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After the Burn: Forest Carbon Stocks and Fluxes across fire disturbed landscapes in Colorado, U.S.A.

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Introduction

- Ecological disturbances can strongly regulate material and energy flows.
- A documented increase in the size and severity of disturbances, in particular wildfire, in recent decades.
  - Trend expected to continue with longer wildfire seasons (Westerling et al. 2006) and an increase in fire likelihood (Moritz et al. 2012), particularly in the Rocky Mountain West.
- Fire can have consequences on carbon, nutrient, and water cycling within the ecosystems (McLauchlan et al. 2014).
- Forests cover approximately 4.17 Mha globally, contain 1,240 Pg C in biomass (Lal 2005) & fires impact approximately 383 million ha yr^{-1} releasing 2,078 Tg C yr^{-1} (Schultz et al. 2005).

How does fire affect the recovery and resilience of carbon stocks in Rocky Mountain ecosystems (Figure 1)?

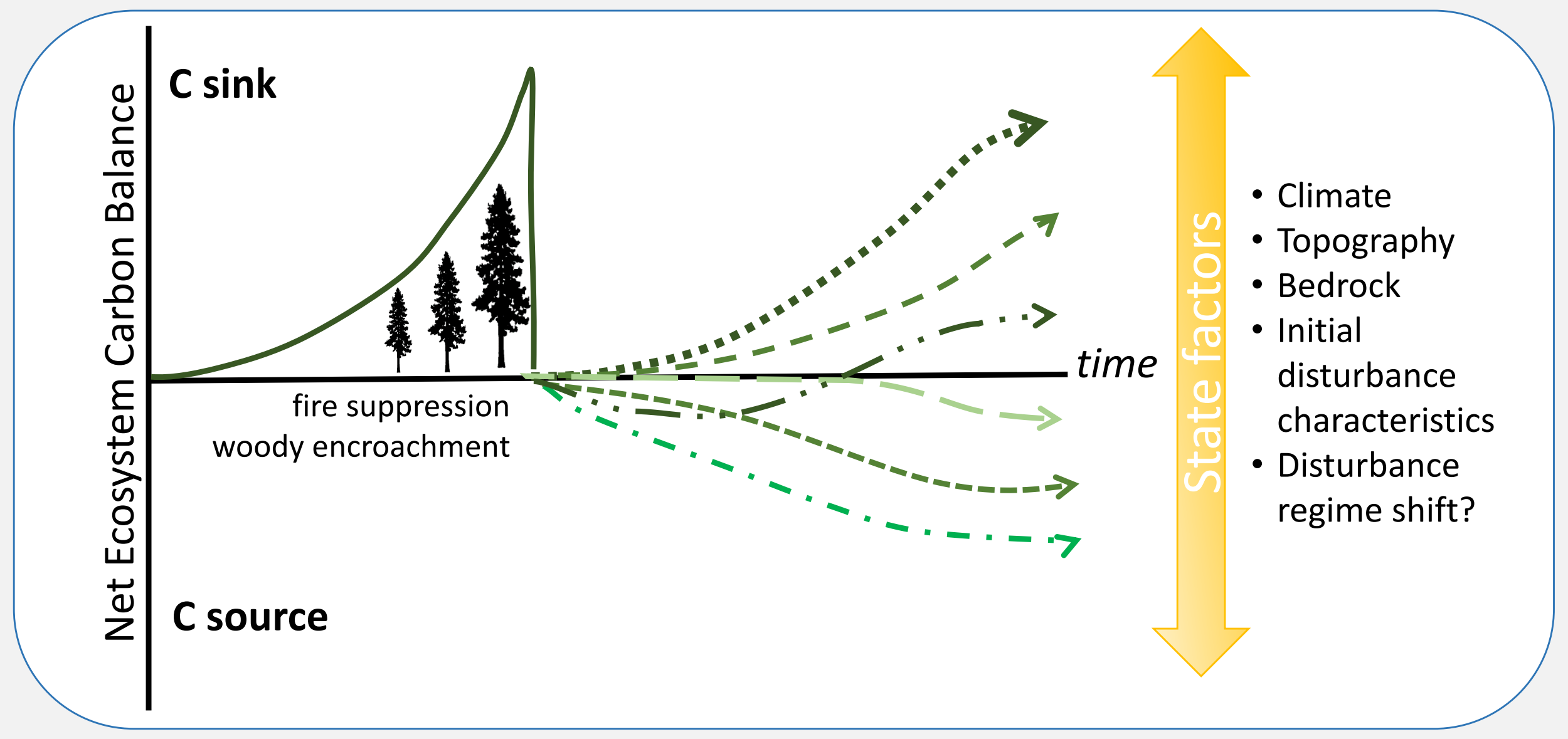


Figure 1: Conceptual model of forest net ecosystem carbon balance for Rocky Mountain Forests. Years of fire suppression have led significant build up of understory vegetation. Given changing climate conditions (e.g. earlier snowmelt, Westering et al. (2006)) it is unclear if forests' net ecosystem carbon balance will remain positive, i.e. a sink, or if the new landscape will be a source of C to the atmosphere. Adapted from McLaughlan et al. (2014).

