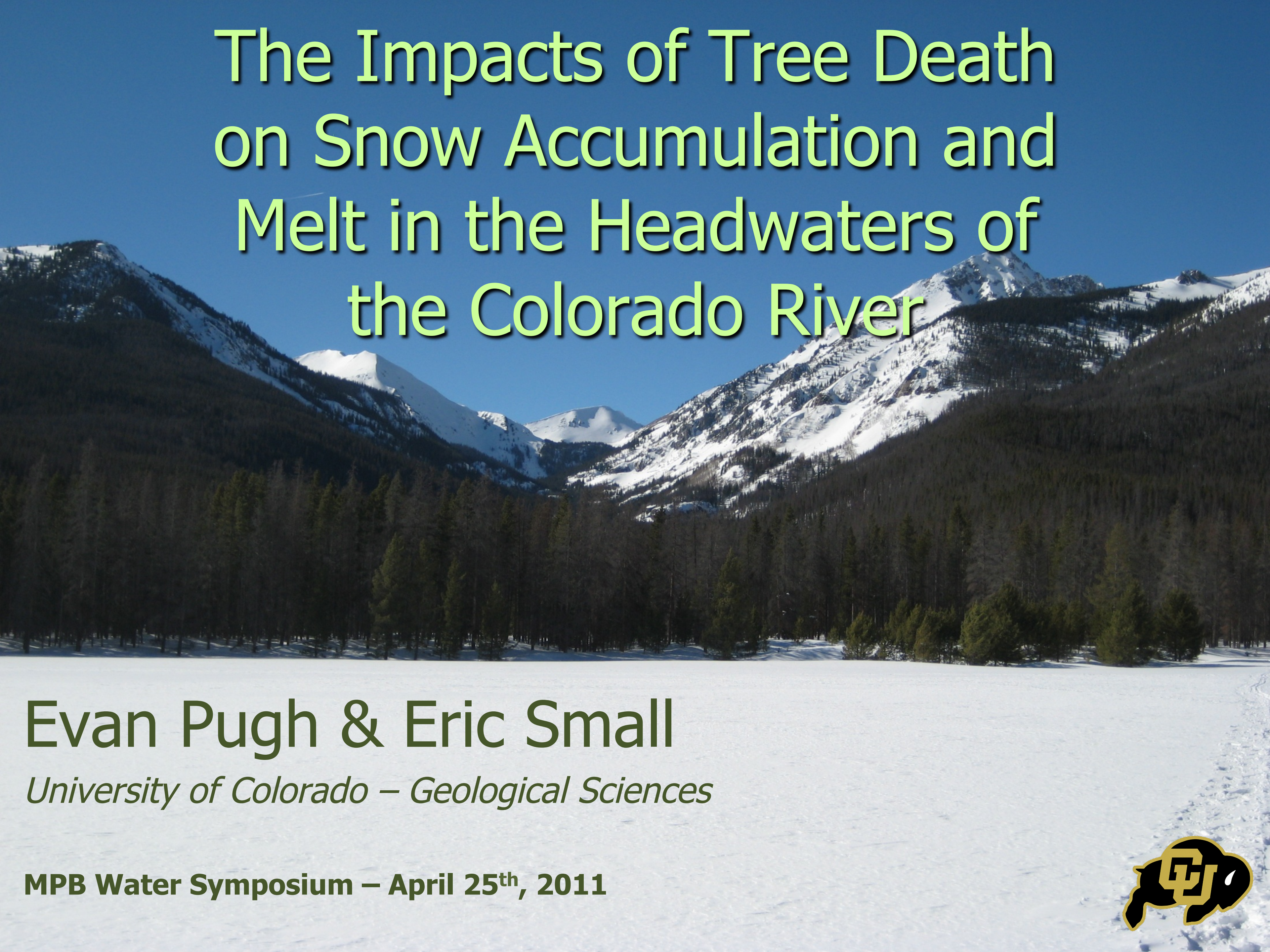

The Impacts of Tree Death on Snow Accumulation and Melt in the Headwaters of the Colorado River

Evan Pugh & Eric Small

University of Colorado – Geological Sciences

MPB Water Symposium – April 25th, 2011

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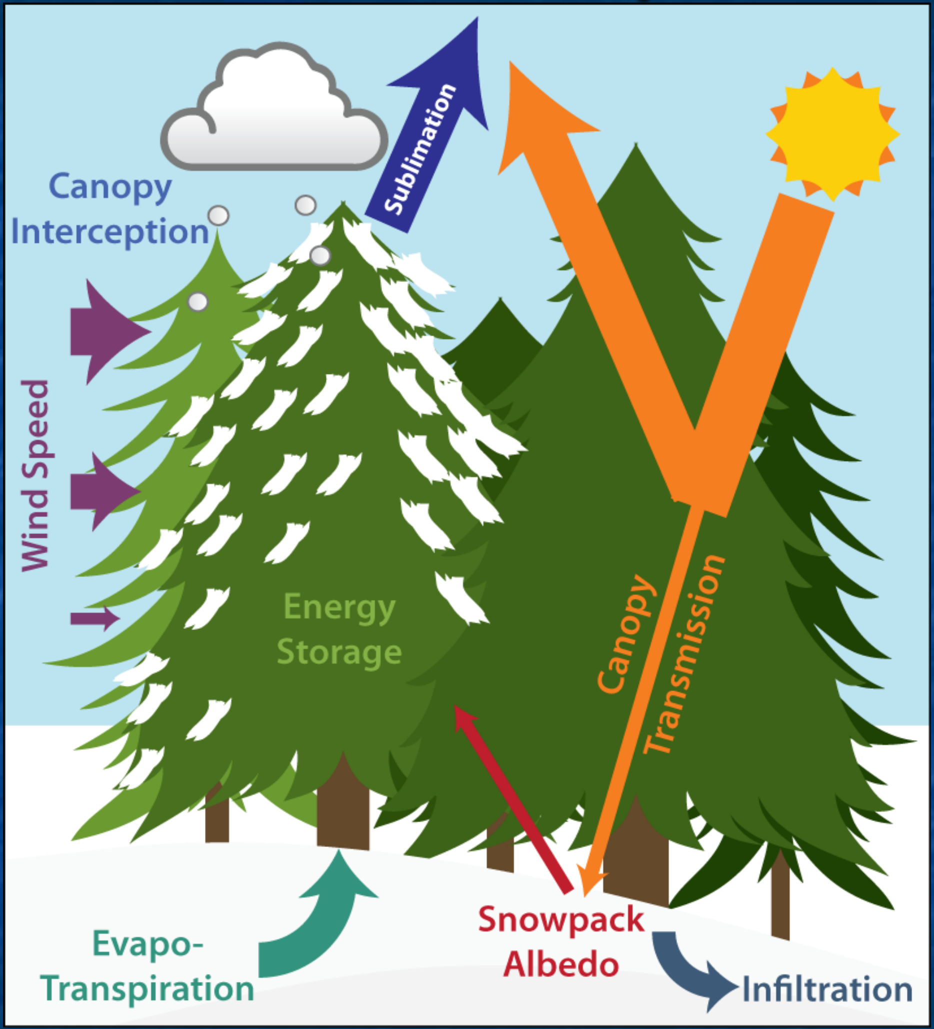
The Forest System



MORE THAN <u>40%</u> OF FORESTED WATERSHEDS IN COLORADO IMPACTED!

Image: Gordon ES and Pugh E. 2011. A conceptual model of water quantity impacts from insect-induced tree death in snow-dominated coniferous forests, *Hydrological Processes*, in prep.

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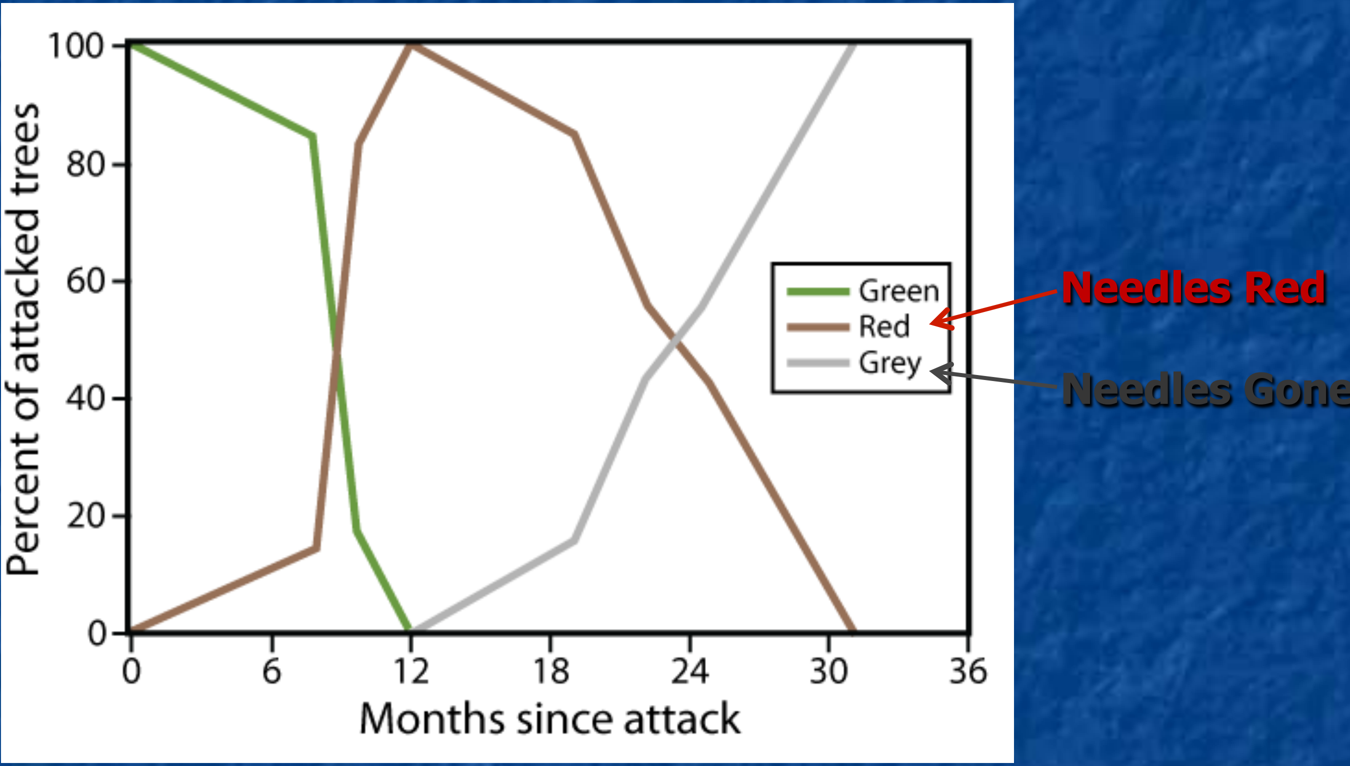
Stages of Tree Death



