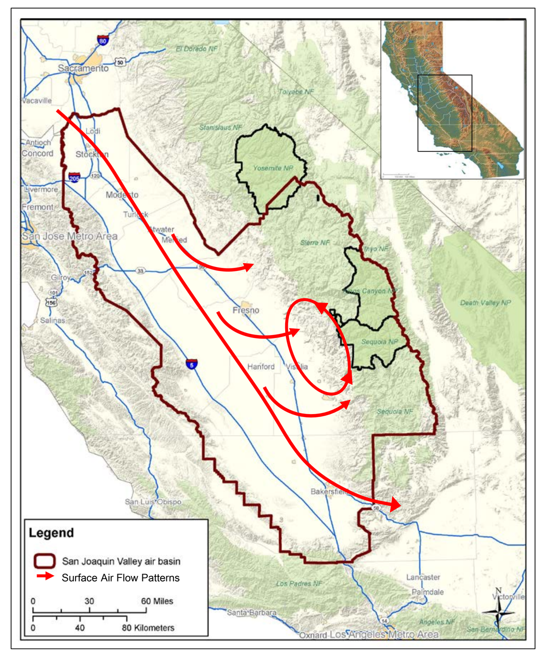
Ozone distribution in ecologically vulnerable terrain of the southern Sierra Nevada, CA

Jeanne Panek[1], David Saah[2], Annie Esperanza[3], Andrzej Bytnerowicz[4], Witold Fraczek[5], Ricardo Cisneros[6]

Introduction

Ozone concentration patterns across the extensive wilderness areas in the Sierra Nevada, CA, remain largely uncharacterized, despite being downwind of major pollution sources. These natural areas, including four national parks and four national forests, contain ecosystem types that have been documented as being vulnerable to ozone injury. While significant direct injury to these forests from ozone pollution has been reported, forests stressed by ozone are also more vulnerable to other agents of mortality, including bark beetle, pathogens, climate change, and ultimately fire. Spatially-explicit analyses of ozone exposure are the first step toward identifying ecosystem vulnerability across the landscape.

Ozone transport to the southern Sierra Nevada



Surface air flow patterns carry pollutants from sources in the San Joaquin Valley Air Basin.

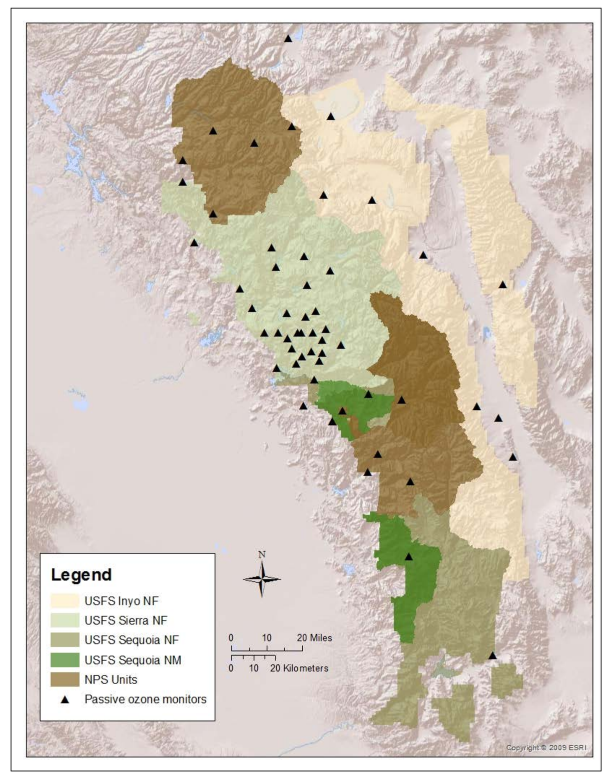
The mountains surrounding the air basin trap pollutants such as ozone and force them to onto the lower slopes and into valleys. Summertime airflow can carry pollutants northward along the front of the Sierra Nevada in a large eddy.

