Torrey Pine Demise – Microcosm of Tree Die-Off Worldwide

Air pollution, including photochemical ozone (O3) and deposition of nitrogen compounds, has adversely affected mixed conifer forests in the U.S. for at least 50 years. Foliar injury, premature needle abscission, crown thinning, reduced growth and vigor have been well-documented for ponderosa and Jeffrey pines on the western side of the pollution deposition gradient in the San Bernardino Mountains (1). Disease of ponderosa pine caused by air pollution has been called X-disease, chlorotic decline, and ozone needle mottle. In the 1960's plant pathologists found that smog-damaged ponderosa pines in the San Bernardino Mountains were particularly susceptible to attack by bark beetles (2). This type of air pollution impaired the oleoresin system of the weakened trees, reducing the sap which was the primary defense against bark beetle emergence (3). Drought conditions in Southern California since 1999 combined with this smog-type pollution further increased pine susceptibility to insect disease (4).

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While investigating the relationship between oleoresin exudation pressure and tree mortality caused by bark beetles, it was discovered that blackstain root fungi (primarily Leptographium sp. and Heterobasidion annosum) were also strongly associated with infestation by bark beetles (1). Although the red turpentine beetle (Dendroctonus valens) doesn't kill pines, its tunneling activity predisposes to colonization and disease caused by other bark beetles (2). Torrey pines are attacked by D. valens, but they are mainly threatened by the California five-spined engraver beetle (Ips. paraconfusus). Conifer bark beetles are associated with fungal complexes with different ecological roles. Some associated species are nutritionally obligate fungi, serving as larval food, where others are pathogenic blue-stain fungi involved in tree host defenses. Even non-pathogenic nutritional fungi associated with bark beetles, however, may participate in depleting host plant defenses (3).

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2. Keen, FP. Insect Enemies of Western Forests. USDA Misc. Publ. 1952. No. 273, 280 pp.
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Besides air pollution, drought is another (abiotic) environmental condition associated with forest mortality on a world-wide basis. Multiple mechanisms increase tree mortality during drought, but a common mechanism is the isohydric regulation of water by avoidance of drought-induced hydraulic failure via stomata closure, resulting in carbon starvation and downstream effects which include decreased resistance to biotic agents (1). Elevated temperatures may exacerbate carbon starvation and hydraulic failure. Outbreaks of native bark beetles, contributing to the death of billions of coniferous trees world-wide, have benefited from global warming by extending their range and ability to breed at higher altitudes (2). Torrey pines have survived over the ages by frequent fog and stratus clouds that provide water and shade in the dry climate. P. torreyana growing in the Channel Islands, which grow on north-facing slopes, have advantages over the pines in the inland sites where cloud cover is lowest and evapotranspiration is highest (3).

1. McDowell, N, Pockman, WT, Allen, CD, Breshears, DD, et al. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytol. 2008. 178(4):719-739.
2. Bentz, BJ, Regniere, J, Fettig, CJ, Hanse, M, et al. Climate change and bark beetles of the Western United States and Canada: direct and indirect effects. Bioscience 2010. 60(8):602-613.
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Short-wave ultraviolet radiation is a major abiotic stressor to trees world-wide. Independent measurements document solar radiation in the 200-400 nm range that now penetrate to earth, contrary to the assertions that all of UV-C and most of the UV-B never reach earth's surface (1). Enhanced UV radiation affects trees by modifying their biological and biochemical environment. The damage includes disruption of membranes and other cellular structures, generation of free radicals, inhibition of physiological processes, e.g. photosynthesis, nutrient assimilation, and chlorophyll and protein synthesis, all resulting in reduced growth and development of the tree (2). Enhanced UV-B reduces genome stability in plants (3). A recent study shows high UV-B intensity lead to defective pollen development in conifers associated with decreased reproduction or even sterility (4). Trees from many areas around the world are showing destructive changes in the trunk/branches and foliage which are especially prominent on sun-exposed surfaces.