Adapted from Wulder et al., 2006

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Overall Effects: Experimental Design

Compare snow and meteorological properties beneath similar living and dead tree stands. Measurements are stand scale

Initially living vs. RED phase. Along headwaters of Colorado River

The 8 site pairs themselves range in slope, aspect, and elevation

Within site pairs:

- Location (<200m apart)
- Elevation (<15m apart)
- Slope (<10° difference)
- Aspect (<45° difference)
- Modeled radiation (<2% difference)

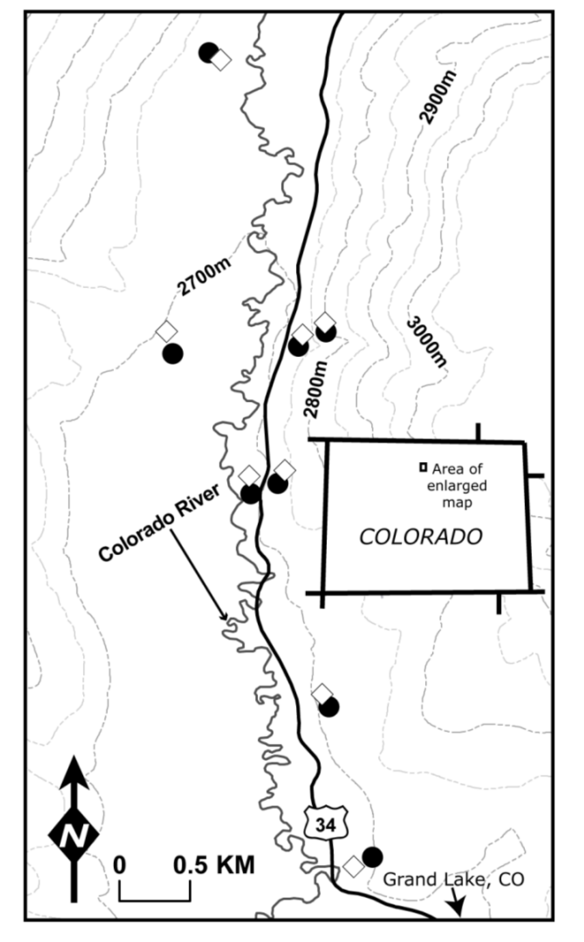

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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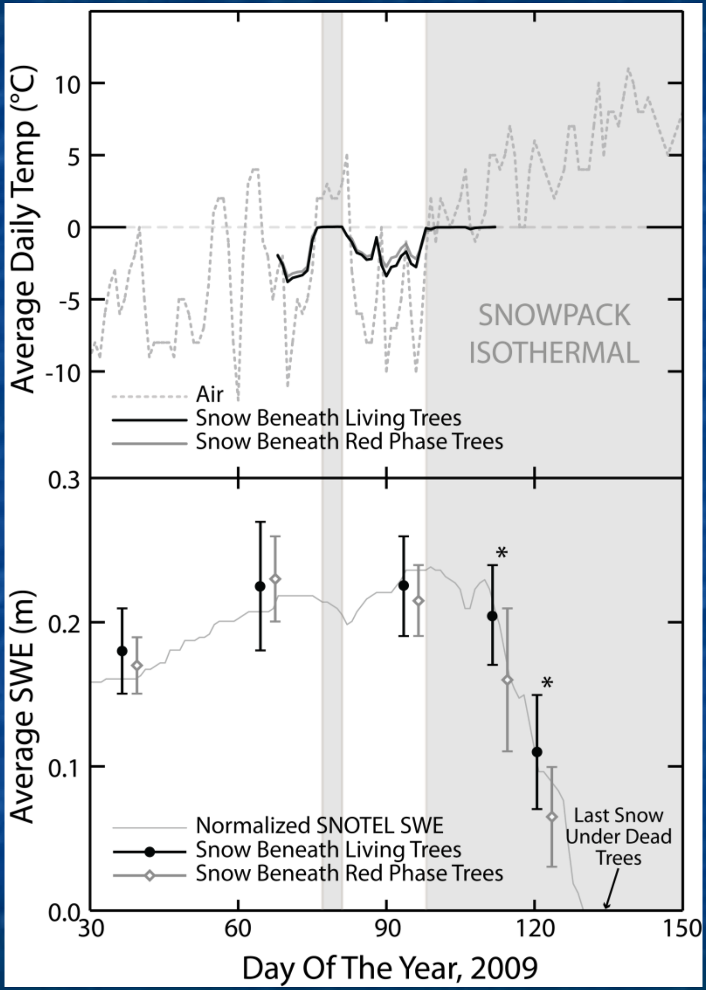
2009: Living vs. Red Phase



Similar accumulation under living and red phase dead
Red phase melted more quickly

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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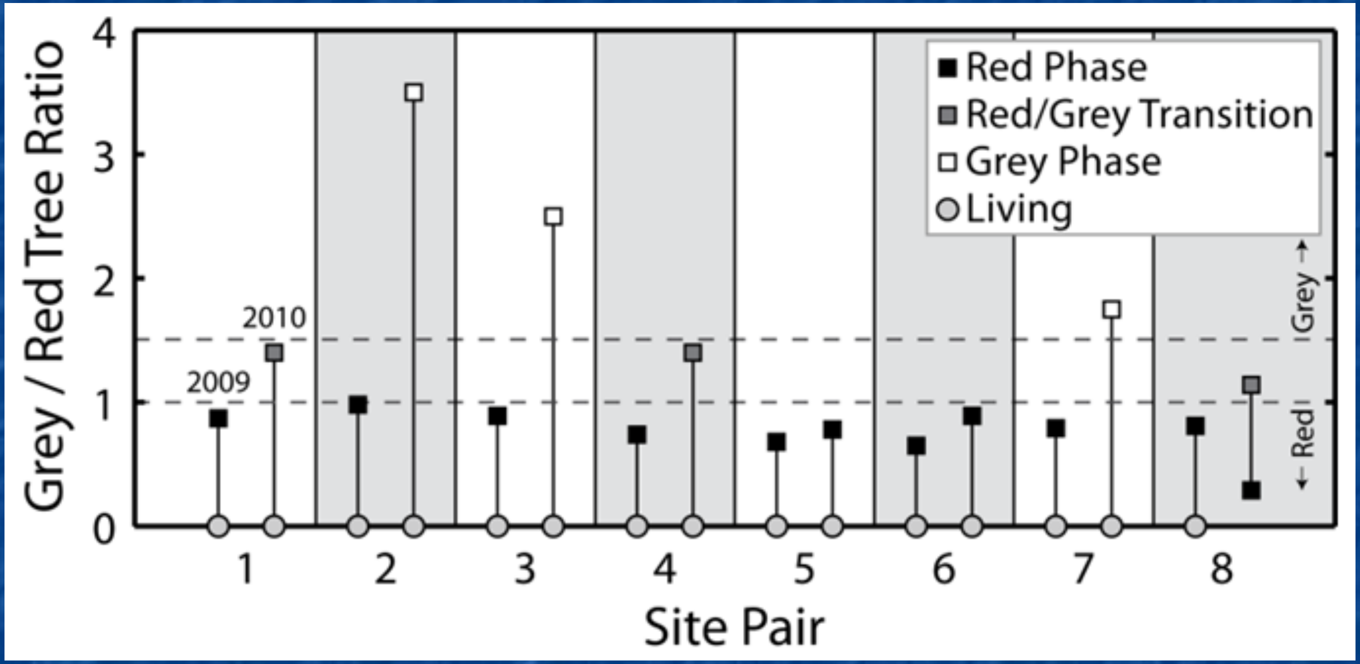
2009 - 2010: Nature Is Dynamic!



In year 2 of study, many red phase stands had progressed to grey phase

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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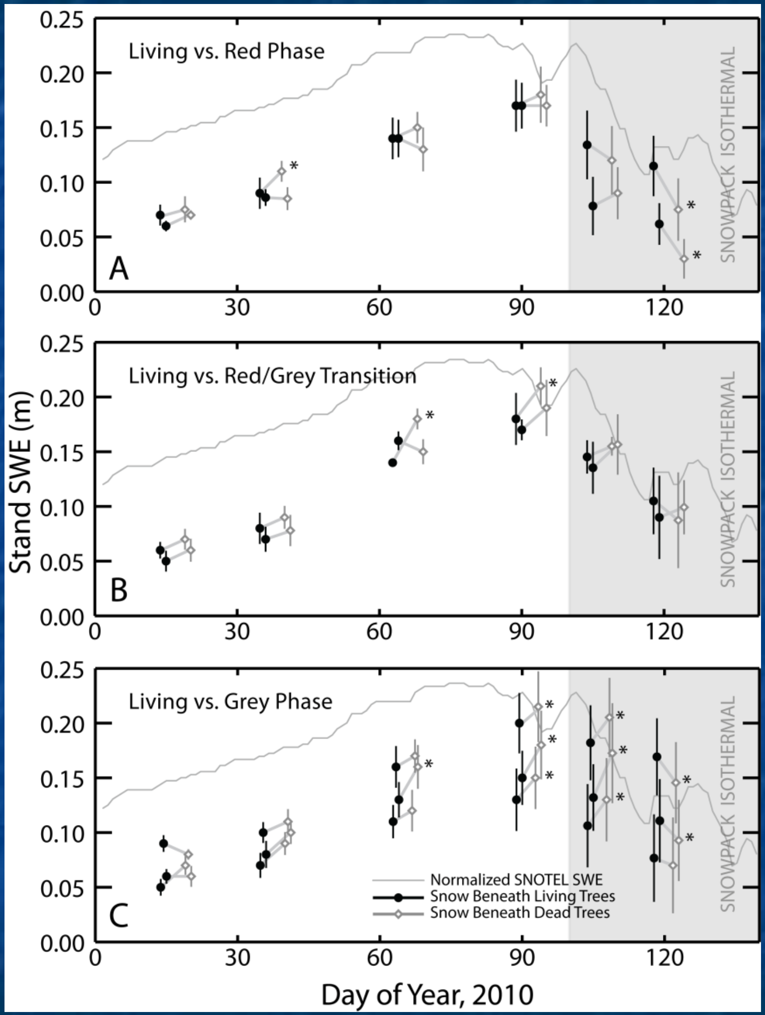
2010: Living vs. Grey Phase



Same trend in living vs. red, but sig. more accumulation under grey phase. Grey still melted more quickly.

