

Climate Change Trends, Vulnerabilities, and Ecosystem Carbon, Redwood National Park, California

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Climate Trends for the Area within Park Boundaries

- Average annual temperature has increased since 1950 (Figure 1), but the rate has not been statistically significant (Figure 2). Spring (March-May) temperature showed the greatest increase at $1.1 \pm 0.7^{\circ}\text{C}$ ($2 \pm 1.6^{\circ}\text{F.}$) per century.
- Total annual precipitation has decreased since 1950 (Figure 3), but the rate has not been statistically significant (Figure 4). Autumn (September-November) precipitation decreased at a statistically significant rate of $-57 \pm 26\%$ per century.
- If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming and changes in precipitation (Table 1, Figure 5).
- For projected average annual precipitation, the climate models do not agree, with over half projecting increases, but many projecting decreases (Figure 5).
- Under the highest emissions scenario, models project up to five more days per year with a maximum temperature $> 35^{\circ}\text{C}$ (95°F.) and an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-6 years (Walsh et al. 2014).

Historical Impacts in the Region

- Analyses of Audubon Christmas Bird Count data across the United States, including counts in northern California, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human climate change and not other factors (La Sorte and Thompson 2007).
- Climate change raised sea level globally 19 ± 2 cm (7 ± 1 inch) from 1901 to 2010 (IPCC 2013). See report from Maria Caffrey with sea level information for the park.

Future Vulnerabilities in the Region

- Continued heating under climate change may continue to reduce coastal fog and increase drought stress in coast redwood trees (*Sequoia sempervirens*) (Johnstone and Dawson 2010).

- Climate change under the highest emissions scenario could double the area burned by wildfire by 2085 AD (Westerling et al. 2011)
- A combination of increased fire and sudden oak death disease could increase mortality in coast redwoods (Metz et al. 2013)
- Park ecosystems are vulnerable to shifts of broadleaf species into conifer forest stands due to climate change (Gonzalez et al. 2010), exacerbated by habitat fragmentation (Eigenbrod et al. 2014).
- Warmer, wetter winters and hotter, drier summers, as projected for the park under climate change, could decrease the survival of northern spotted owls (*Strix occidentalis caurina*) in some areas (Glenn et al. 2011).
- Climate does not seem to be a major factor in population increases of Roosevelt elk (*Cervus elaphus roosevelti*) (Starns et al. 2014).
- Climate change could continue to raise sea level globally 26-55 cm (10-22 inches) by 2100 for the lowest emissions scenario and 52-98 cm (20-39 inches) for the highest scenario (IPCC 2013). See report from Maria Caffrey with sea level information for the park.

Ecosystem Carbon

- Measurements in Humboldt Redwoods State Park, south of Redwood National Park, show that coast redwood trees (*Sequoia sempervirens*) attain a carbon density of 2900 t ha⁻¹, the highest in the world (Busing and Fujimori 2005).
- Based on whole-tree measurements, redwood wood growth increases with tree size and age (Sillett et al. 2010).
- Aboveground vegetation in Redwood National Park contains 7.1 ± 4.1 million tons of carbon (Figure 6), equivalent to the annual greenhouse gas emissions of 1.3 ± 0.7 Americans (Gonzalez et al. 2015). The carbon storage of the park decreased < 1% between 2001 and 2010 (Figure 7).

Table 1. Historical rates of change per century and projected future changes in annual average temperature and annual total precipitation (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2010. Because a rate of change per century is given, the absolute change for the 1950-2010 period will be approximately 60% of that rate. For the projections, note that under RCP6.0, temperature ramps up more slowly than under RCP4.5, but eventually overtakes the low scenario after mid-century. This is a property of how the emissions scenarios are written, with population and energy hitting their peak earlier, but at an eventually more sustainable level in RCP4.5. The table gives central values for the park as a whole. Figures 2, 4, and 5 show the uncertainties.