? PICTURES HERE OF UV DESTRUCTIVE CHANGES ON MORE SUN-EXPOSED VS SHADED TRUNK/BRANCHES OF TREES

1. Herndon, JM, Hoisington, RD, and Whiteside, M. Deadly ultraviolet UV-C and UV-B penetration to earth's surface: human and environmental health implications. JGEESI 2018. 14(2):1-11.
2. Singh, SS, Kumar, P, and Rai, A. Ultraviolet radiation stress: molecular and physiological adaptations in trees. Abiotic Stress Tolerance in Plants. 2006. pp 91-110.
3. Ries, G, Heller, W, Puchta, H, Sandermann, H, et al. Elevated UV-B radiation reduces genome stability in plants. Nature 2000. 406(6791):98.
4. Benca, JP, Duijnstee, IA, Looy, CV. UV-B-induced forest sterility: implications of ozone shield failure in Earth's largest extinction. Science Advances 2018. 4(2): e1700618.

Forensic evidence is consistent with coal fly ash (CFA) as the primary material used widespread ongoing tropospheric aerosol geoengineering (TAG) (1). The main elements in CFA are oxides of silicon, aluminum, iron, and calcium, with lesser amounts of magnesium, sulfur, sodium, and potassium. Primary components of CFA are aluminum silicates and an iron-bearing (magnetic) fraction that includes magnetite (Fe_3O_4). Trace elements in CFA include: arsenic, barium, beryllium, cadmium, chromium, lead, manganese, mercury, nickel, phosphorus, selenium, thallium, titanium, and zinc (2). CFA contains small amounts of radioactive nuclides and unconsumed carbon (soot) (3,4). Jet-sprayed aerosolized CFA over land and sea is likely one of the most important sources of air pollution in Southern California since less than 5% of energy in the state is generated by coal-fired power plants (5). High levels of aluminum in snow, rainwater, and fog in samples from California implicate CFA since coal burning (with CFA as byproduct) is the main source of Al in the atmosphere (6).

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2. Fisher, GL. Biomedically relevant chemical and physical properties of coal combustion products. Environ. Health Perspec. 1983. 47:189-199.
3. Pandit GG, Sahu, SK, Puranik, VD. Natural radionuclides from coal fired thermal power plants – estimation of atmospheric release and inhalation risk. Radioprotection 2011. 46: S173-S179.

4. Kulaots I, Hurt RH, Suberg, EM. Size distribution of unburned carbon in coal fly ash and its implications. Fuel 2004. 83:223-230.
5. California Energy Commission – California's declining reliance on coal – overview – Tracking Progress 2017.
6. Aksu, A. Sources of metal pollution in the urban atmosphere (a case study: Tuzla, Istanbul) J. Environ. Health Sci. 2015. 13:79.

The fog that is formed in Southern California provides an environment conducive to scavenging particulate pollution and converting sulfur dioxide (SO2) and nitrogen oxides (NO2) to sulfuric and nitric acid. Fog from this region is often more acidic (pH between 2.5 and 3) than rain and it can remain suspended in the air for hours (1). Metal pollutants (besides aluminum) that have been measured in fogwater from Southern California include iron (Fe), copper (Cu), chromium (Cr), lead (Pb), and nickel (Ni) (1,2). There is growing concern about the levels of mercury found in fog water from the central California coast (3). Acidic fog has effects on plants that include photosynthetic activity, CO2 assimilation, and stomatal resistance (4). Acid fog can lead to deficiencies of calcium (Ca) and boron (B) by leaching these elements from needles in fir trees (5). Acid fog and rain release aluminum into a chemically active form that reduces root growth and inhibits uptake of nutrients in trees. Aluminum exchange for calcium (Ca) and magnesium (Mg) leads to a deficiency of these nutrients which is considered a major factor in forest decline (6).

