Air pollution increases forest susceptibility to wildfires in southern California

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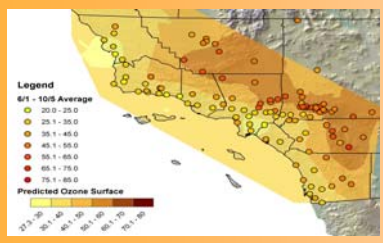
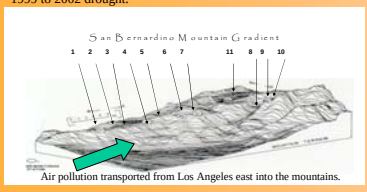
Abstract--Many factors increase susceptibility of forests to wildfire. Among them are increases in human population, changes in land use, fire suppression, and frequent droughts. These factors have been exacerbating forest susceptibility to wildfires over the last century in southern California. Here we report on the significant role that air pollution has on increasing forest susceptibility to wildfires, as described in a case study in the San Bernardino Mountains. Air pollution, specifically ozone (O_3) and wet and dry deposition of nitrogenous compounds (by-products of fossil fuel combustion), has significantly increased with population and industrialization of the region after WWII. Ozone and elevated nitrogen deposition cause specific changes in forest tree carbon, nitrogen, and water balance that enhance individual tree susceptibility to drought, bark beetle attack, and combined, contribute to whole ecosystem susceptibility to wildfire. For example, elevated O_3 and N deposition increase leaf turnover rates, leaf and branch litter, and decrease decomposability of litter. Uncharacteristically deep litter layers develop in mixed conifer forests affected by air pollutants. Elevated O_3 and N deposition decrease the proportion of whole tree biomass in foliage and roots, the latter effect increasing tree susceptibility to drought and beetle attack. Because both foliar and root mass is compromised, carbohydrates are stored in the bole over winter. Elevated O_3 increases drought stress by significantly reducing plant control of water loss. The resulting increase in canopy transpiration, combined with [O_3 + N deposition]-induced decreases in root mass significantly increases tree susceptibility to drought stress, and contributes to the success of bark beetle when combined with increased bole carbohydrates. Phenomenological and experimental evidence is presented to support the role of these factors contributing to increasing the susceptibility of forests to wildfire in southern California.

Factors contributing to forest susceptibilty to wildfires:

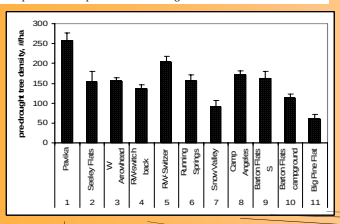
- **100 yrs of compounding factors**
- **Rapid change in human populations and land use patterns**
- **Shift from forest utilization to recreational use**
- **Fire suppression and reduced management**
- **Forest densification**
- **Periodic drought**
- **Explosion in bark beetle populations**
- **AIR POLLUTION IS A SIGNIFICANT, PREDISPOSING STRESSOR CONTRIBUTING TO INCREASED SUSCEPTIBILITY TO WILDFIRE**

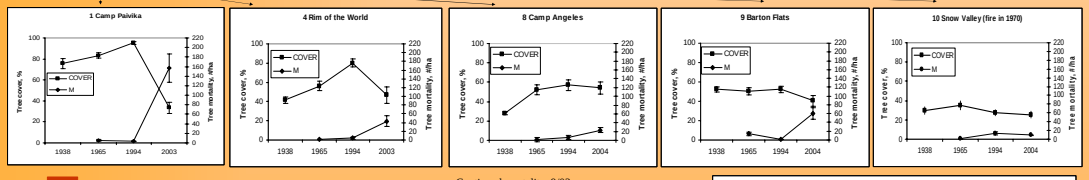


Topology of O3 concentrations across the Transverse Range from Bytnerowicz and Arbaugh, unpublished data (2005). Below: Stand density shown across a pollution gradient from west to east in the San Bernardino Mountains. Higher stand density was correlated to higher pollutant exposure, and to higher rates of mortality in the 1999 to 2002 drought.

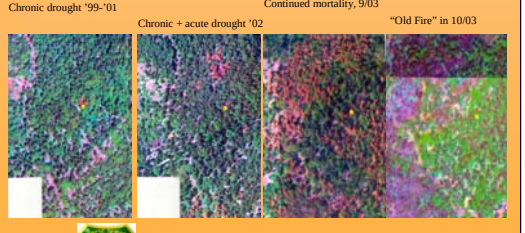


Air pollution transported from Los Angeles east into the mountains.