	1950-2010	2000-2050	2000-2100
Historical			
temperature	+0.4°C/century (0.7°F./century)		
precipitation	-24%/century		
Projected (compared to 1971-2000)			
Low emissions (IPCC RCP 4.5)			
temperature		+1.6°C (+2.9°F.)	+2.2°C (+4°F.)
precipitation		+2%	+2%
High emissions (IPCC RCP 6.0)			
temperature		+1.5°C (+2.7°F.)	+2.5°C (+4.5°F.)
precipitation		~0	+5%
Highest emissions (IPCC RCP 8.5)			
temperature		+2.1°C (+3.8°F.)	+3.8°C (+6.8°F.)
precipitation		+3%	+4%

Figure 1

Historical Trend in Annual Average Temperature, 1950-2010

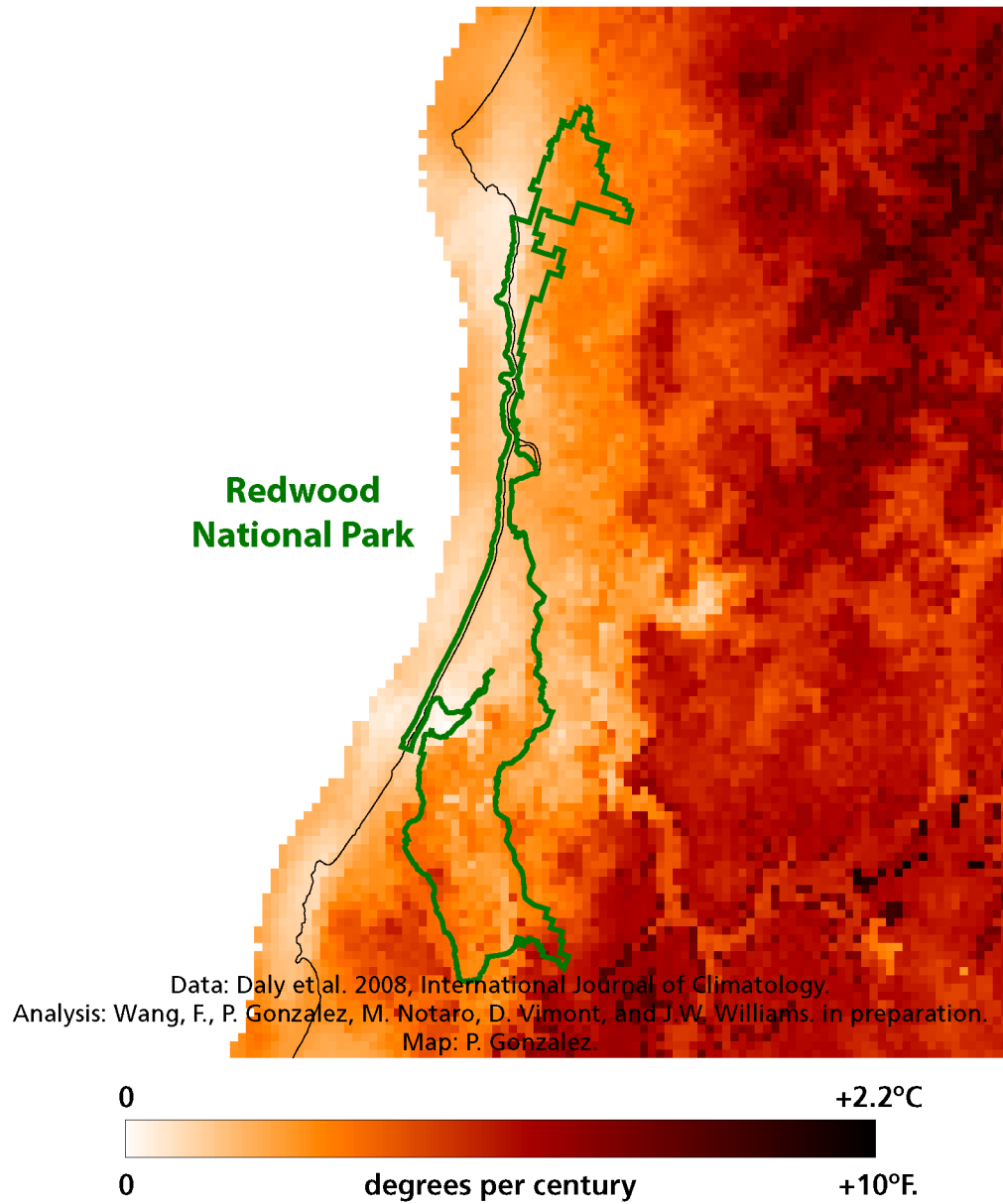


Figure 2. Historical annual average temperature for the area within park boundaries. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