Methods

Defining the region: The extent of the ozone analysis boundary was determined by a scientifically supported, standardized definition for "ecological region" developed as part of an ongoing natural resource analysis collaboration across 3 universities, 4 agencies, and 2 NGOs in the mid to southern Sierra Nevada. The region is termed the Protected Area Centered Ecosystem and defined following NPS methodologies.

Ozone concentrations: Ogawa-type passive ozone samplers were deployed for two-week periods in 2006, 2007 and 2008 during the highest ozone concentrations period of the year – June through October – to estimate average 24-hour ozone concentrations for each two-week period.

Spatial ozone surfaces: A geographically-weighted regression equation was developed from the data using ArcGIS. The final suite of explanatory variables included elevation, distance to drainage bottom and maximum normalized wind velocity. The median adjusted R^2 for the model was 0.45 for all two-week periods. The highest frequency R^2 was in the 0.50-0.70 range. A continuous ozone concentration layer was extrapolated to the region using this model, at 3,500 m resolution.



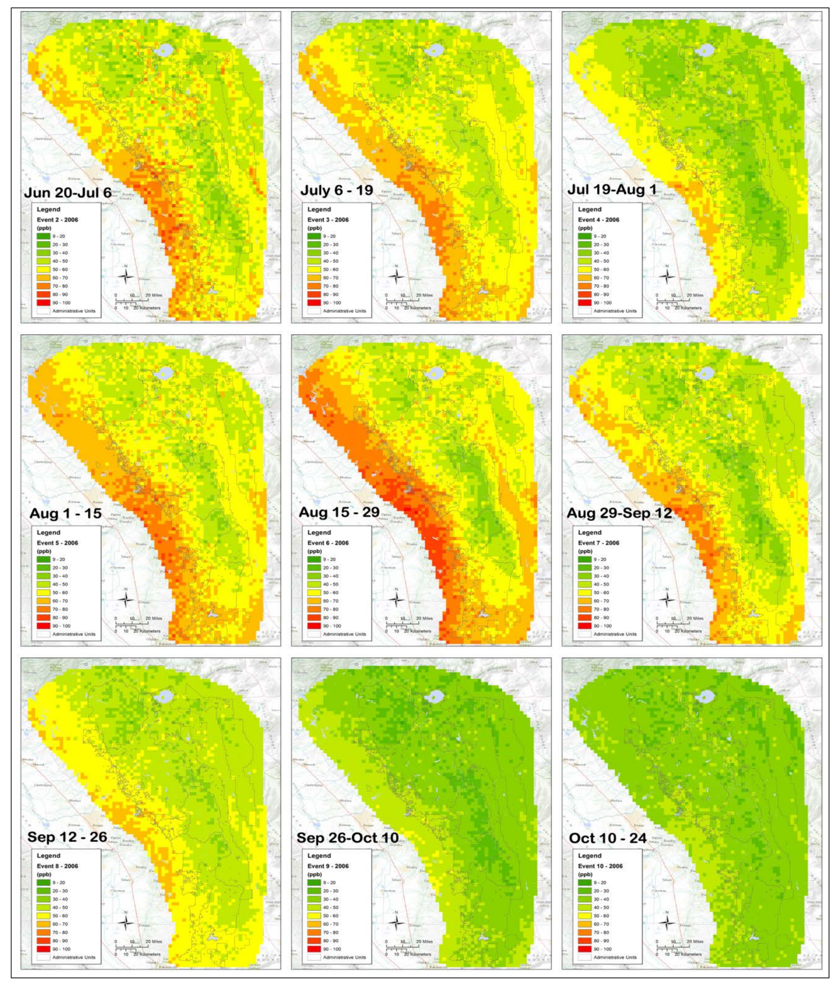
Ozone monitoring sites in the mid to southern Sierra Nevada

Ozone sampling sites, shown as triangles, were established throughout the region, which included four national parks and four national forest service units.

