Impacts of Compound Bark Beetle-Forest Fire Disturbance on the Water Budget of a Subalpine Rocky Mountain Forest Ecosystem

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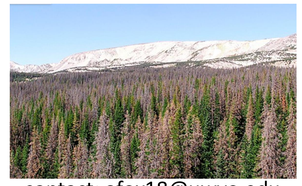
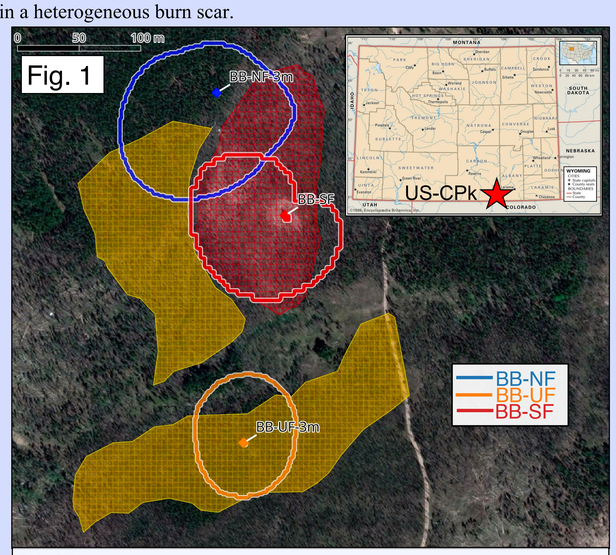


Introduction

- The twin disturbances of bark beetle epidemics and fire have shaped Rocky Mountain ecosystems in recent years, impacting forest carbon and water cycles in this region.
- Between 2007 and 2013 the mountain pine and spruce beetles experienced a major population boom resulting in widespread tree mortality and disruption of the water and carbon cycles.
- Rocky Mountain forests have been experiencing more severe and frequent fires than at any point in the past 2,000 years.
- In 2018, the US-CPk Ameriflux study site in Southeast Wyoming burned after experiencing a mountain pine beetle outbreak.
- We analyzed soil water budget for this site to study the recovery dynamics associated with the collision of these two disturbances.

Site

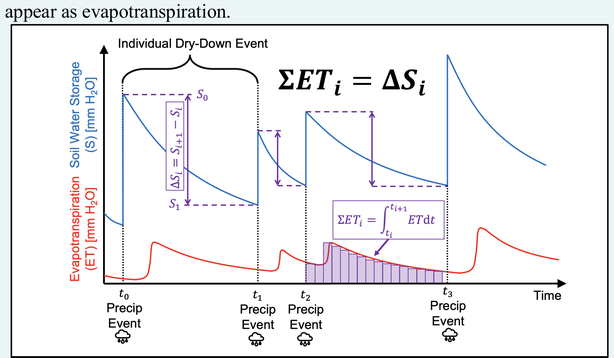
The US-CPk Ameriflux sits in subalpine lodgepole pine forest in SE Wyoming in the Snowy Range (100mi NW of Denver, CO) at 2745m ASL. The site experienced a mountain pine beetle outbreak from 2008-2012 that resulted in 70% tree mortality, followed by a forest fire in 2018 that resulted in a heterogeneous burn scar.



US-CPk site map.
Outlines indicate 90% tower footprints for all three fire treatments. Shaded regions indicate burn scars, with orange indicating understory (BB-UF) burn, and red indicating stand-replacing (BB-SF) burn. Beetlekill covers the entire map.

