



Insects, Diseases and Abiotic Disorders in Southwest Forests and Woodlands

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Recent events in the forests of the Southwest, and across western North America, have prompted scientists to consider the role of climate variability in insect and disease cycles. The Arizona ponderosa and piñon pine mortality due to bark beetles during 2002-2004 and the decline of aspen since 1999 are examples of events that appear to be tied to recent climatic episodes (Breshears et al. 2005; Raffa et al. 2008; van Mantgem et al. 2009; McDowell et al. 2010; Anderegg et al. 2013; Breshears et al. 2013; Eamus et al. 2013; Williams et al. 2013; Joyce et al. 2014). Extreme to exceptional drought conditions in the Southwest in 2002 (U.S. Drought Monitor 2002) have plausibly tipped the balance towards bark beetle outbreaks in pine forests and woodlands. The ecological impacts of 2002 may not have been as severe if it had not been for the preceding six of seven years with below normal precipitation. Over 70 million pine trees along with millions of other conifers died in 2002-03 (USDA-FS 2002, 2003), and more than 2.8 million acres in Arizona were affected by tree mortality, between 2002-2004, of which almost 1.1 million acres were attributed to *Ips confusus* (USDA-FS 2015). Approximately 7.6% of southwestern forests experienced bark beetle-related mortality between 1997 and 2008 (Williams et al. 2010).

Fluctuations in conifer mortality caused by bark beetles can be related to climatic variation. The non-aggressive spruce bark beetle has long been known to only utilize wind-thrown or snow-broken trees, but recent bark beetle outbreaks on the Kenai Peninsula, Alaska may be linked to warmer than average temperatures in the past decade (Juday, 2004). Logan and Powell (2009) have shown that mountain pine beetle (MPB) populations increased due to elevated temperatures in the Stanley Valley of Idaho. MPB has also been implicated in unprecedented outbreaks in white bark pine at high elevation sites in Idaho. Average temperature increases of 3°C enabled the MPB at those high elevations to achieve univoltine (having one generation per year) reproduction; MPB had been known to only complete a life cycle once every two years. These patterns have been seen across the globe and for many decades as described



Figure 1. Ponderosa pine mortality linked to drought and bark beetle attack in central Arizona 2002. Photo by: USFS.

in Allen et al. (2010). Their review of climate induced tree mortality draws upon 88 well-documented episodes of increased mortality due to drought and heat, including 19 from western North America.

Studies focusing on Arizona and other southwestern states point to multiple, interacting climate-related mechanisms that increase the propensity for forest mortality. The chief candidates include drought, physiological water stress, carbon starvation, higher temperatures, and/or pests and pathogens. One specific mechanism related to drought is the increase in moisture demand, as measured through vapor pressure deficit (VPD), the difference between the saturation vapor pressure and the actual vapor pressure (Weiss et al. 2012; Breshears et al. 2013; Williams et al. 2013). This mechanism is of particular concern, because as temperatures increase there is a corresponding non-linear increase in VPD, which hastens soil moisture depletion and plant transpiration, and complex interactions between hydraulic failure (water loss from transpiration exceeds

water coming up from plant roots), carbon starvation (when trees close stomata to avoid water loss, photosynthesis declines and trees may use up stored carbon), and reduced defense against biotic agents (insects and disease organisms) (Breshears et al. 2013; McDowell et al. 2010; Meddens et al. 2014). Modeling studies show that while drought is a key element in all mortality pathways, including predisposition to insect attacks (Gaylord et al. 2013), increased VPD during drought has a much greater effect than increased temperature alone (Eamus et al. 2013). Moreover, the impacts of drought outweigh the benefits of CO₂ fertilization, especially in the drier portions of species distributions—which is important in ecotonal areas (McDowell et al. 2010).

An additional factor influencing pine tree mortality in the late 1990's and early 2000's points to increased stand density in pine (Covington et al. 1997). At a regional geographic scale, van Mantgem and colleagues (2009) concluded that endogenous competition factors did not cause increased tree mortality across the western U.S., because forest density and tree basal area declined slightly. At smaller scales, increased stand density contributes to lowered soil moisture levels, which can contribute to reduced resistance to bark beetle attack (Kolb et al., 1998; Negron et al. 2009). Nevertheless, a recent assessment of southwestern piñon pine mortality concluded that “studies disagree about the influences of stem density, elevation and other factors” (Meddens et al. 2014).

Based on aerial survey data, aspen tree mortality started to become evident in the late 1990's (USFS 2000). Aspen defoliation in Arizona and New Mexico averaged ~ 20,375 acres from 1990 to 1997. A series of events has contributed to the decline of aspen since 1997.