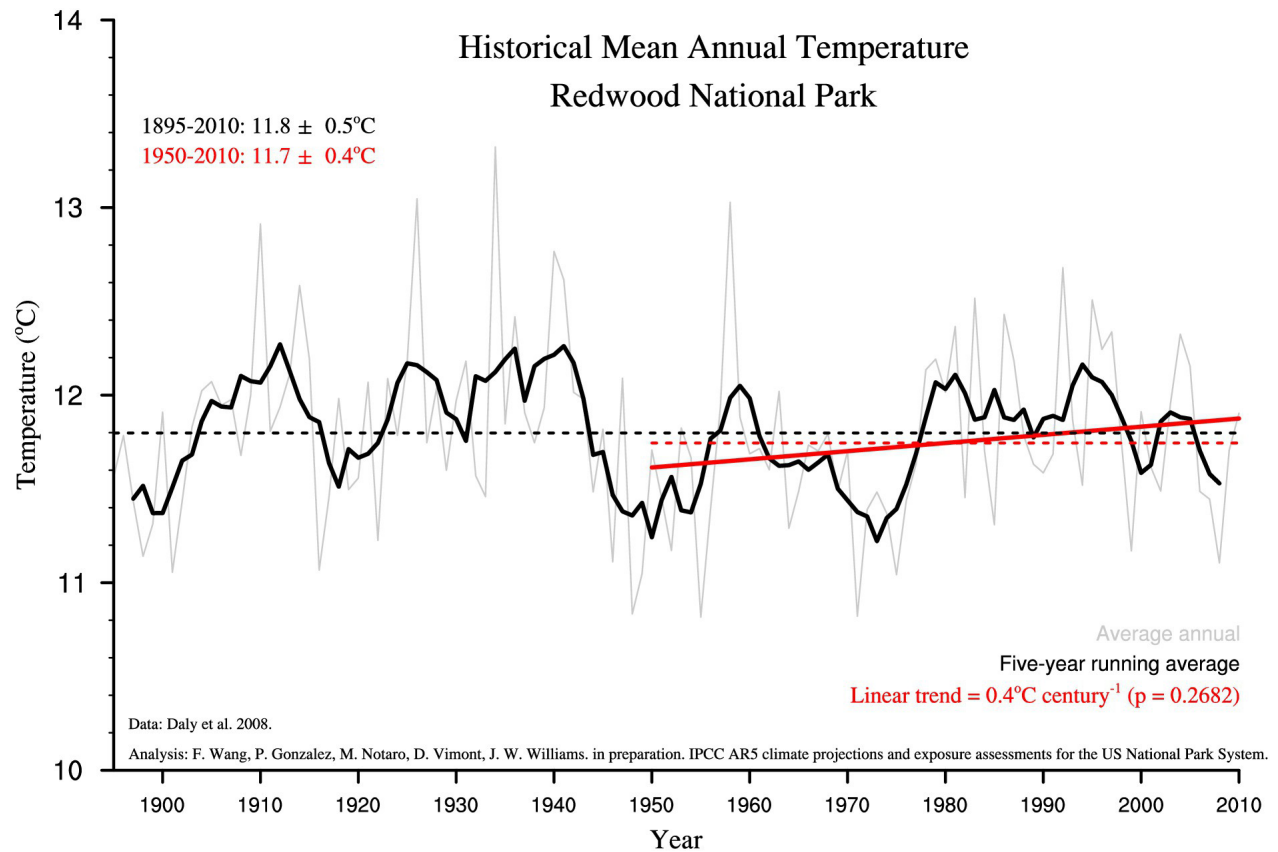


Figure 3

Historical Trend in Total Annual Precipitation, 1950-2010

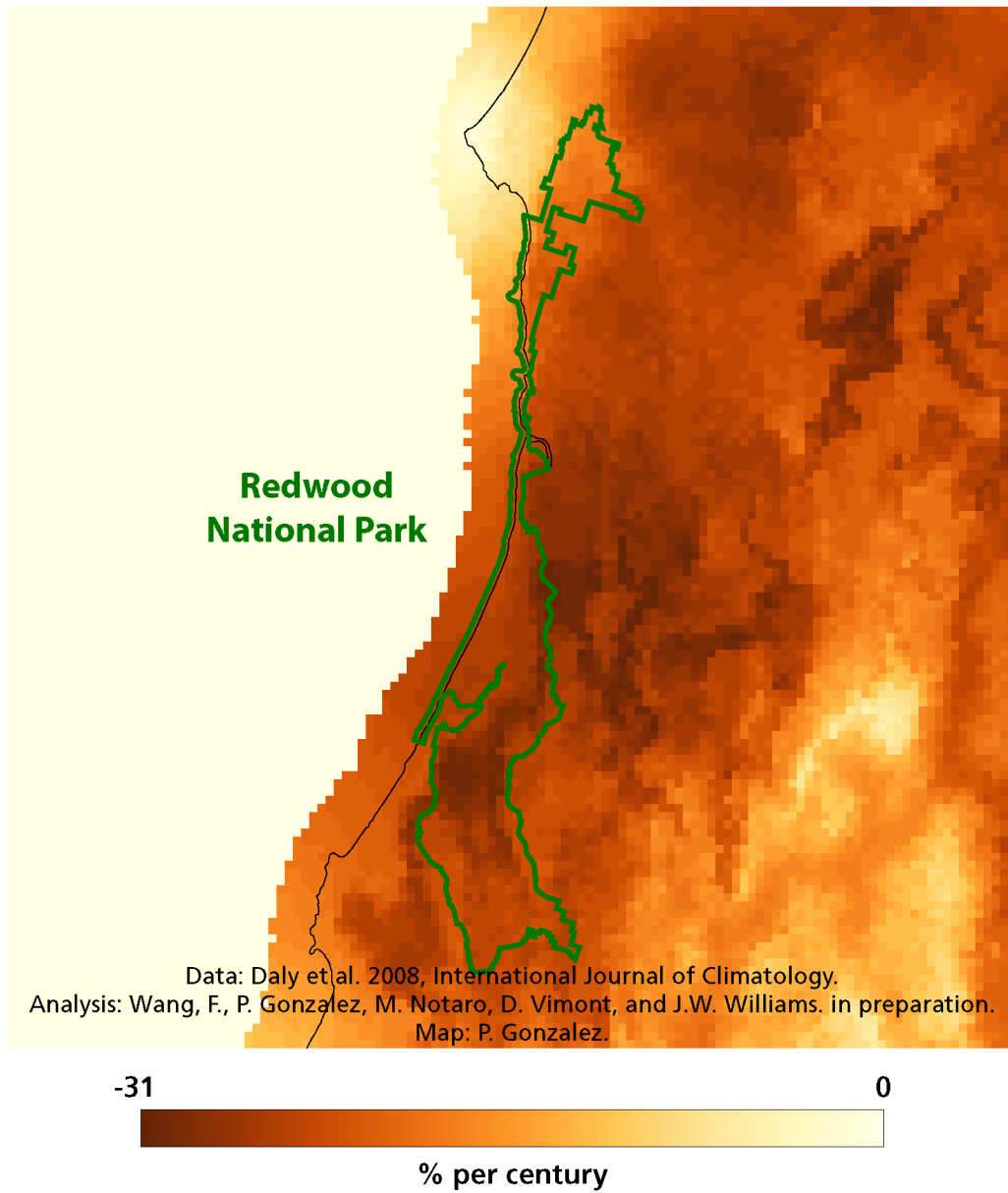


Figure 4. Historical annual total precipitation for the area within park boundaries. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