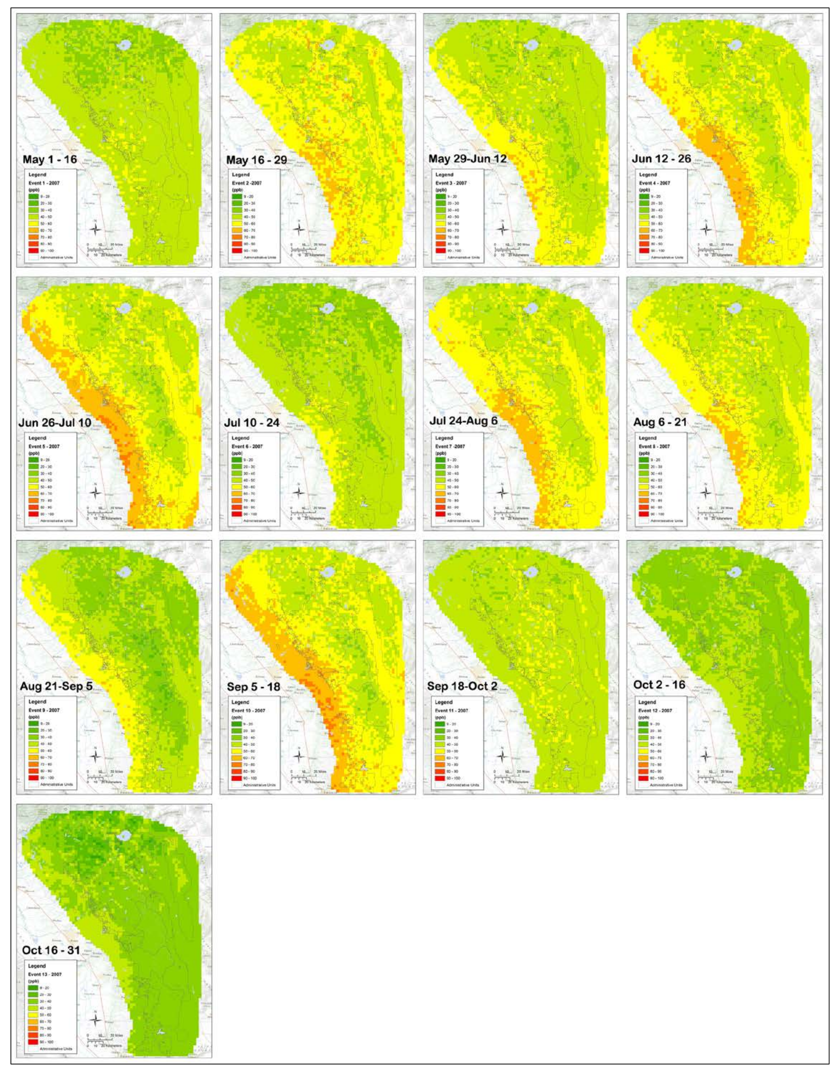
Results

Patterns of ozone distribution

2006

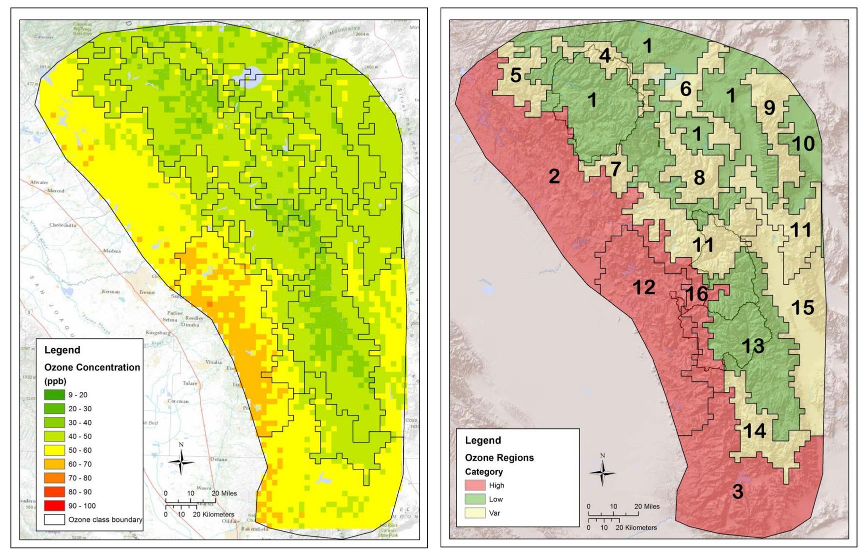


2007



The spatially explicit time sequences above show that ozone laps onto the lower western slopes of Sierra Nevada much like ocean waves lapping onto a beach. Each two-week ozone period impacts the "shoreline", or the front of the range, depending on its overall magnitude. Generally the lower elevation western slopes receive the highest ozone concentrations. However, if the period has overall higher ozone concentration, the "wave front" is greater in magnitude, reaching further north, higher in elevation, and deeper into mountain valleys. There is an elevation above which anthropogenic ozone rarely reaches, the nominal "high-tide line". This break delineates a high-elevation region that has consistently lower ozone concentration from one period to the next, as seen below.

