Fig.1. Dying stands of PIFL (Mono Basin)

Forest Mortality in High-elevation Pine Forests of Eastern California, USA; Influence of Climatic Water Deficit

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Fig.2. Dying stands of PIAL (Rock Crk Cyn)

Background

Despite widespread forest dieback across western North America, subalpine forests of the eastern Sierra Nevada have experienced far less mortality than elsewhere, and events have been localized and episodic. We studied two drought-related mortality events, one in limber pine (*P. flexilis*, PIFL, Fig. 1, Millar et al. 2007) that occurred from 1987 to 1994, and one in whitebark pine (*Pinus albicaulis*, PIAL, Fig. 2, Millar et al. in review) that occurred from 2006 to 2010.

Silvical and environmental contexts were highly similar in both cases. Relative to conditions across the species' ranges in this region, mortality stands were characterized as:

- Lower portions of elevation range for each species
- Easternmost locations of the Sierran escarpment
- Northerly aspects
- Tree-form stands (not krummholz)
- High-density stands, with high basal area and closed canopies
- Young (early mature) trees, even-aged stands
- Monotypic stands with little understory vegetation
- Presence of mountain pine beetle (*Dendroctonus ponderosae*); lack of white pine blister rust infestation
- Average stand-level mortality of 65% for PIFL and 75% for PIAL

Climatic correlations varied between the two cases. In both situations we extracted increment cores from dead and live trees in the mortality stands and used stem ring-widths to indicate annual growth. With climatic data derived from composite long-term local weather stations and the PRISM model (Daly et al. 1994), we assessed correlations of ring widths to climatic variables (Table 1). PIFL had significant but low correlations to water-year precipitation, minimum temperatures, and PDSI, while PIAL had weak correlations to all, with significant values only for water-year precipitation lagged by 2 years. Trees that eventually died had higher correlations to precipitation and drought indices than trees that lived in both species, although this trend was stronger for PIFL.