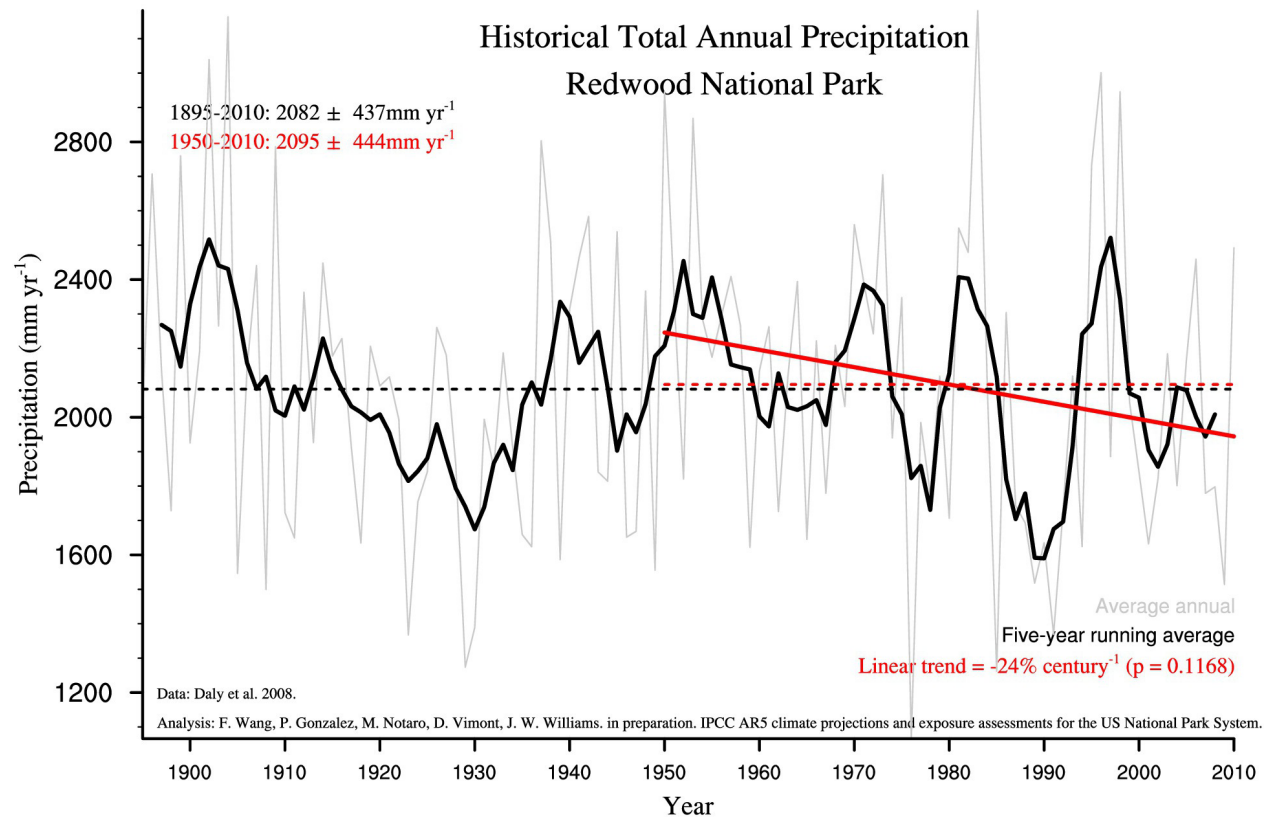


Figure 5. Projections of future climate for the area within park boundaries. Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each average value. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