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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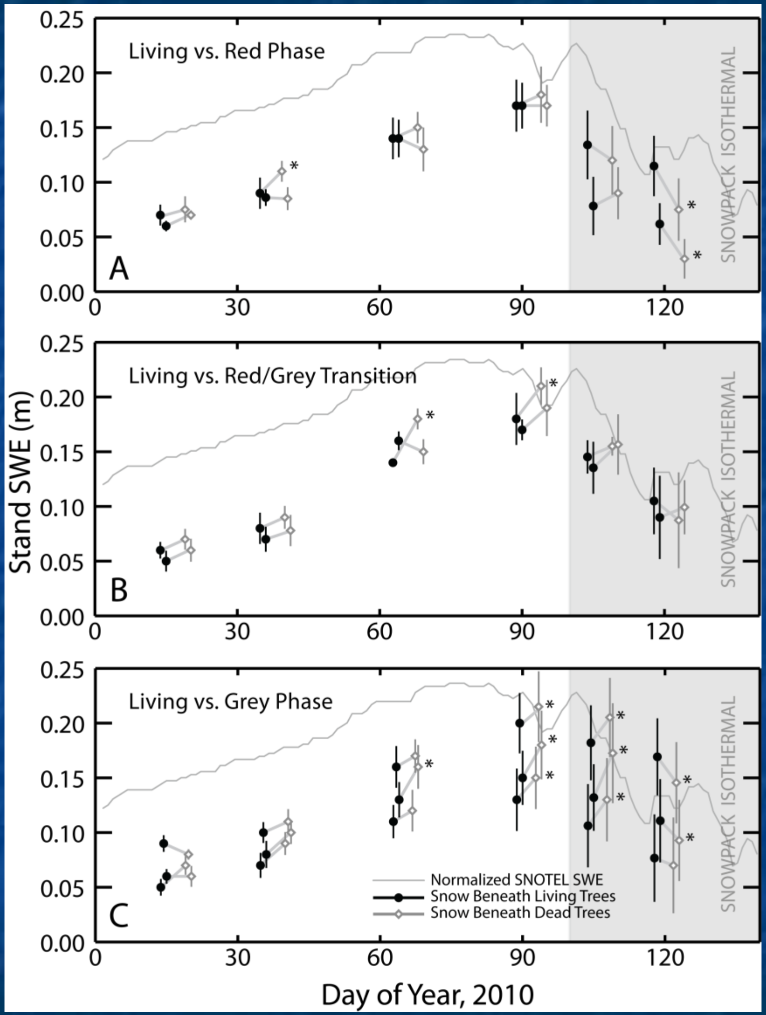
2010: Living vs. Grey Phase



Saw this trend in 2011 as well

Same trend in living vs. red, but sig. more accumulation under grey phase. Grey still melted more quickly.

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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Individual Processes

2010: Snow Surface Albedo

2009 - 2010: Canopy Solar Transmission

2011: Canopy Snow Interception/Sublimation

2011: Longwave Enhancement / Stand Energy Storage

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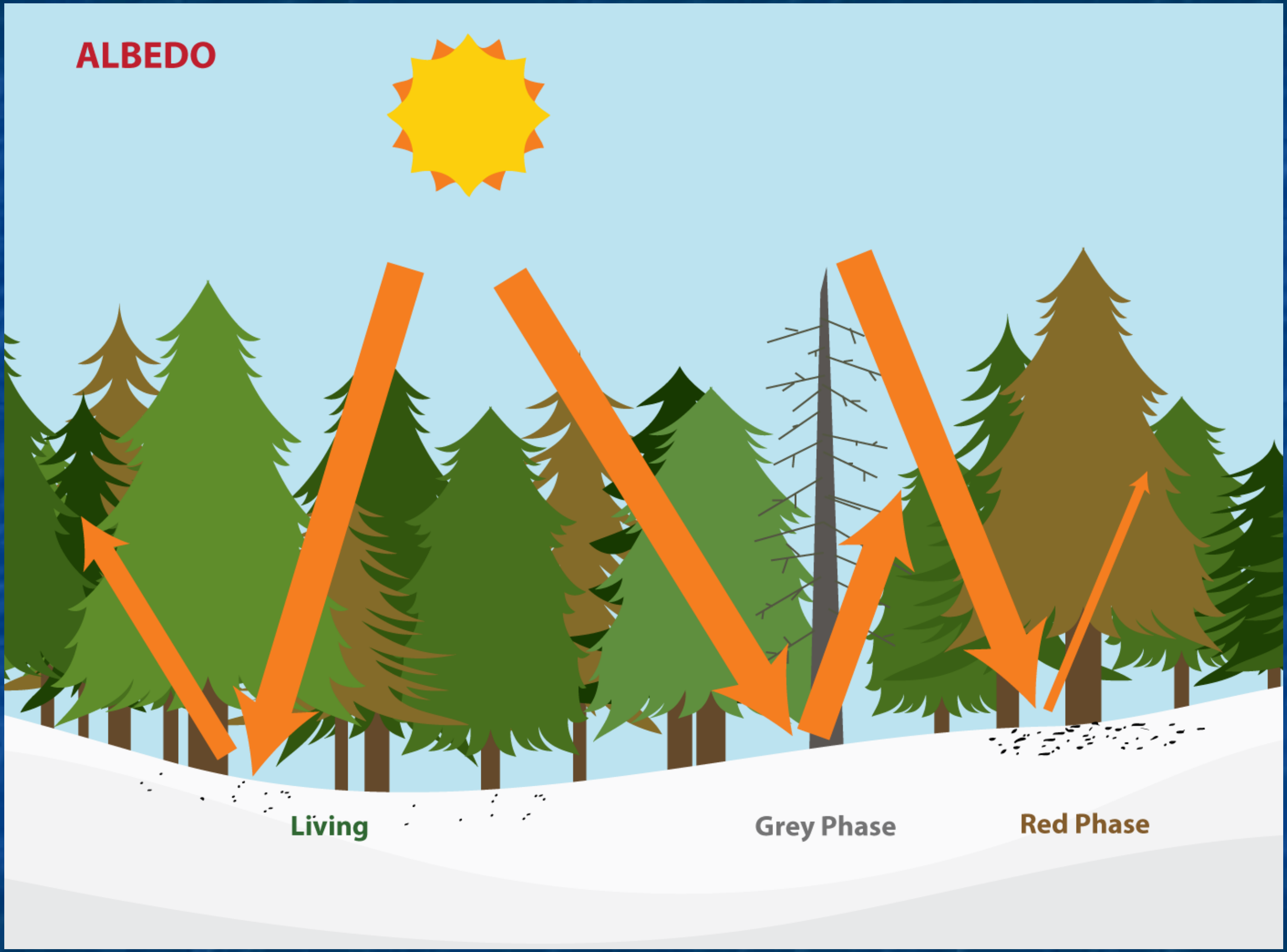
Snow Surface Albedo