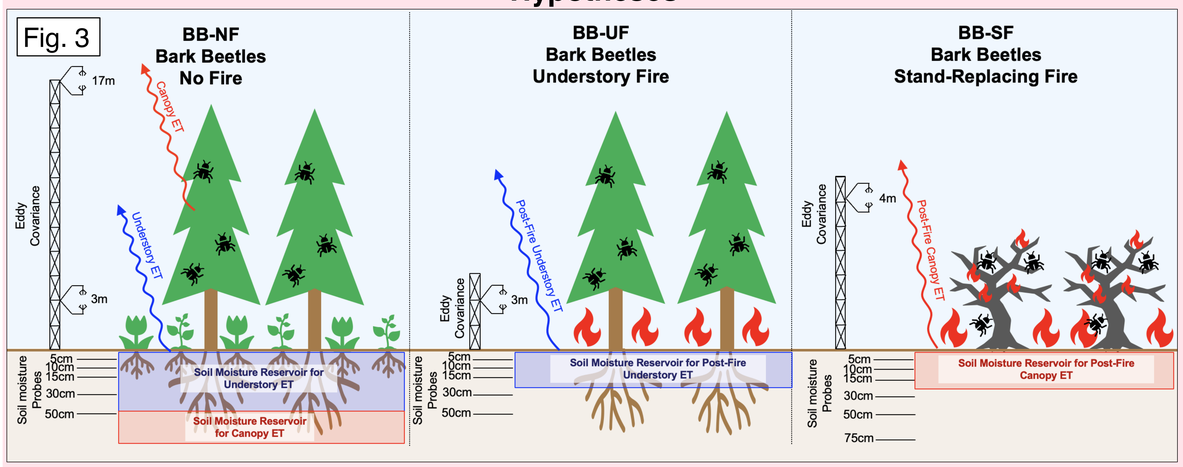
The Soil Water Budget

We used a soil – evapotranspiration water budget to link ecosystem evapotranspiration (ET) to changes in soil moisture storage (S) at different depths. When the soil dries down after precipitation events, we can expect it to appear as evapotranspiration.



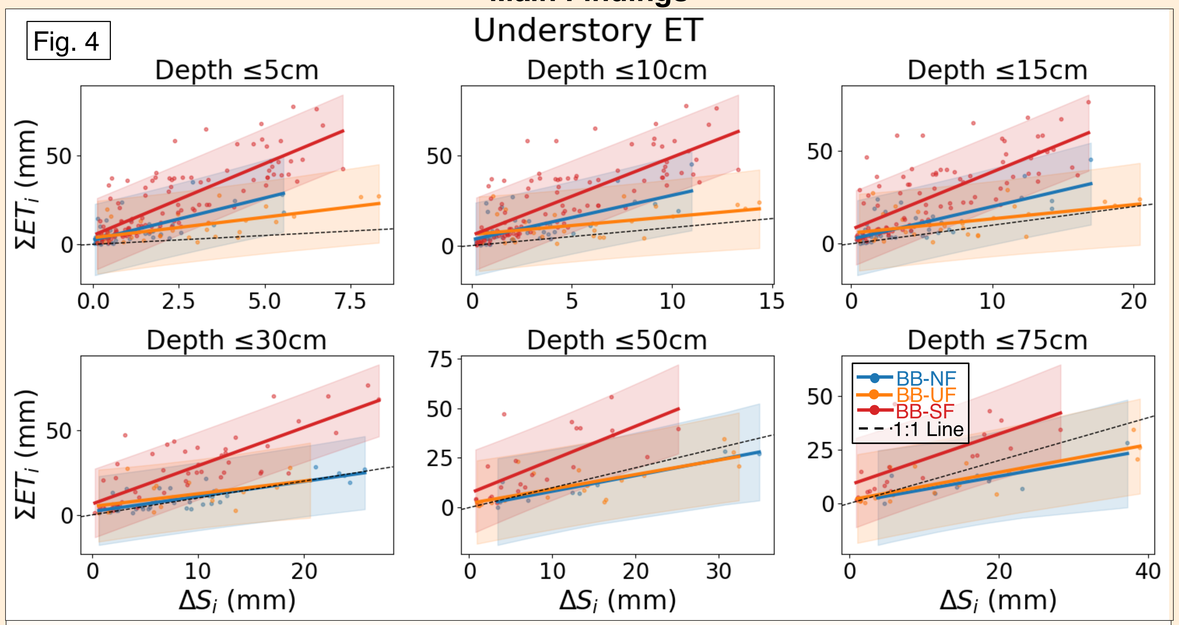
Conceptual diagram showing how the soil – ET water budget was computed

Hypotheses



- Recovering understory in a low-severity burned beetle-killed forest (center, BB-UF) will source water from shallower soil moisture reserves than the understory in an unburned beetle-killed forest (left, BB-NF).
- Evapotranspiration from recovering saplings in a severely-burned beetle-killed forest (right, BB-UF) will source water from shallow soil moisture reserves similarly to the recovering understory of a low-severity-burned beetle-killed forest (center, BB-UF) as saplings begin to reestablish. Deep soil moisture reserves will not be crucial for recovery.