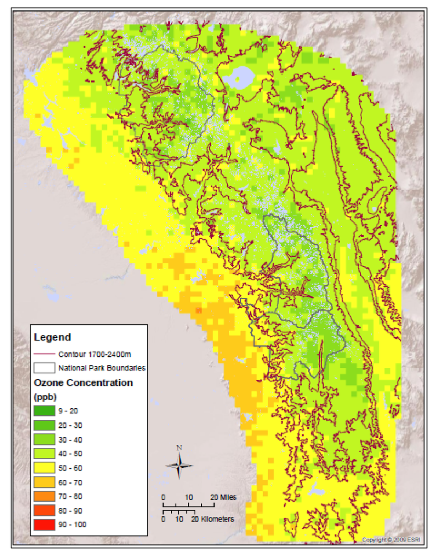
Ozone hot-spot analysis



Region ID	Area (km2)	% Low	% Variable	% High	Class
1	10405	90%	8%	2%	Low
2	6739	0%	27%	73%	High
3	5372	0%	8%	92%	High
4	968	29%	51%	20%	Variable
5	977	9%	79%	13%	Variable
6	1170	22%	54%	24%	Variable
7	539	41%	36%	23%	Variable
8	1274	26%	59%	15%	Variable
9	1358	41%	55%	4%	Variable
10	1342	98%	2%	0%	Low
11	3957	39%	56%	4%	Variable
12	4411	0%	1%	99%	High
13	4190	85%	15%	0%	Low
14	1446	31%	55%	14%	Variable
15	3292	3%	57%	40%	Variable
16	1604	2%	29%	69%	High

Object-based image segmentation identified 16 sub-regions of ozone exposure, resulting classification of sub-regions into "high" (red), "variable" (yellow) and "low" (green).

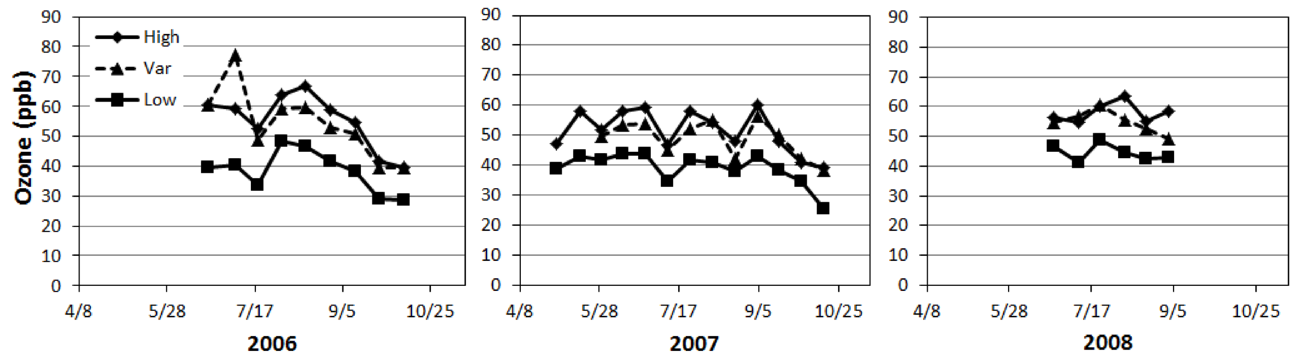
Elevation is a barrier to ozone distribution