- In 1998, 85,980 acres were defoliated in New Mexico and Arizona by western tent caterpillar (*Malacosoma californicum*), large aspen tortrix (*Choristoneura conflictana*), black leaf spot (*Marssonina populi*) (USFS 1999), and one of the species of *Melampsora* rust (Fairweather, personal comm.).
- Drought conditions that started in 1995 and continued through spring of 2004 stressed aspens throughout the Southwest (U.S. Drought Monitor 2002).
- On June 4, 5, and 6, 1999 low temperatures were 18, 12 and 8° F below normal, respectively. The timing of these frost episodes coincided with the early flush of growth on many of the aspen clones in Arizona and as a result 148,655 acres were defoliated by frost in 1999 (USFS 2000). A single defoliation event in the spring such as frost is generally tolerated by trees except when the trees have had additional stress factors such as drought or defoliation from insects or disease organisms (Manion 1991).
- During the drought, elk browsed young shoots produced in stands of declining mature aspen. The over-grazing of young aspen shoots was particularly



Figure 2. Aspen mortality and dieback at Dry Lake (center) and Woody Mountain (above right) near Flagstaff, Arizona. Photo by: USFS.

damaging in light of the death of the mature trees due to frost and drought. Continued grazing of aspen shoots in stands with a dead or declining overstory may eventually destroy the ability of clones to survive. (Populations of the non-native Rocky Mountain elk were estimated at 23,000 head in 1986, then peaked at 31,000 adults in 1992, and by 1999 had declined to 25,000 [Wakeling, personal comm.]. Arizona Game and Fish Department has recognized this problem and is implementing a program to help reduce these conflicts [Arizona Game and Fish Department, 2002]).

- Studies by Anderegg and colleagues (2011) point to hydraulic failure in aspen roots and branches as the key mechanism for widespread aspen forest mortality in Colorado. The authors point out that the drought-induced combination of depletion of shallow soil moisture and high atmospheric moisture demand were key factors in regional aspen mortality, whereas depletion of carbohydrate reserves did not play a key role.

From 2000 to 2005 aspen defoliation has averaged 51,500 acres per year in Arizona (USFS 2000b, 2002, 2003, 2004, 2005; Dudley, personal comm.) with little of the defoliation attributed to insects or diseases. An intensive study of the aforementioned factors is being conducted by USFS (Fairweather et al. 2005). Forest Pathologist Mary Lou Fairweather with USFS, has described the continued high levels of defoliation as “decline” (USFS 2004) and “dieback” with many clones experiencing greater than 50% mortality in the overstory and many more trees that have 10 to 30% live crown remaining (USFS 2005) (Figure 2). Studies by Anderegg et al. (2011) showed that aspen decline in Colorado was due at least in part to hydraulic failure in roots and stems. Also that drought stress did not lead to depletion of carbohydrate reserves.

Using tree-ring data, Swetnam and Lynch (1993) and Ryerson et al. (2003) examined the correlation between western spruce bud worm outbreaks and climate variability over multi-century periods. They found that “periods of increased and decreased budworm activity coincided with wetter and drier periods, respectively.”

Some well-studied insect outbreaks are apparently not linked to climate; examples include recent outbreaks in New Mexico of forest tent caterpillars in aspen, as well as past outbreaks of the pandora moth (Furniss and Carolin, 2002). However, the inability of the trees to recover from defoliation has been associated with low moisture availability (Ford, 1996).

In summary, effects of insects on forests are complex, and species and site dependent. Many influences, such as drought, decreased precipitation, increased temperature, increased vapor pressure deficit, and increased stand density, combined in nonlinear and overlapping ways to create the recent and devastating pine bark beetle outbreaks in Arizona forests. Climate clearly plays a role in many, but not all, Southwest insect cycles. Modeling studies for the western U.S. and Canada show potential increases in elevational and geographic range for insect pests such as spruce beetle and the MPB (Logan et al. 2003; Bentz et al. 2010), as a result of potentially increased temperatures associated with climate change. Modeling studies for the Southwest suggest that increased vapor pressure deficit, which is correlated with both tree mortality and bark-beetle outbreaks in the Southwest, could portend even greater forest dieback, based on projections of enhanced 21st century drought severity and frequency (Williams et al. 2013; Joyce et al. 2014). It would be plausible to expect similar effects in Arizona, depending on local factors, such as stand density (which humans can influence through thinning and prescribed fire treatments) and plant vigor, and regional factors, such as bark beetle dynamics, and future drought severity and variability (Macalady and Bugmann 2013; Meddens et al. 2014).

Application to Education

Challenges to communicating forest and climate science include complex and confusing concepts, an abundance of research addressing specific forest-climate interactions, but a lack of research that rigorously takes into account the role of insects in Southwest tree mortality episodes (Macalady and Bugmann, 2013; Meddens et al. 2014). Therefore, it may become necessary to simplify the details initially when communicating forest-climate science. Ultimately, it is important that educators demonstrate the complexity of all of the interplaying issues, in order to communicate no false impressions of an “easy” or “one-size-fits-all” solution for land managers.

Additional Sources of Information

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4. Western forest insects An Online Catalog of Western Forest Insects and Diseases
<http://www.fs.usda.gov/detail/r6/forest-grasslandhealth/insects-diseases/?cid=stelprdb5300513>
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8. CIRMOUNT (Consortium for Integrated Climate Research in Western Mountains) – Anticipating Challenges to Western Ecosystems and Resources. www.fs.fed.us/psw/cirmount
9. Western North America Defoliator Working Group Meeting Reports
http://www.fs.usda.gov/detail/r6/forest-grasslandhealth/insects-diseases/?cid=fsbdev2_027459
10. eXtension Climate, Forests and Woodlands
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