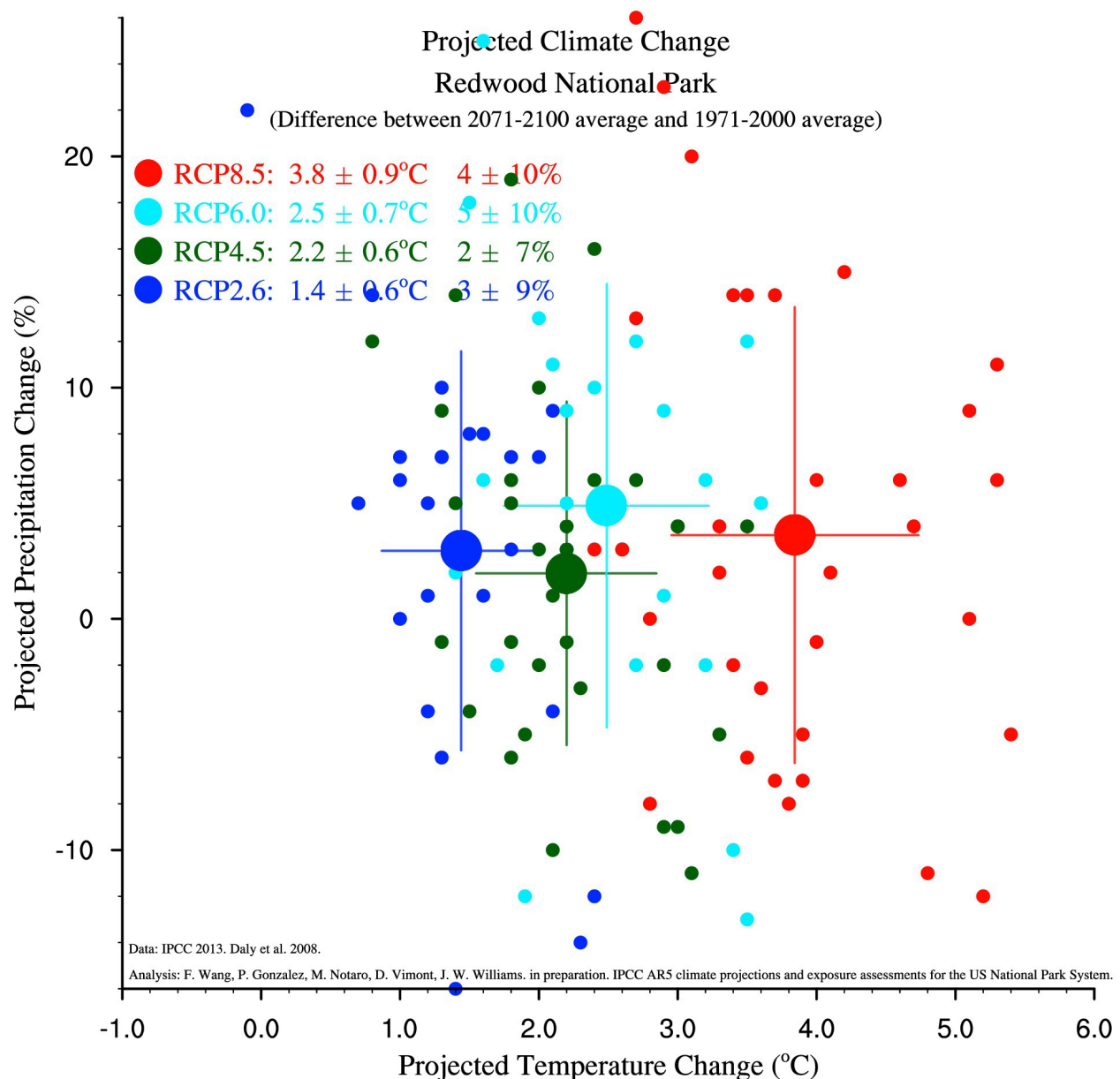


Figure 6

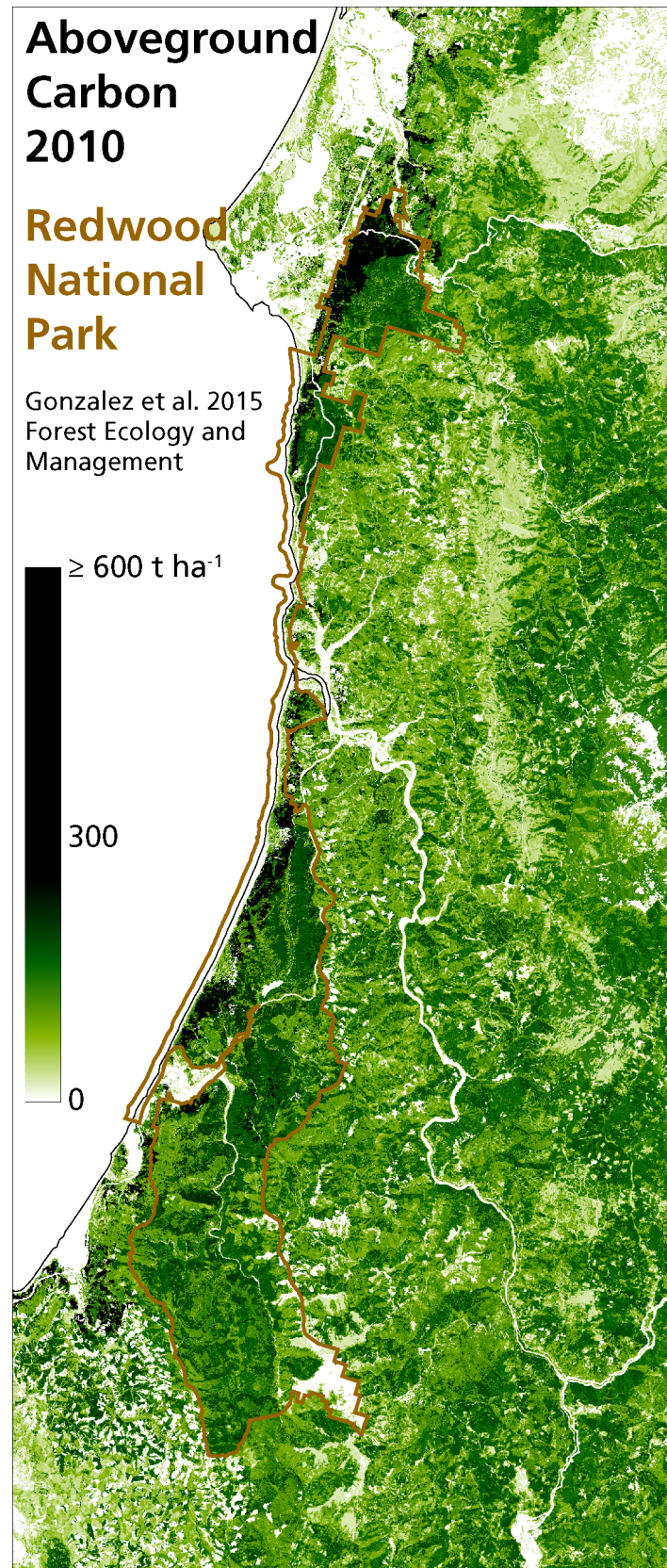
