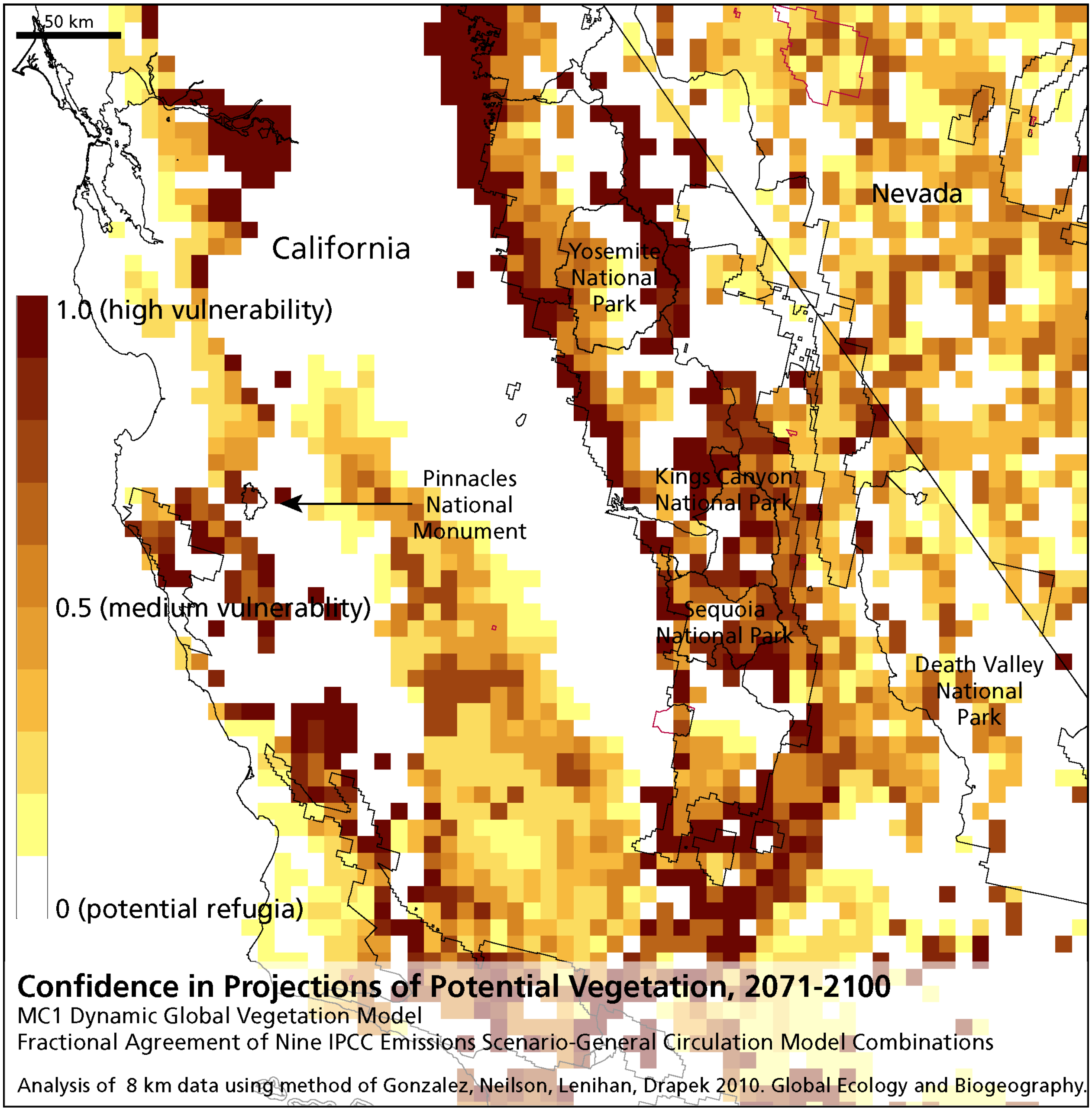

50 km
Biomes
California
Nevada
Alpine
Sub-alpine forest
Temperate conifer forest
Temperate broadleaf forest
Temperate mixed forest
Temperate shrubland
Temperate grassland
Desert
Sub-Tropical grassland
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Sequoia National Park
Death Valley National Park
Potential Vegetation, 2071-2100 Climate, Worst Case
MC1 Dynamic Global Vegetation Model
Any of Nine IPCC Emissions Scenario-General Circulation Model Combinations Projects Biome Change
Analysis of 8 km data using method of Gonzalez, Neilson, Lenihan, Drapek 2010. Global Ecology and Biogeography.

Figure 15.


50 km
California
Nevada
Yosemite National Park
Pinnacles National Monument
Kings Canyon National Park
Sequoia National Park
Death Valley National Park
1.0 (high vulnerability)
0.5 (medium vulnerablity)
0 (potential refugia)
Confidence in Projections of Potential Vegetation, 2071-2100
MC1 Dynamic Global Vegetation Model
Fractional Agreement of Nine IPCC Emissions Scenario-General Circulation Model Combinations
Analysis of 8 km data using method of Gonzalez, Neilson, Lenihan, Drapek 2010. Global Ecology and Biogeography.