Main Findings



Results of the water budget method from figure 2 applied to test the hypotheses from figure 3. Slopes >1 indicate ET exceeding soil moisture storage change, and slopes <1 indicate soil moisture storage change exceeding ET.

- Understory ET in BB-UF was more closely related to shallow soil moisture dynamics than understory ET was in BB-NF.
- ET in BB-SF was less closely related to shallow soil moisture dynamics than the understories in both other treatments . However, this may be due observational bias: springtime snowmelt may saturate the very top layers of soil (<5cm deep) and cause water ponding above where soil moisture probes are installed, resulting in undetected ET from those unobserved layers.

Conclusions

- BB-UF treatment is more reliant on shallower soil moisture due to understory development while BB-NF has trees that have survived two mortality events and thus use deeper soil moisture Recovery from understory fire is heavily reliant on shallow soil moisture in this region after bark beetles.
- Understory regeneration post-understory-fire may be bolstered by a thinned canopy following beetle-kill, resulting in more light penetration and higher throughfall, but further analysis is needed.
- Deeper soil moisture may be more important than expected for recovery in BB-SF
- Fire recovery in BB-SF seems to be very inefficient at moving water out of the ecosystem through evapotranspiration, despite being receiving full exposure to heat and sunlight.

Additional Results

Fig. 5 — Slope of the $\Sigma ET \sim \Delta S$ Relationship

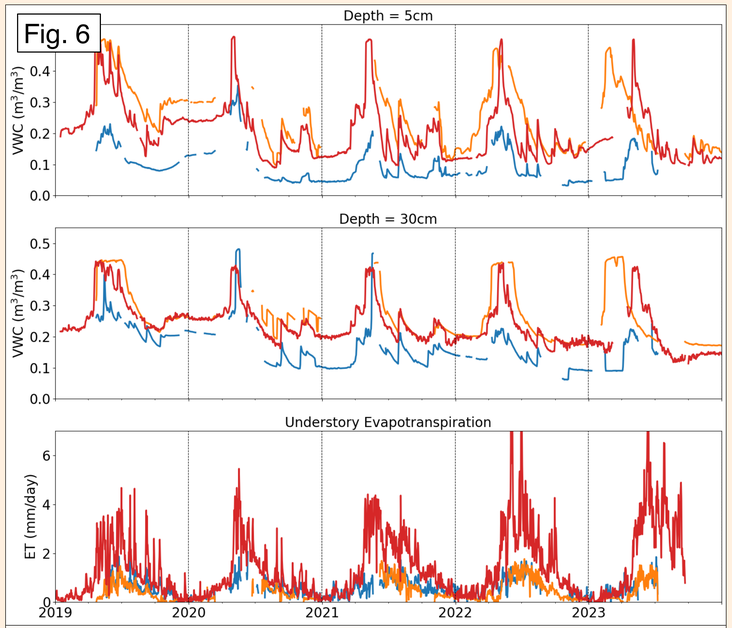
Depth (cm)	Ecosystem ET BB-NF	Ecosystem ET BB-UF	Ecosystem ET BB-SF	Understory ET BB-NF	Understory ET BB-UF
5	13.47	9.0	8.08	4.74	2.32
10	7.05	4.13	4.34	2.47	0.99
15	5.08	3.09	3.1	1.76	0.76
30	2.6	3.1	2.26	0.89	0.75
50	2.31	2.39	1.69	0.79	0.73
75	1.88*	2.23*	1.19	0.62	0.65
100	1.28*	N/A	1.12	0.42	N/A

Slope of the water budget shown in Fig. 4 for all treatments and depths in the study.

Legend
Slope >> 1
Slope ≥1
Slope = 1
Slope ≤ 1
Slope << 1

**Deeper soil moisture is extrapolated from shallower depths where indicated*

Fig. 6



Selected raw time series data used in the water budget from figure 2. Same legend as figure 4.

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