Hypothesis: Lower albedo under red, higher under grey

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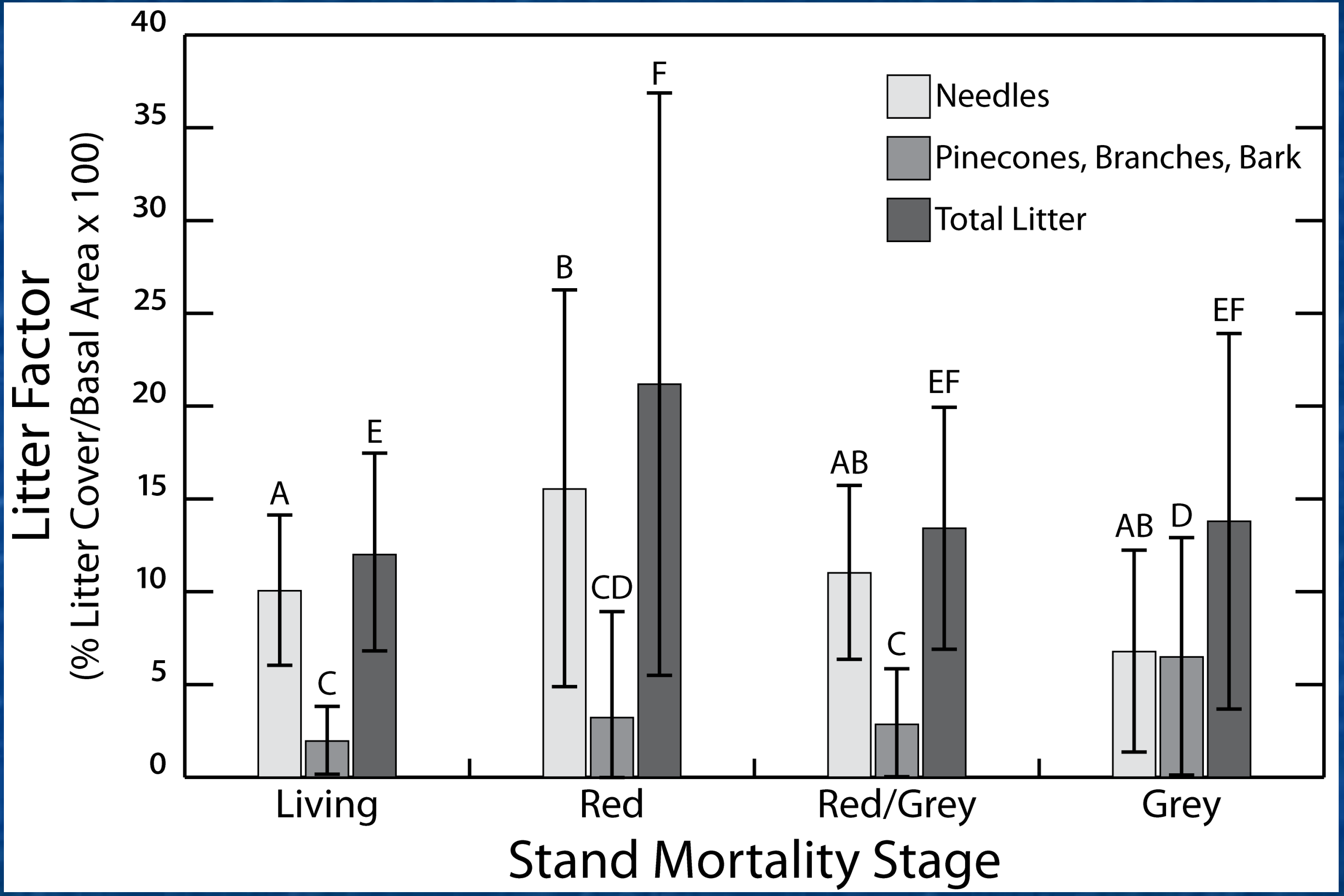
Snow Surface Albedo



Significantly more litter under red phase stands

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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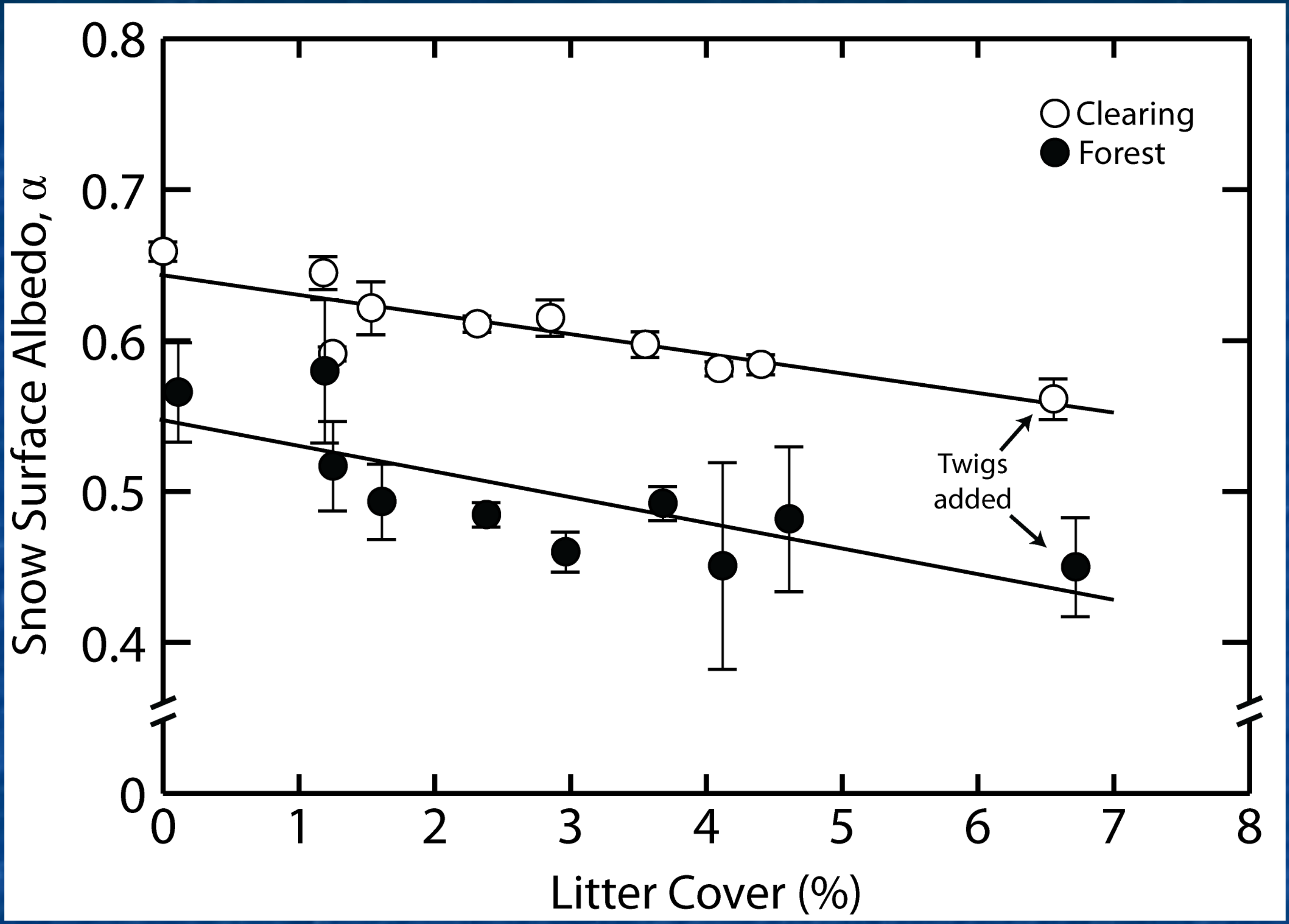
Snow Surface Albedo



- **Clearing (slope = -0.013x, R^2 = 0.75, n = 288)**
- **Forest (slope = -0.018x, R^2 = 0.61, n = 321)**

Strongly significant linear relationship

Image: Pugh E and Small EE. 2011. The impact of pine beetle infestation on snow accumulation and melt in the headwaters of the Colorado River. *Ecohydrology,* in review.

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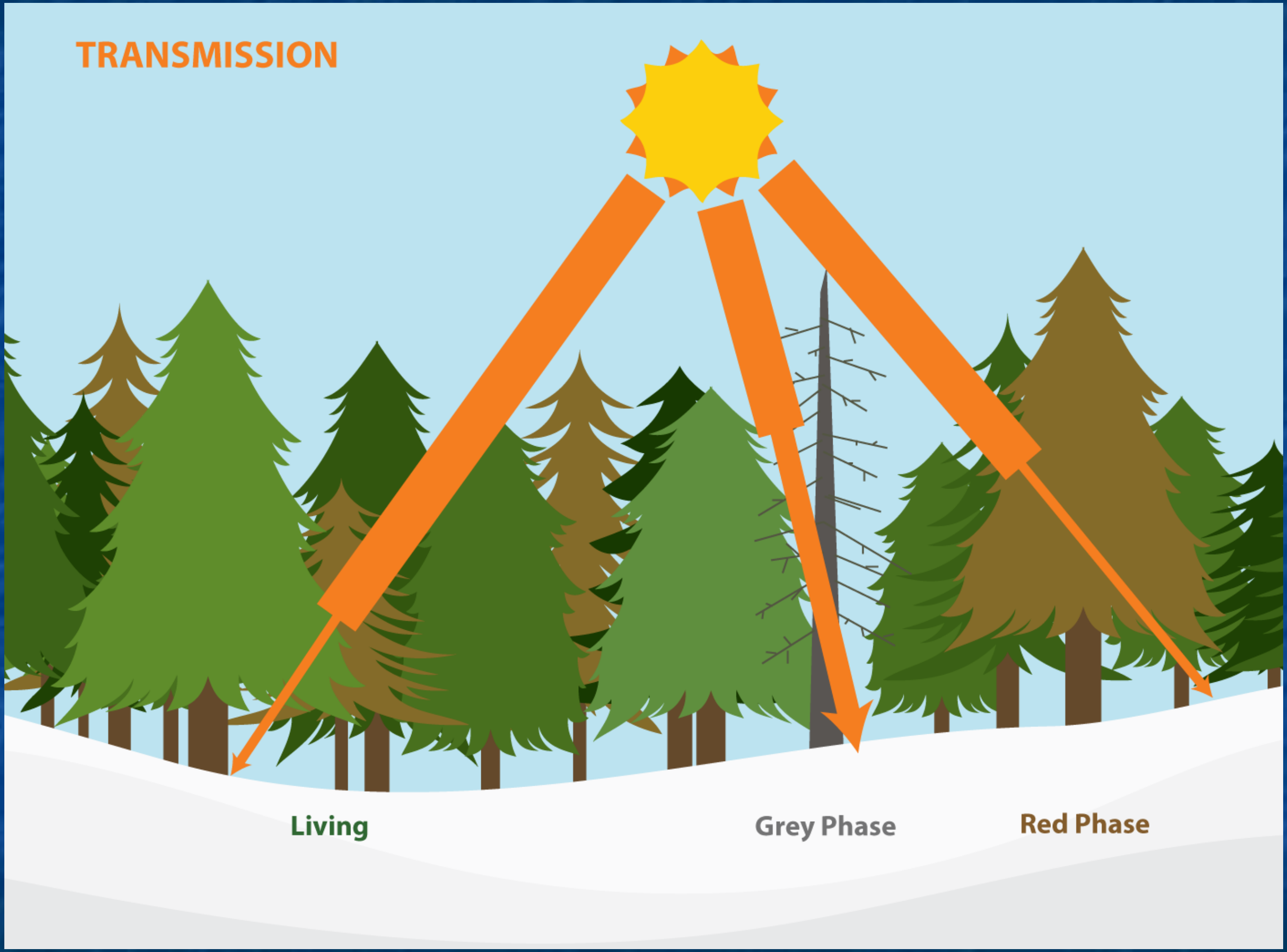
Canopy Solar Transmission