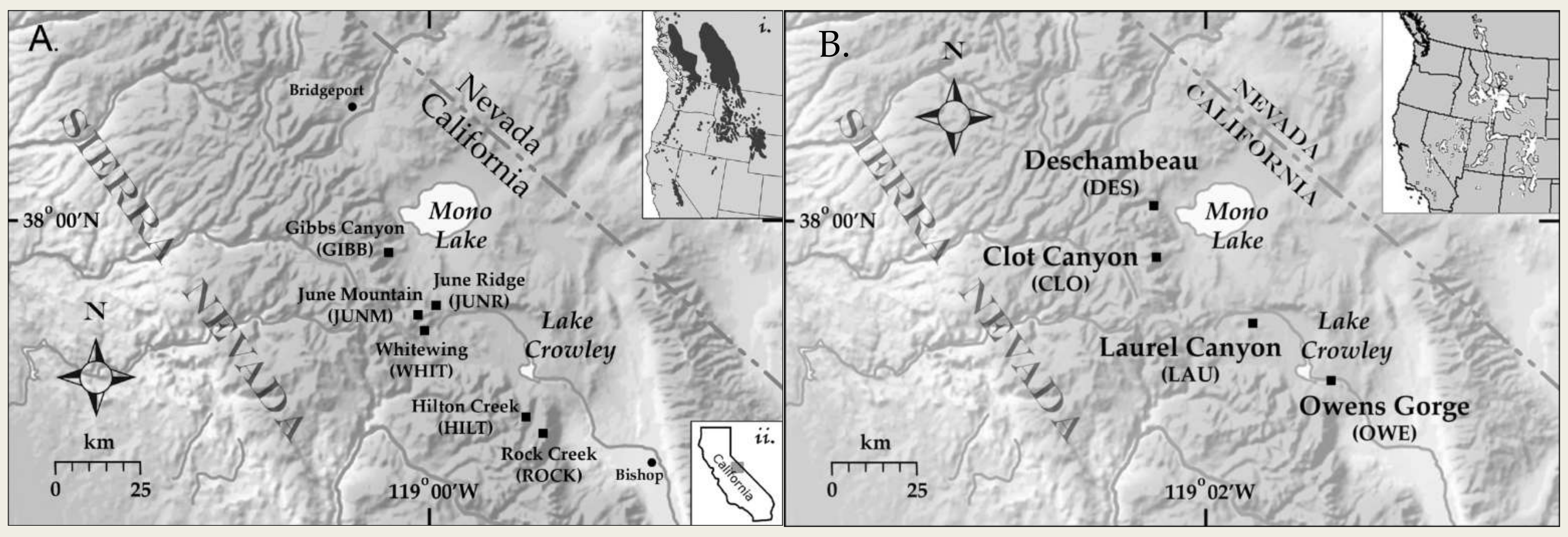

Fig.3a,b. Intensively-studied mortality stands of a) PIAL and b) PIFL in the east-central Sierra Nevada.

Standardized Ring Width	Water Yr Precipitation	Water Yr Precipitation 2-yr lag	Minimum Temperature	Maximum Temperature	PDSI
Limber pine					
Live tress	0.52*	0.37*	0.48*	-0.01	0.27*
Dead trees	0.57*	0.31*	0.22*	-0.22*	0.46*
Whitebark pine					
Live tress	0.15	0.29*	0.11	0.00	0.00
Dead trees	0.18	0.34*	0.13	-0.08	0.00

Table 1. Correlations of standardized ring-width and climatic variables from live and dead trees in mortality stands of PIFL- and PIAL pines. PDSI is the Palmer Drought Severity Index, a measure of drought stress to plants. Significance of $p < 0.05$ indicated by *.

Climatic Water Deficit (CWD)

Given relatively low and weak correlations of growth to climatic variables, we further investigated relationships to moisture availability, which we estimated using modeled CWD values. CWD is a measure of evaporative demand that exceeds available water and is computed as potential evapo-transpiration (ET) minus actual ET. CWD values range from 0, when soils are fully saturated, to positive values with no upper limit. Higher values indicate soils depleted of water, and water increasingly unavailable to meet transpiration demand.

We modeled CWD values from PRISM regional climate projections, downscaled to 270-m (Flint and Flint, unpubl.) and applied to a regional water-balance model (Flint and Flint, 2007a, 2007b). We assessed CWD for 1) our intensively studied mortality sites in the east-central Sierra for PIAL and PIFL (Fig. 3), 2) air-survey data (2006-2010) from the USFS PSW Regional Forest Health Monitoring Program for the east-central Sierra portion of the range of PIAL, and 3) 13 east-central stands of healthy PIFL representing diverse stand conditions for the species.

Correlations of ring-widths and century-long CWD values (~1900-2010) were significant and negative for both species (Table 2, Fig. 4). Correlations were larger in PIFL than PIAL, and, within PIFL, larger for trees that eventually died. In both species, correlations were highest for 2-year lagged CWD values.

Values of CWD were significantly higher in both species at mortality stands than healthy stands across diverse environmental and silvical conditions of the species' ranges in the east-central Sierra Nevada (Table 3). Further, CWD values were higher during the episodes of mortality in both species relative to the century-long averages.

Standardized Ring Width	CWD	CWD 2-yr lag
Limber pine		
Live trees	-0.29*	-0.34*
Dead trees	-0.54*	-0.44*
Whitebark pine		
Live trees	-0.19*	-0.43*
Dead trees	-0.19*	-0.46*

Table 2. Correlations of ring-width and CWD for live and dead trees at PIFL- and PIAL mortality stands. Significance of $p <$ 0.05 indicated by *.