The 1,700–2,400 m elevation band marks a significant elevational break in ozone concentrations. The 2,400-m mark can be thought of as the ozone concentration "high-tide" line.

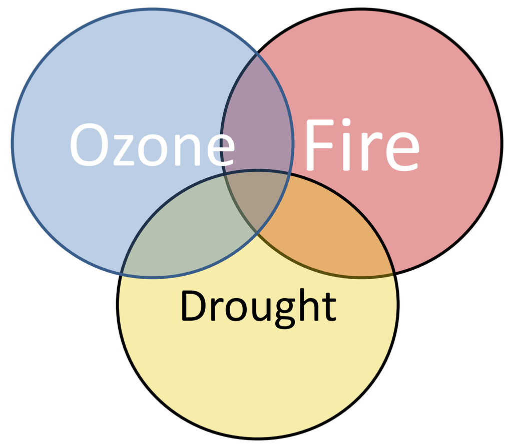
Temporal Trends

Comparison of high, variable and low ozone classes over time



The time trends of mean ozone concentration in the sub-region classifications (high, variable, low) track one another over time, consistently rising and dropping together. This suggests that by knowing the ozone concentration over time in one sub-region class, the concentrations in the other sub-regions can be generally estimated. "High" and "low" classes track each other most consistently, while the "variable" class, not surprisingly, tracks the least consistently, generally somewhere between the other two

Management Implications



The pine-forested landscape along the western front of the Sierra Nevada is highly vulnerable to stress and is potentially at risk of higher mortality. Sub-regions 2, 12, 16, and 3 are the areas with highest ozone exposure. Sub-regions 12, 16, and 3 are also experiencing increasingly longer dry seasons on average, resulting in less soil moisture availability, due to earlier-season snowmelt. Furthermore, these sub-regions are at "extreme" fire risk due to significantly altered fire regime. Because of the confluence of these important stressors, the pine forests in these areas on the southern and southwestern flanks of the Sierra Nevada should get management priority.

Conclusions and Future Research

Characterizing the spatial distribution of ozone concentration through the combined use of passive samplers and GWR quantified patterns of ozone exposure across the landscape. Some of these patterns corroborated insights inferred from other studies. Ecosystems, particularly sensitive pine forests, in high concentration regions in the south and southwestern Sierra Nevada are more vulnerable to mortality. Regions above 2,400 m are relatively pristine. Future research will include analyzing the 26 years of foliar ozone injury in the region's forests to explore the relationship between ozone concentration and injury, and using the relationship to predict ozone injury across the landscape.

Acknowledgements

This research was funded by the National Park Service Natural Resources Condition Assessment program and the USDA-FS Pacific Southwest Research Station. The authors thank Dr. Haiganoush Preisler for important conceptual contributions during the project.

Author Affiliations

1. Center for Forestry, University of California, Berkeley, CA 94720
2. Spatial Informatics Group, 3248 Northampton Ct., Pleasanton, CA 94588
3. Sequoia and Kings Canyon National Parks, 47050 Generals Highway, Three Rivers, CA 93271
4. USDA-FS, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507
5. ESRI, 380 New York St., Redlands, CA 92373
6. USDA-FS, Sierra National Forest, 1600 Tollhouse Rd., Clovis, CA 93611