Hypothesis: Lower albedo under red, higher under grey

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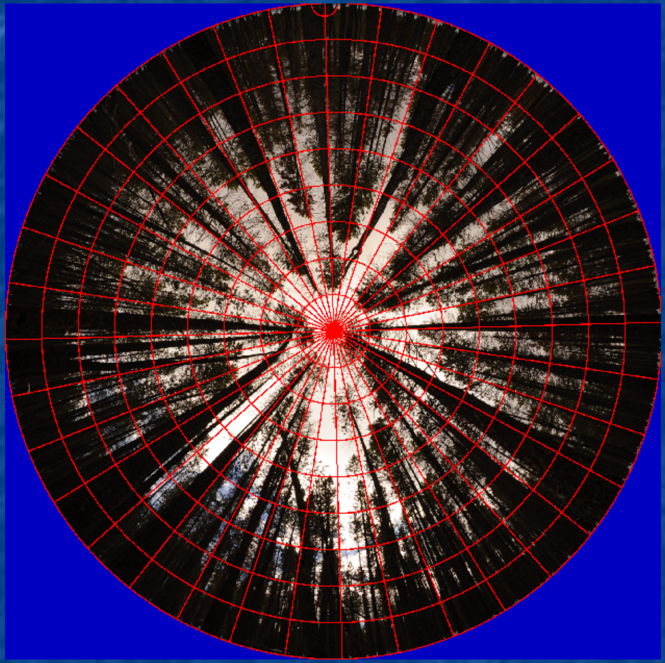
Canopy Solar Transmission



Measured with paired pyranometers and modeled with hemispherical photography

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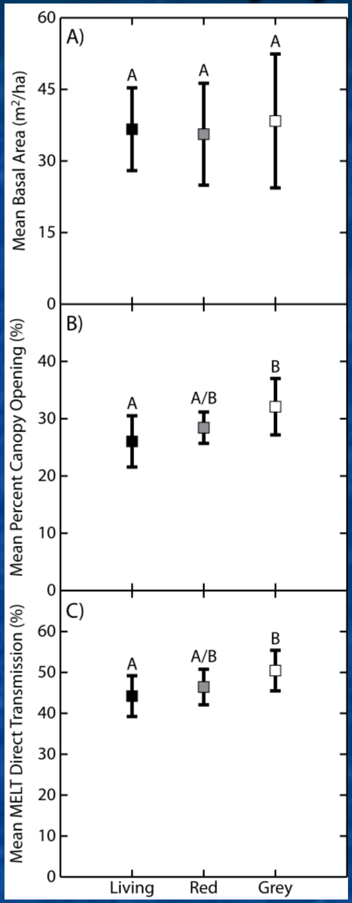
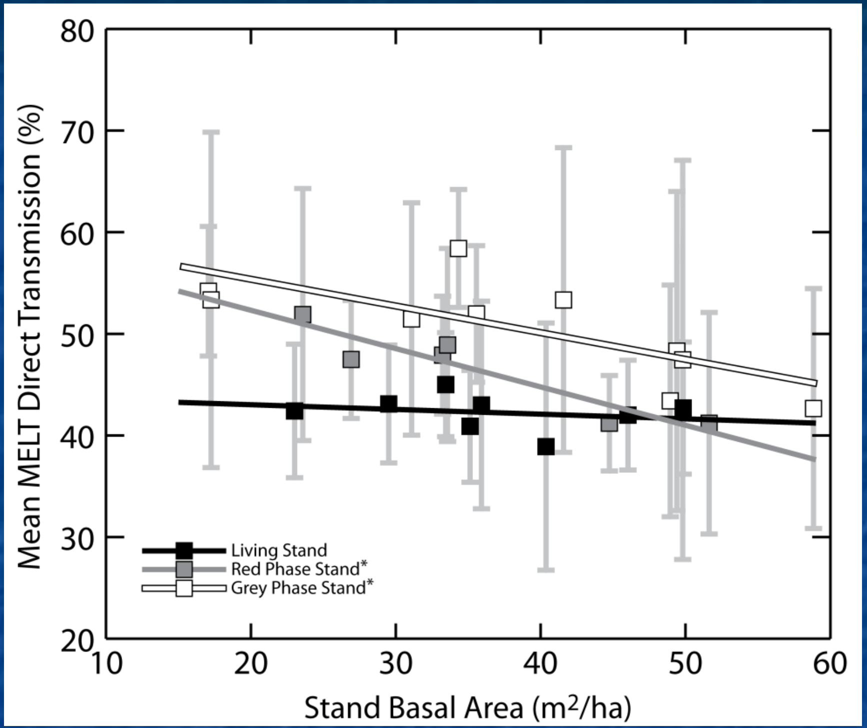
Canopy Solar Transmission





Mortality	Living	Red	Grey
Living	–	**1.7**±2.1	**6.6**±1.9
Red	**-1.7**±2.1	–	**4.9**±2.0
Grey	**-6.6**±1.9	**-4.9**±2.0	–

Using ANCOVA analysis: For a given basal area, there is more canopy transmissivity in red and grey phase stands

Image: Pugh E and Small EE. 2011. Increased light transmission through lodgepole pine canopies impacted by the mountain pine beetle. *Agricultural and Forest Meteorology,* in prep.

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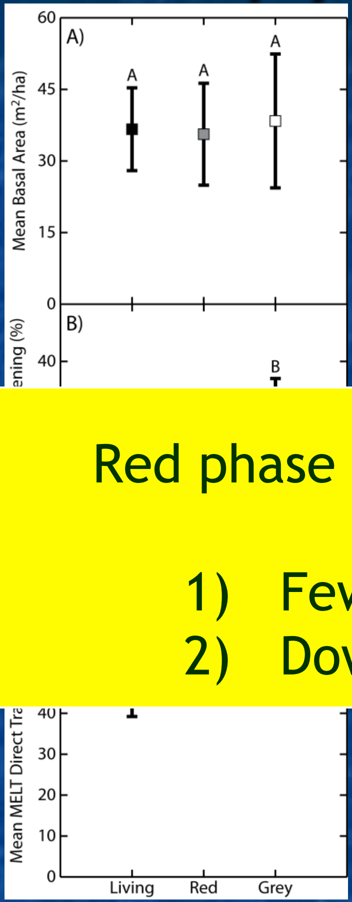
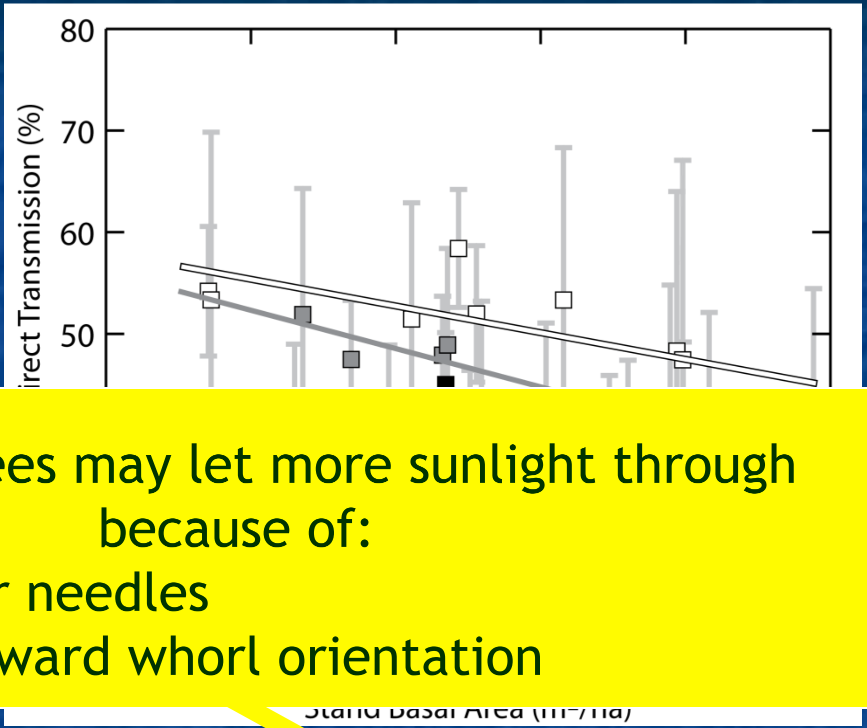
Canopy Solar Transmission





Red phase trees may let more sunlight through because of:

1) Fewer needles
2) Downward whorl orientation

Mortality	Living	Red	Grey
Living	–	**1.7**±2.1	**6.6**±1.9
Red	**-1.7**±2.1	–	**4.9**±2.0
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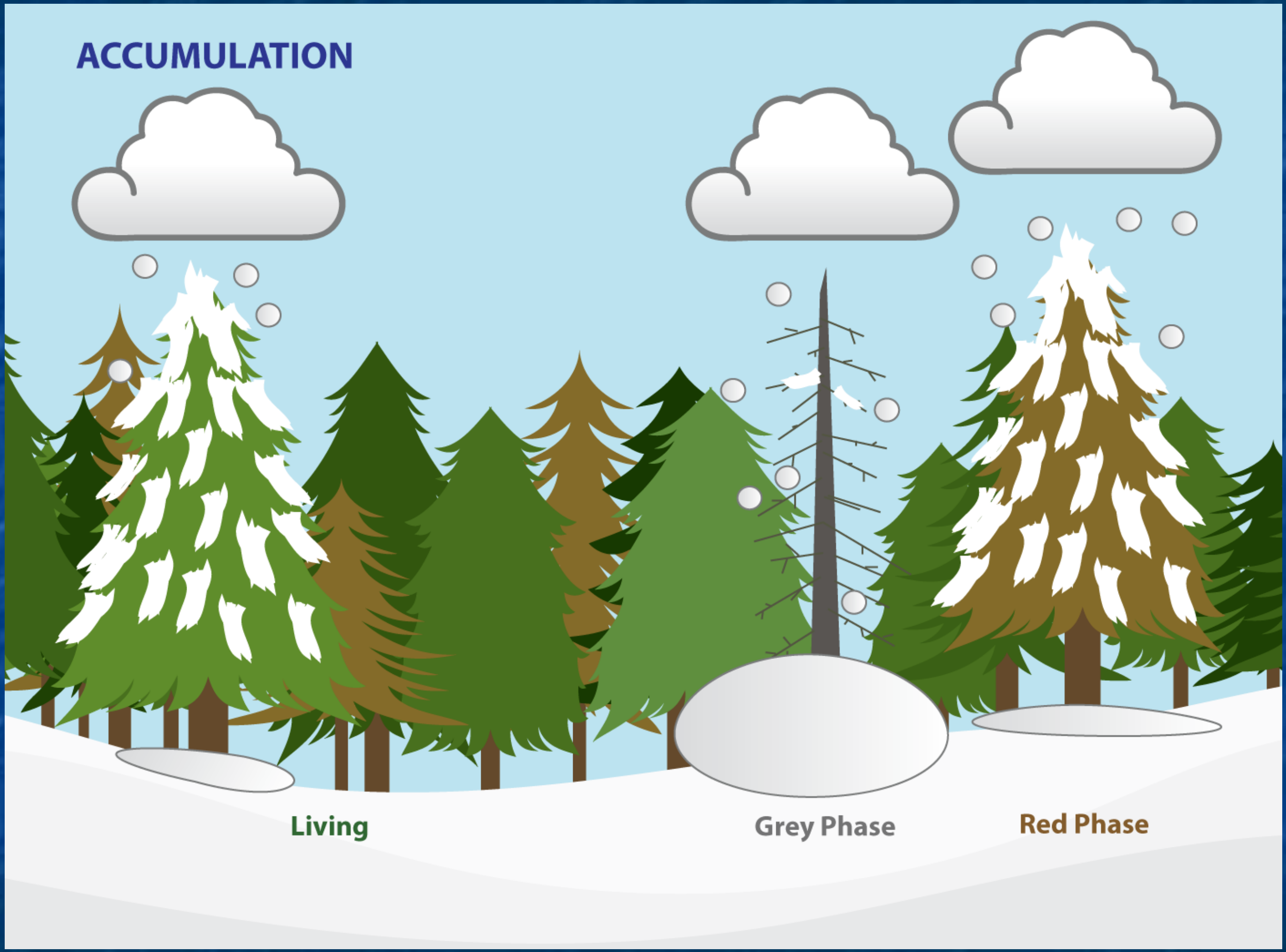
Canopy Snow Interception



Hypothesis: Similar accumulation under red, more under grey

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Canopy Snow Interception

Measured before and after storms in 3 clearings, 3 living stands, and 2 grey phase stands. All close (~150 m radius)

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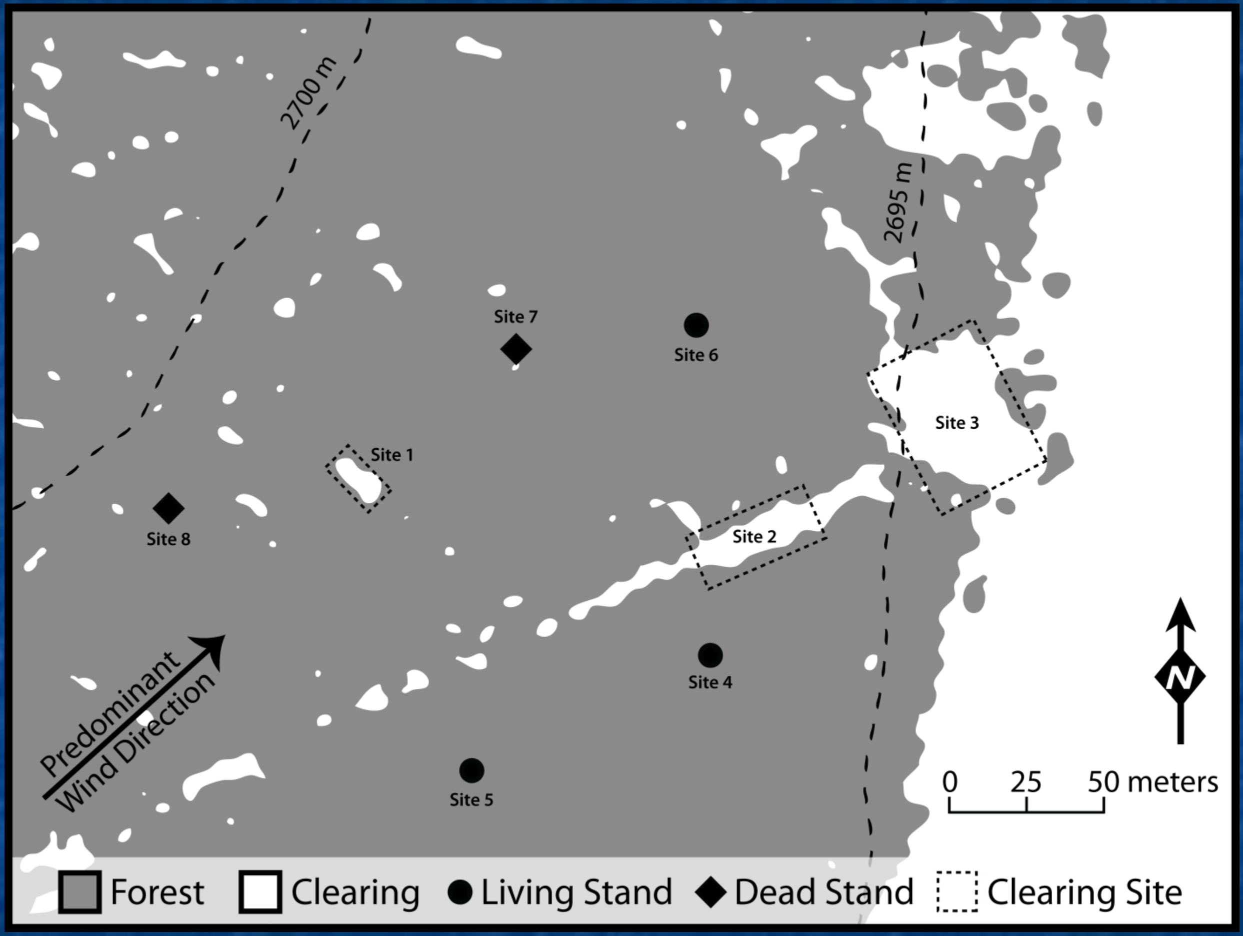

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Image: Pugh E and Small EE. 2011. The impact of conifer death on stand-scale canopy snow interception, in prep.

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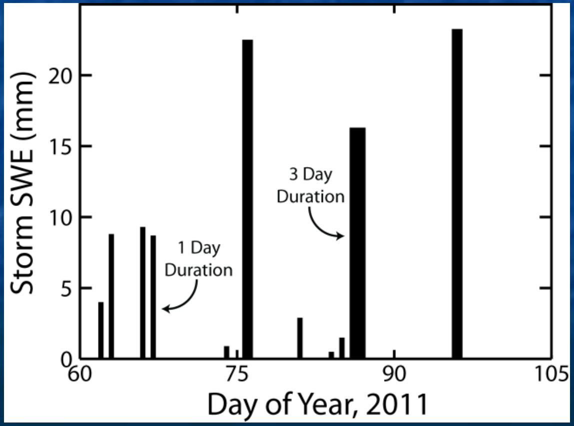
Canopy Snow Interception

Method confounded by:
- Snowmelt
- Above-freezing nighttime temps
- Rain-On-Snow events

Measured 24 storms, but only used 11 in analysis



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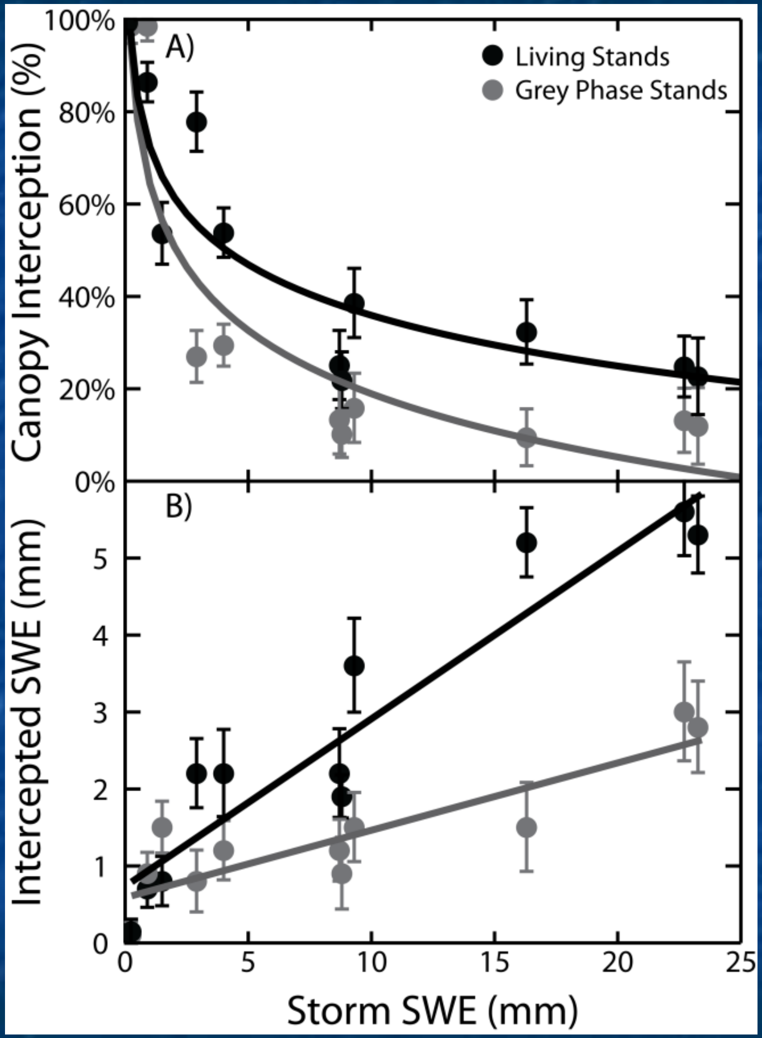

Significantly more snow was intercepted in living stands.
Covaries linearly with storm size.