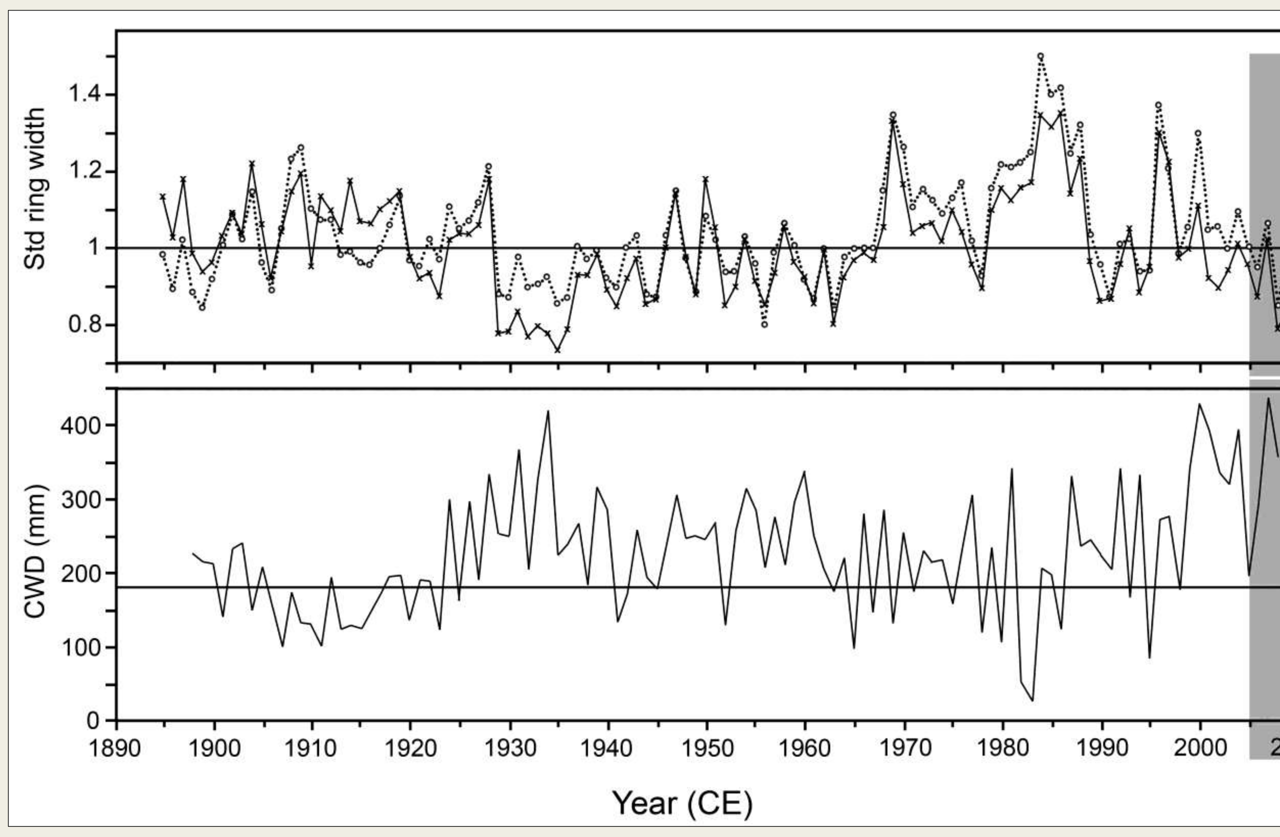

Fig. 4. Correlations of ring width (top) and CWD (bottom) for live (dotted) and dead (solid) trees from PIAL mortality stands.

Summary and Significance

- CWD is an effective indicator and correlate of drought-related mortality in high-elevation forests of limber- and whitebark pine in the east-central Sierra Nevada. CWD appears to better indicate drought stress to high-elevation pines better than individual climatic variables or indices such as PDSI.
- CWD values are higher overall for stands that died than healthy stands.
- CWD values are higher for episodes of mortality compared to century-long values.
- CWD values for mortality stands were at or above the high range of values that Stephenson (1990) indicated as defining conifer forest biomes, pointing to high stress conditions of these stands.
- Sites in the Sierra Nevada have been modeled to be especially sensitive to groundwater transfer from higher slopes (Lundquist and Loheide 2011). PIAL and PIFL mortality sites are situated such as to have no or minimal slopes above them, suggesting little late-season groundwater and greater exposure to CWD deficit.