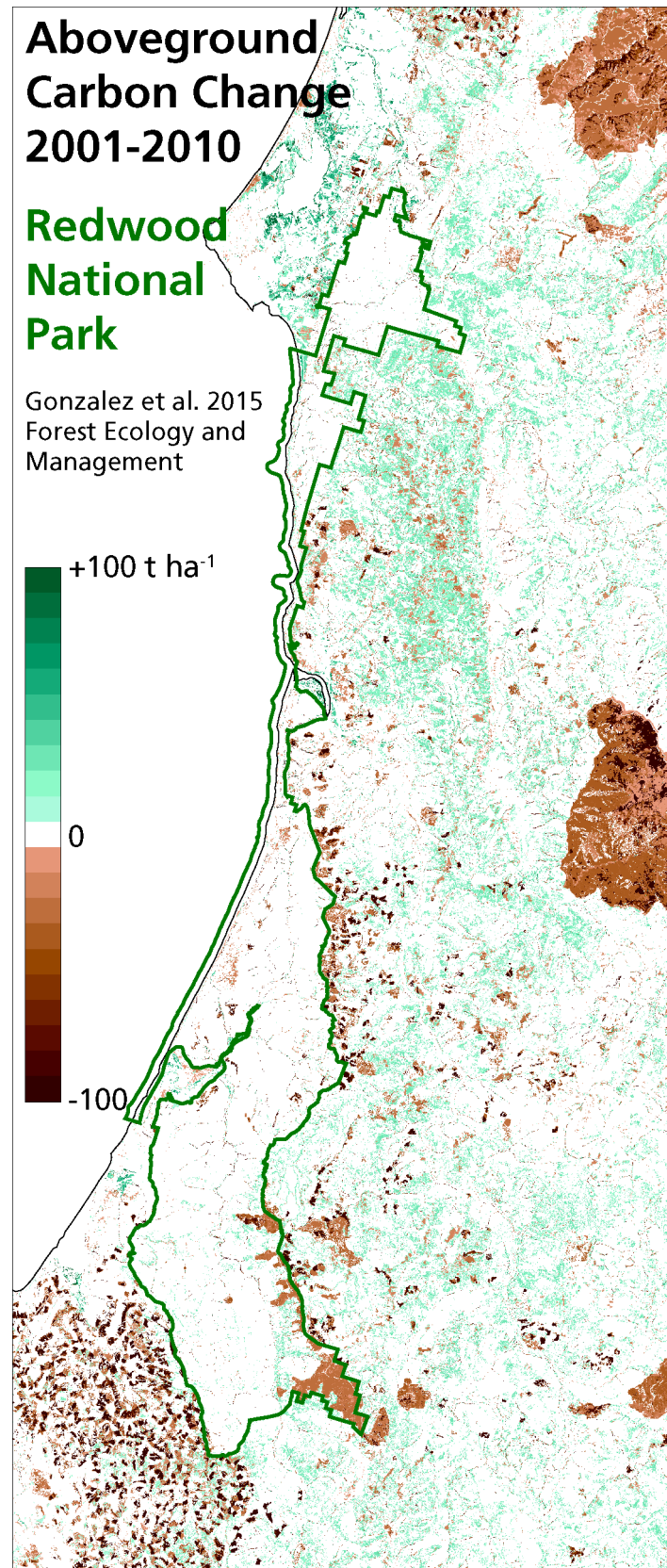


Figure 7



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