Image: Pugh E and Small EE. 2011. The impact of conifer death on stand-scale canopy snow interception, in prep.

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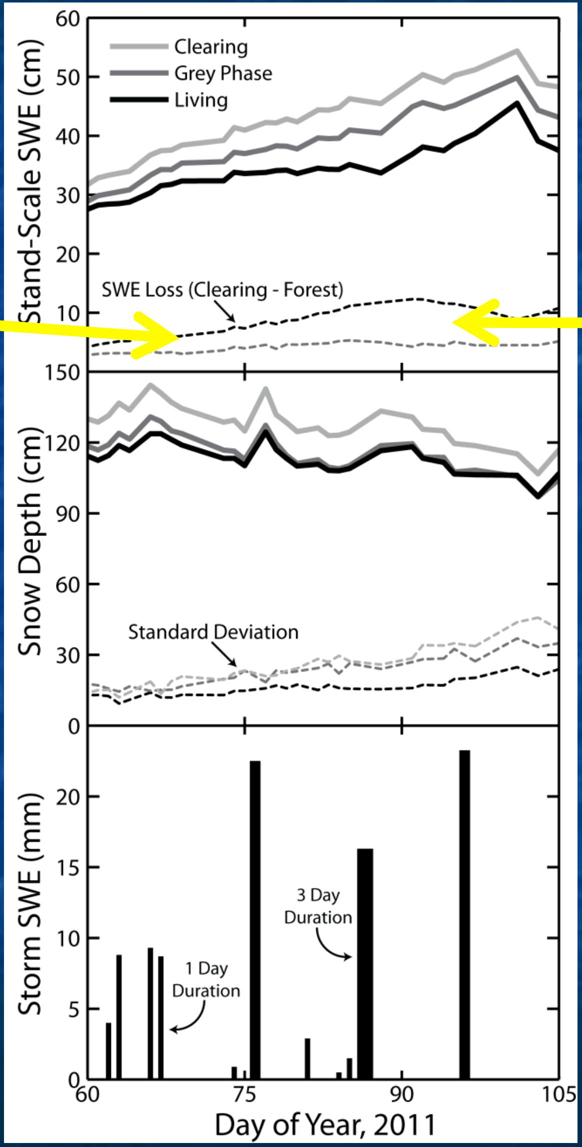
Canopy Snow Interception

Accumulation:

Living: ~70 mm SWE LOSS

Dead: ~30 mm SWE LOSS

Using the "SWE LOSS" method of Storck et al., 2002



Melt:

Living: ~100 mm SWE LOSS

Dead: ~50 mm SWE LOSS

Roughly 2x as much SWE LOSS in living stands

Image: Pugh E and Small EE. 2011. The impact of conifer death on stand-scale canopy snow interception, in prep.

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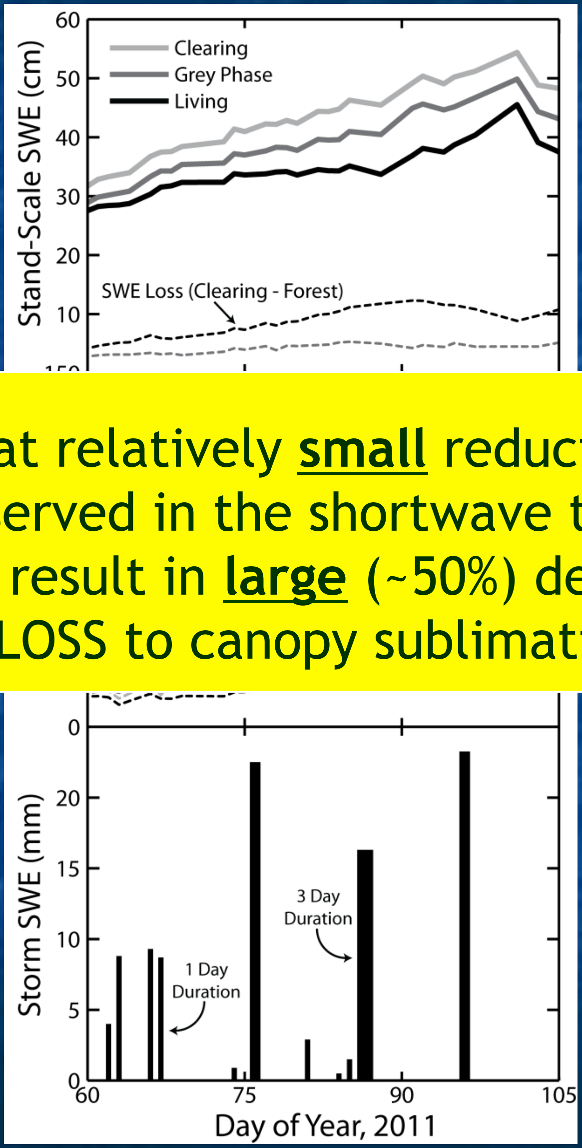

It seems that relatively **small** reductions in canopy gaps observed in the shortwave transmission experiment result in **large** (~50%) decreases in SWE LOSS to canopy sublimation.

Image: Pugh E and Small EE. 2011. The impact of conifer death on stand-scale canopy snow interception, in prep.

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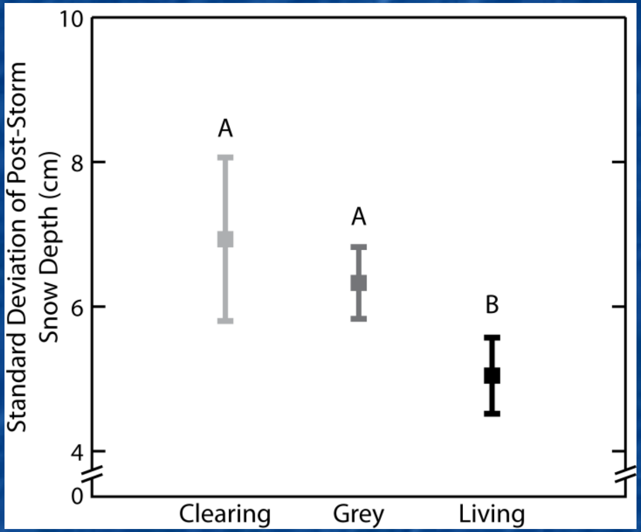
Also of note…



Post-storm snow depth standard deviation in grey phase stands more closely mirrored clearings than living stands ($p<0.001$; Tukey-Kramer HSD).

Image: Pugh E and Small EE. 2011. The impact of conifer death on stand-scale canopy snow interception, in prep.

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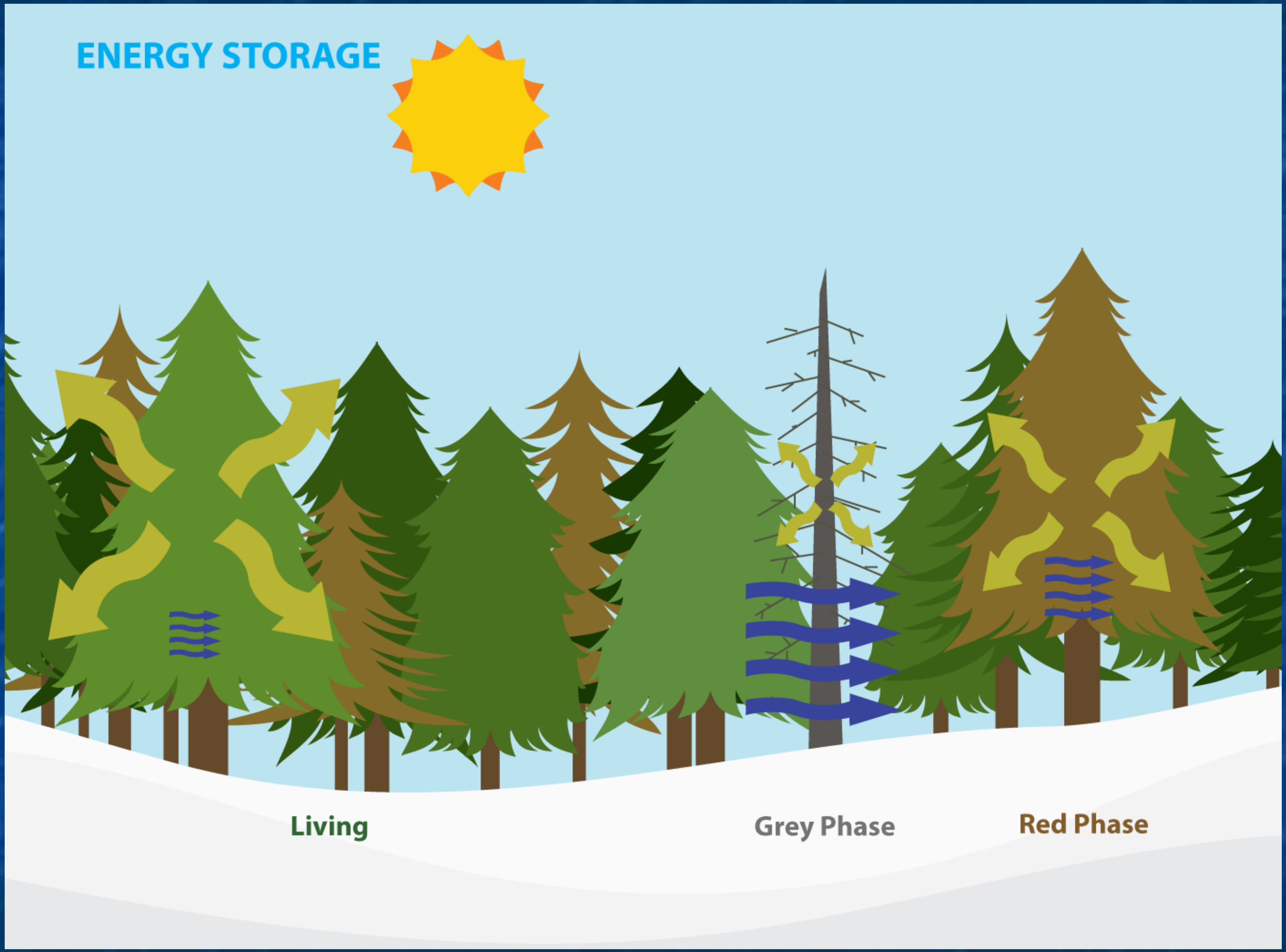
Stand Energy Storage