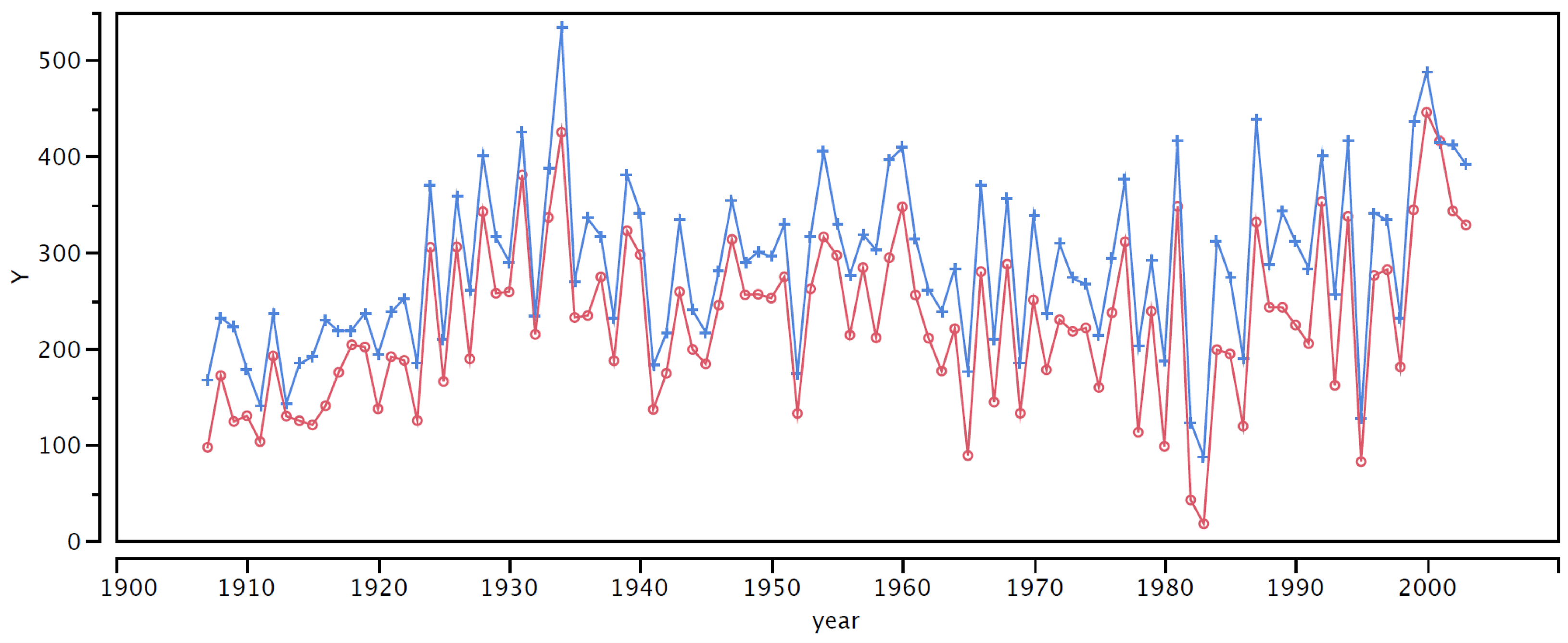

Fig. 5. CWD values for PIFL mortality stands (blue) and healthy old-growth stands (red), 1906-2010.

	CWD 1896-2010	CWD 1987-1994	CWD 2006-2010
Limber pine			
Mortality stands	288	341	428
Healthy stands	221	252	358
Whitebark pine			
Mortality stands	181	195	252
Air-survey; dead stands			387
Air-survey; live pixels			307

Table 3. CWD values for dead and healthy PIFL and PIAL stands at century-long scale, period of PIFL mortality (1987-1994) and period of PIAL mortality (2006-2010). Healthy stand contrast for PIAL is only available from air-survey data, which include the entire range of PIAL in the east-central Sierra. Other data are from intensively studied stands (Fig 3).

References

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