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4. Trumble, JT, Walker, GP. Acute effects of acidic fog on photosynthetic activity and morphology of Phaseolus lunatus. Hort. Science. 1991. 26(12):1531-1534.
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Air pollution is a primary world-wide cause of the degradation/contamination of the natural environment. Levels of chemical elements in tree bark have been used successfully to assess environmental quality and pollution. Chemical/element analyses of tree bark have been carried out mainly in urban/industrial centers (1). Pinus sp. (e.g. Scots pine) is one of the most frequently used trees for this type of biomonitoring, since airborne pollutants deposit and persist in the outermost dead but porous bark (2). Higher elements of lead, copper, iron, nickel, chromium, and cadmium have been documented in polluted urban areas compared to rural areas. (1,3). Douglas Fir bark from Oregon was shown to have a reduced pH and contain high levels of iron and aluminum in the older trees (4). High levels of mercury were found in Pinus sp. tree bark from a polluted area in Italy – mercury is an ideal element to be monitored though bark because it is not bioavailable in soil and its presence in bark is almost entirely through atmospheric transport (5). Nearly all the pollutants measured in tree bark are either primary components (e.g. Fe/Al) or trace elements (Cu, Cd, Cr, Hg, Pb, and Ni) in coal fly ash.

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3. Kord, B and Bord, B. Heavy metal levels in pine (Pinus eldarica Medw.) tree barks as indicators of atmospheric pollution. BioRes 6(2):927-935.
4. Buamscha, MG, Altland, JE, Sullivan, DM, Cassidy, J. et al. Chemical and physical properties of Douglas Fir bark relevant to the production of container plants. HortScience 2007. 42(5):1281-1286.
5. Costagliola, P. Benvenuti, M, Chiarantini, L, Lattanzi, P, et al. Tree barks as environmental biomonitors of metals – the example of mercury. Adv. Environ. Pollut. Res. 2017:11-18.

Although there is scant data on sensitivity of insects to heavy metal contamination, it is known that bark beetles are tolerant to multiple toxic elements. In a study of a heavily polluted area in Finland, trees with high levels of heavy metals in bark (compared to lower levels in phloem and xylem) suffered high rates of attack by bark beetles. In this study, cadmium accumulated in the beetles (1). Bark beetles are good bioindicators for iron and aluminum (2). There is an increased deposition and mobility of Zn, Cu, and Al beneath beetle-impacted trees (3). In spruce-breeding bark beetles collected in Germany, site-specific differences were found for elements with high ecotoxicity; i.e. Pb, Cd, Hg and Al (4). Isolated fungi associated with bark beetles are also tolerant to pollutants (1). The dominant herbivorous beetle of California coastal scrub, Trirhabda germinate Horn, is relatively resistant to acidic fog (pH 2.75) (4). Although Ultraviolet C is lethal to insects (6), bark beetles presumably have some protection from UV in their habitat under tree bark.

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Recent decades have seen an unprecedented explosion in fungal diseases of trees in both natural forests and managed landscapes, in part due to globalization and climate change (1). Stress tolerance (including to UVB radiation) and virulence of fungi may be determined by environmental conditions during conidial formation (2). Fungi have complex regulatory mechanisms for uptake, utilization, and detoxification of essential metals like iron, zinc, and copper and certain fungi are tolerant to ecotoxic metals like As, Cd, Cr, and Pb (3,4). Melanized fungi are often radio-resistant. Melanins have a remarkable ability absorb electromagnetic radiation for both energy transduction and shielding (5). Trees around the world are displaying more fungal growth on more sun-exposed surfaces, likely indicating tolerance or even utilization of short wave ultraviolet radiation. (SEE BELOW)

? PICTURES HERE OF FUNGAL GROWTH ON SUN-EXPOSED (AND UV DAMAGED) SIDE OF TREES.