Hypothesis: Faster wind speeds and less energy storage in tree stem water will cause dead stand temperatures and humidity to more closely mirror clearings

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Stand Energy Storage

5 poles in 5 stands (2 dead, 3 living)
Measure in situ from ***March 1 – April 15***




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Stand Energy Storage

Experimental Design

- Directly north of tree 1 meter away = solar shielding
- iButtons on north side of pole = solar shielding
- Sensor every 25 cm: some under snow, some in air
- Pole of low density balsam wood coated in glossy waterproofing spray
- All sensors calibrated against CS500 for two weeks prior to deployment
- Same sites as interception experiment

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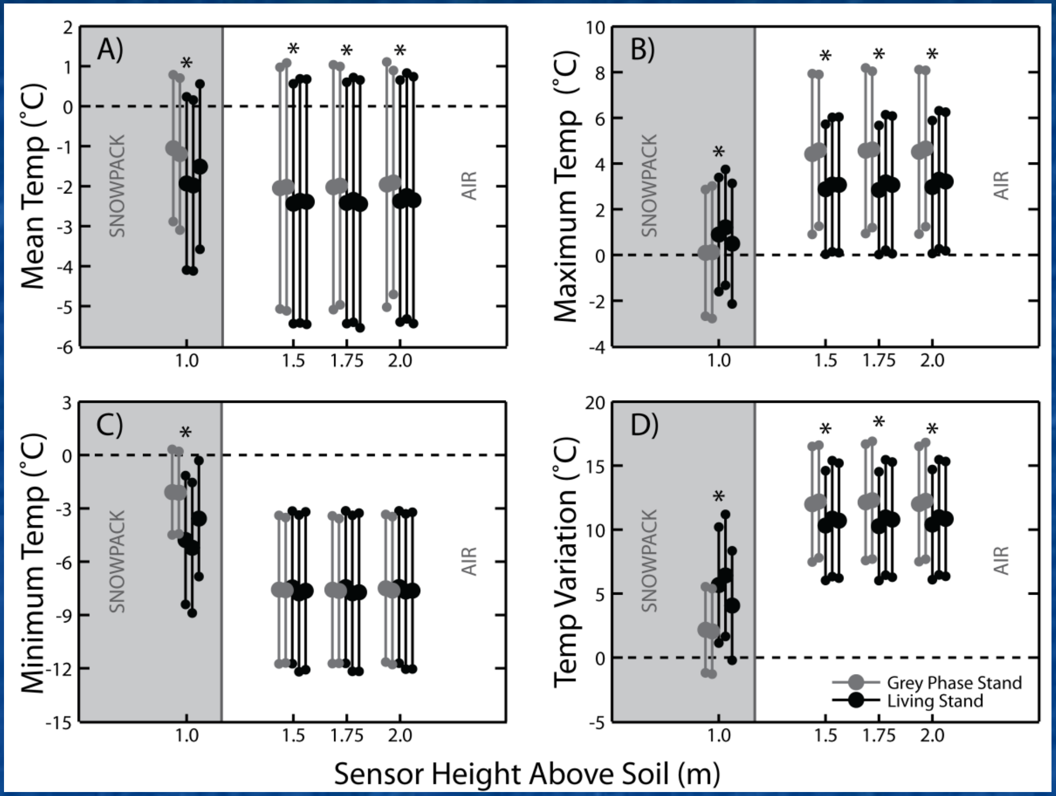

Lots of paired t-tests

AIR: Dead stands more variable, variation comes from maximum temps not minimum

SNOW: Dead less variable than living, warmer ← *Denser*

Image: Pugh E and Small EE. 2011. More variability in subcanopy temperatures following beetle-induced tree death, in prep.

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Stand Energy Storage

Compared temp mean/max/min/variation against mean wind and max wind daily percentiles.

AIR: In all stands: mean wind sig. correlated with min temp
In live stands only: variation correlated with mean wind
However, correlations only explain 10 – 15% of temperature trends

SNOW: Wind not correlated with temperatures

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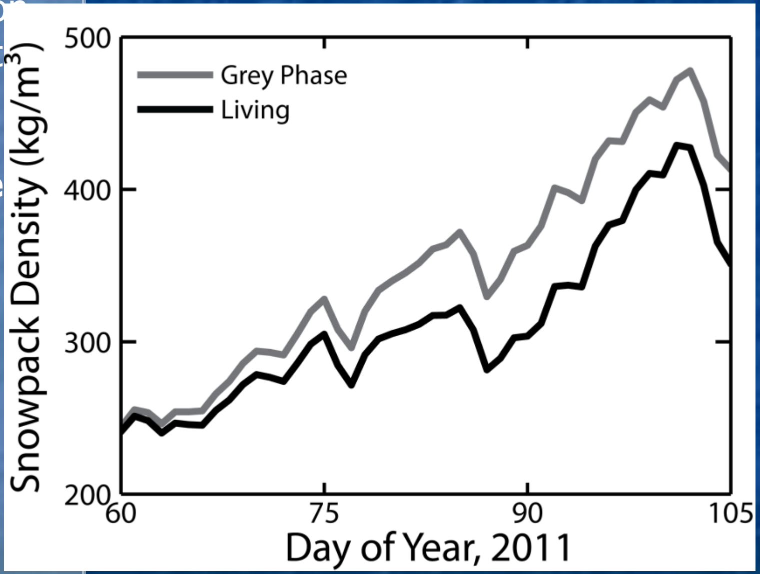
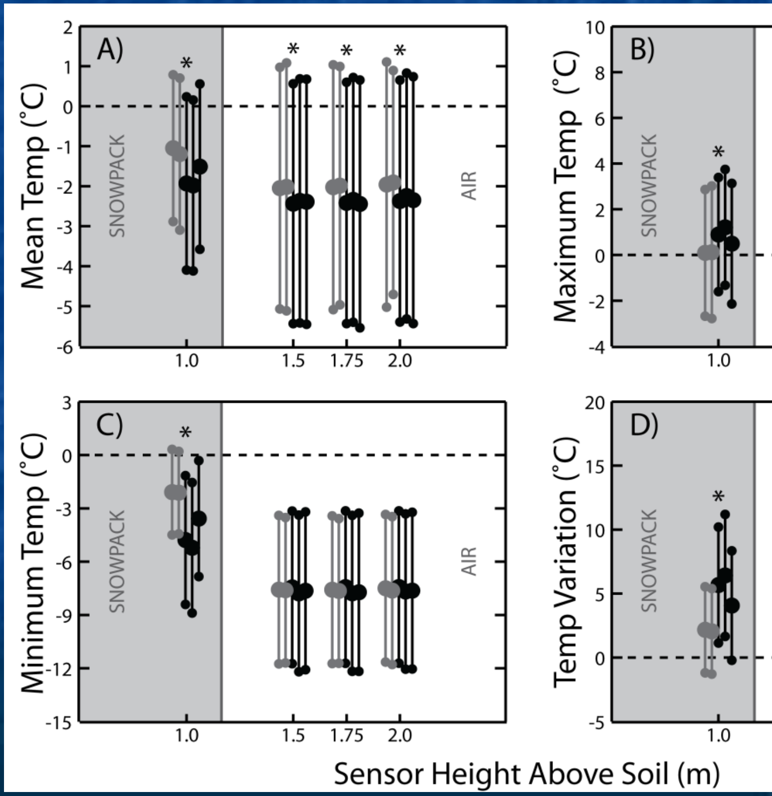
Stand Energy Storage

So what likely controlled subcanopy temperature variation?
Energy storage in water

Example in snow:





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Stand Energy Storage

Important to consider both longwave and shortwave in models of dead stand snowpack energy balance.

A tree canopy that lets more shortwave ***IN*** will also let more longwave ***OUT***

Also need to consider stand air mixing / turbulence

Requires a computational model

Concept Model: Red Phase

- **Snow melts out more quickly under red phase forests (as much as 1 week earlier)**
- **Red phase forests have lower snow surface albedo because of tree litter/debris**
- **Lower albedo doesn't account for all of the earlier melt, but plays a large part**
- **Red phase stands transmit slightly more light than living stands, but less than grey phase stands**
- **Low albedo snow + increased transmission may create more melt energy than grey phase stands**

Concept Model: Grey Phase

- Grey phase stands intercept less snow, leading to additional subcanopy accumulation
- However, additional subcanopy accumulation doesn’t seem to be larger than interannual variation
- Grey phase forests transmit more solar radiation to the forest floor than either living or red phase
- Grey phase dead forests have higher snow surface albedo because of removal of tree litter input
- Grey phase dead stands may or may not melt more quickly than living stands – depends on snow year

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Future Research

Future research includes *parameterizing* a snow accumulation and melt model with these albedo, interception, sublimation, transmission, and subcanopy temperature data.

Model Goals

By varying forest cover density to levels associated with tree death, accurately predict snow accumulation, SWE loss, and melt timing.

OUTLINE

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→ Forest System
→ Stages of Death

Overall Effects
→ 2009: L vs. R
→ 2010: L vs. G

Processes
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Conceptual Model
→ Red Phase
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Conclusions

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