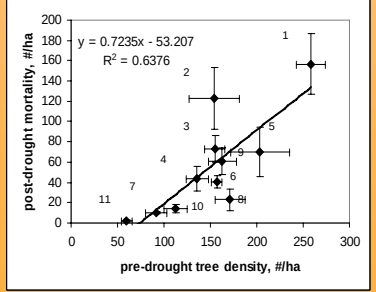




Using historic aerial photographs, tree cover, and tree density and mortality rates were measured in four to eight 1-ha plots. The same location was sampled in 1938, 1965, 1994, and 2004 (R. Minnich). A subset of sites are presented below:



Time series of imagery at **Camp Paivika** composited red, near infra-red, and thermal bands clearly shows dead trees, and burned areas.
(Imagery from Phil Riggan)



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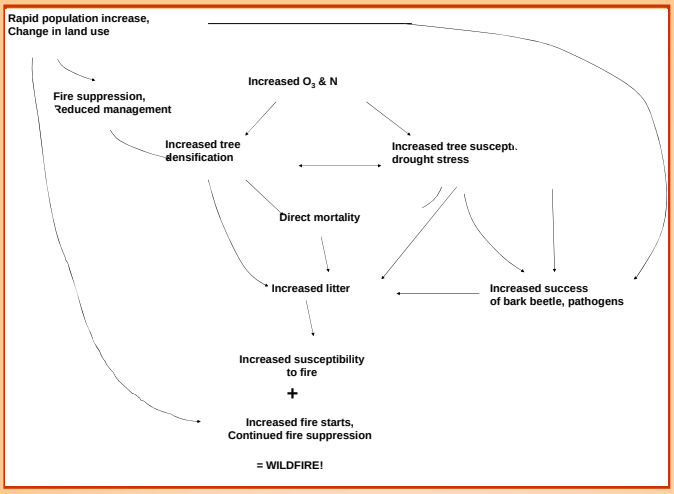


How can there be a link between air pollution and forest susceptiblity to wildfires?

Air pollution is comprised of:
CO_2, CO, particulates, NOx, and O_3.

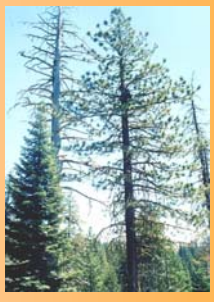
Nitrogen oxides (and associated nitrogenous compounds) and ozone exposure stimulates changes in ecosystem structure and function that increases forest susceptibility to wildfire.

>Nitrogenous compounds stimulate forest stand densification, leaf turnover rates, and reduce root mass
>Ozone exposure also increases leaf turnover rates, increases lower branch abscission, and reduces root mass. Ozone exposure also increases lignification in leaves, reducing decomposition rates of decomposition.
>Litter layer significantly builds in pollution-impacted sites
>Both excess nitrogen deposition and ozone exposure shift within-tree allocation of resources:
>Carbohydrates are stored in subcortical tissues in the bole, just where bark beetles feed.

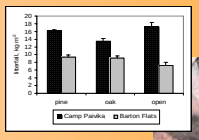
High O_3 exposure and excess N deposition:

>Lower leaf mass
>Lower root mass
>Lower carbohydrate content in roots and leaves
>Carbohydrates stored in bole!

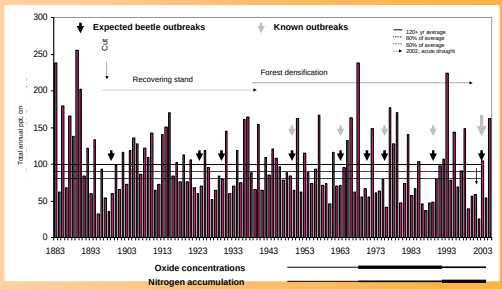
Grulke and Balduman, 1999; Grulke et al. 2001;



O_3-induced thinning crown of ponderosa pine in the San Bernardino National Forest, CA. Lower branches are abscissed due to higher O_3 uptake in the shaded canopy and overall lower carbon balance in shaded branches.



Thinning crown leads to excessive litter build-up. Leaves produced in a high O_3 environment are highly lignified and are slow to decompose. Fenn & Dunn 1989; Fenn et al., 2005



A long term record of precipitation shows frequency of drought in the eastern San Bernardino Mountains. A year with 60% of the long term average precipitation results in severe drought stress in ponderosa pine, and 80% results in moderate drought stress. Approximately one half the time, ponderosa pine experiences moderate (32%) or severe (16%) drought stress. The 2002 drought was a once in 200 yr acute drought event which was preceded by three years of chronic, severe drought (40 to 60% of long term average).

1st yr of drought	dates of Aerial photos	% of 123 yr record [1] 1	2	3	4	3-4 yr average	bark beetle [2]	pollution SUM06 [3]	tree cover % [4]
	Late 1800's								[logged]
1897		54	35	60		50			
1922		68	60	70		66			
1927		51	65	84	79	70			
	1938								76±5
1947		78	88	84	64	79			
1958		71	73	46		63	++		
	1965							100	83±3
1969		55	66	55		59	+++	170	
1973		61	63	79	42	61	++	140	
1986		47	37	48	48	45	++	160	
	1994							150	95±1
1999		39	56	59	25	45	++++	110	
	2004								34±5

At the site with the most pollutant exposure, tree mortality after the 1999-2002 drought and subsequent bark beetle attack was 60%, 3x higher than at sites with less pollutant exposure. At sites with prescribed or wildfire and lower stand density, tree mortality was 4%. However, all stressors contributed to the recent high mortality observed in the San Bernardino Mountains, many of which were set in motion decades ago: population growth, land use changes, and air pollution-effected stand density and within-tree allocation of resources (lower root mass, higher bole carbohydrates). These long term effects predisposed the trees, and the stands, to be particularly sensitive to drought and successful bark beetle attack.