1. Fisher, MC, Henk, DA, Briggs, CJ, Brownstein, JS, et al. Emerging fungal threats to animal, plant, and ecosystem health. Nature 2012. 484(7393).
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4. Oladip, OG, Awotoye, OO, Olayinka, A, Maboeta, MS, et al. Heavy metal tolerance traits of filamentous fungi isolated from gold and gemstone mining sites. Brazilian Journal of Microbiology 2018. 49:29-37.
5. Dadachova, E, and Casadevall, A. Ionizing radiation: how fungi cope, adapt, and exploit with the help of melanin. Curr. Opin. Microbiol. 2008. 11(6):525-531.
6. Gordon, TR, Storer, AJ, Wood, DL. The pitch canker epidemic in California - Plant Disease 2001. 85(11):1128-1139.

Among eukaryotes, fungi are the most versatile and ecologically successful phylogenetic lineage, and they rapidly adapt to extreme environmental conditions (1). Fusarium spp., major pathogens of trees world-wide, represent such “extreme tolerant” or extremophile fungi (2). In recent decades, many symbiotic insects and fungi have been introduced into non-native ranges world-wide, and these fungus-insect couples are much more destructive, attacking living, not just dead and dying trees (3). For example, the polyphagous shot hole borer (PSHB), an ambrosia beetle native to Asia, along with its fungal symbiont, Fusarium euwallaceae, has destroyed trees of numerous different species in California (4). Torrey Pines are susceptible, and have been affected by Fusarium cincinatum, the cause of pitch canker, which can be transmitted by Ips parconfusus (5). Pitch canker is a destructive disease of pines in many parts of the world, and it is a known to be a severe threat to Monterey and other California pines (6). Fusarium incarnatum was cultured from the whitened, sun-bleached bark of Gumbo Limbo trees in Key West (6).

? HERE SHOW PICTURES OF SIMILARITY IN FUNGAL DISEASE OF TORREY PINE TO PITCH CANKER AND ONE PICTURE OF WHITENED SUN-EXPOSED SIDE OF GUMBO LIMBO

1. Rampelotto, PH. Extremophiles and extreme environments. Life (Basel). 2013 3(3):482-485.
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3. Hulcr, J, and Dunn, R. The sudden emergence of pathogenicity in insect-fungus symbioses threatens naïve forest ecosystems. Proc. R. Soc. B 2011 278:2866-2873.
4. Paap, T. de Beer, ZW, Migliorini, D, Nel, WJ, and Wingfield, MJ. The polyphagous shot hole borer (PSHB) and its fungal symbiont Fusarium euwallaceae: a new invasion in South Africa. Australian Plant Pathology 2018.
5. Gordon, TR, Storer, AJ, Wood, DL. The pitch canker epidemic in California – Plant Disease 2001. 85(11):1128-1139.
6. Wingfield, MJ, Hammerbacher, A, Ganley RJ, Steenkamp, ET, et al. Pitch canker caused by Fusarium circinatum – a growing threat to pine plantations and forests world-wide.

7. Fungal culture obtained by Mark Whiteside, M.D. – F. incarnatum reported by Aaron Palmateer, PhD. Florida Extension Plant Diagnostic Center/University of Florida.

The official explanation of disease and death of Torrey Pines due to "drought and bark beetles" is grossly oversimplified and it ignores the environmental stressors of pollution (air, water, and soil), and harmful ultraviolet radiation. The abiotic stressors, i.e. runaway warming, drought, UVB and C radiation, and air pollution are causing trees to be weakened and susceptible to insects like bark beetles, fungal infections, and perhaps other biotic factors (e.g. viruses/bacteria). The plight of the Torrey Pines is much the same as conifers and other trees throughout the world. Climate manipulation in the form of tropospheric aerosol geoengineering contributes to all these abiotic factors; i.e. it causes warming by keeping earth's heat trapped in like a blanket, it causes drought (with the occasional deluge), it further damages earth's protective stratospheric ozone layer, which allows more deadly UV radiation to penetrate to earth, and it contaminates the biosphere with all the toxic elements present in coal fly ash (our references). It may be too late to save the Torrey Pines, but if this form of deliberate air pollution can be halted, some of the earth's forests can be preserved. Humans and other animals cannot live without trees.