Study Design & Location

To **quantify** the **effects of fire on ecosystem carbon stocks** 12 montane plots, 10 subalpine plots, and 9 montane watersheds were sampled (Figure 2) during the summer of 2015.

- Above ground biomass (live & dead), coarse woody debris, and soil (organic layer + 10 cm mineral, n=10/plot) sampled in each 15 x 15 m plot.

To examine **how fire interacts with ecosystem state factors** (e.g. climate, soils) **to effect net C balance**, soil laboratory incubations were conducted.

- Aerobic incubations at 5°C, headspace CO_2 collected.
- Three soils from each plot sampled weekly for 7 weeks and again after 12 weeks (n=30 montane & 36 subalpine).

To investigate **how carbon moves within the terrestrial ecosystem** as well as **between the terrestrial & aquatic**, soil samples were taken along a geomorphic position (Figure 2c) and weekly stream samples were collected to quantify fluvial losses.

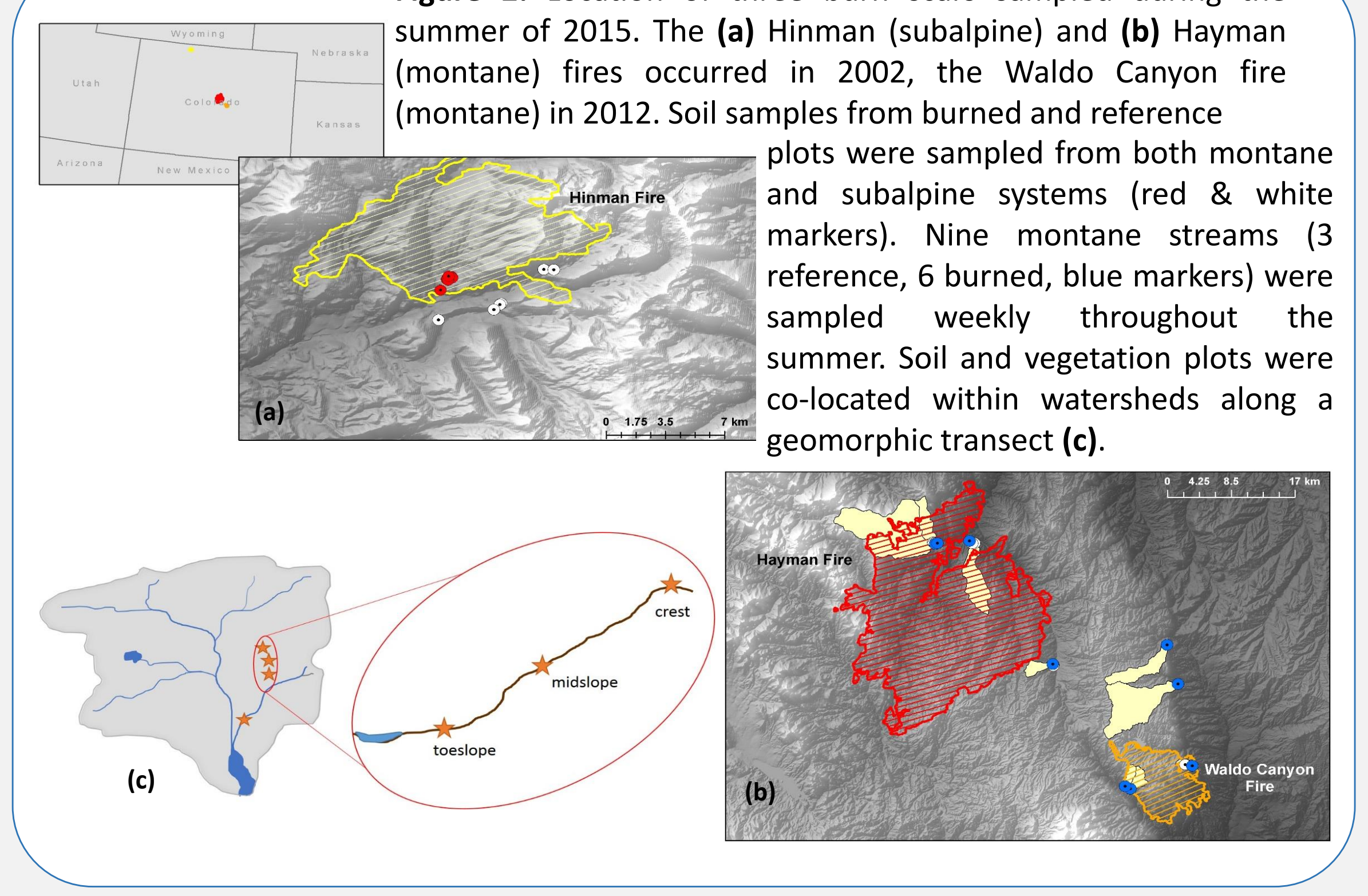
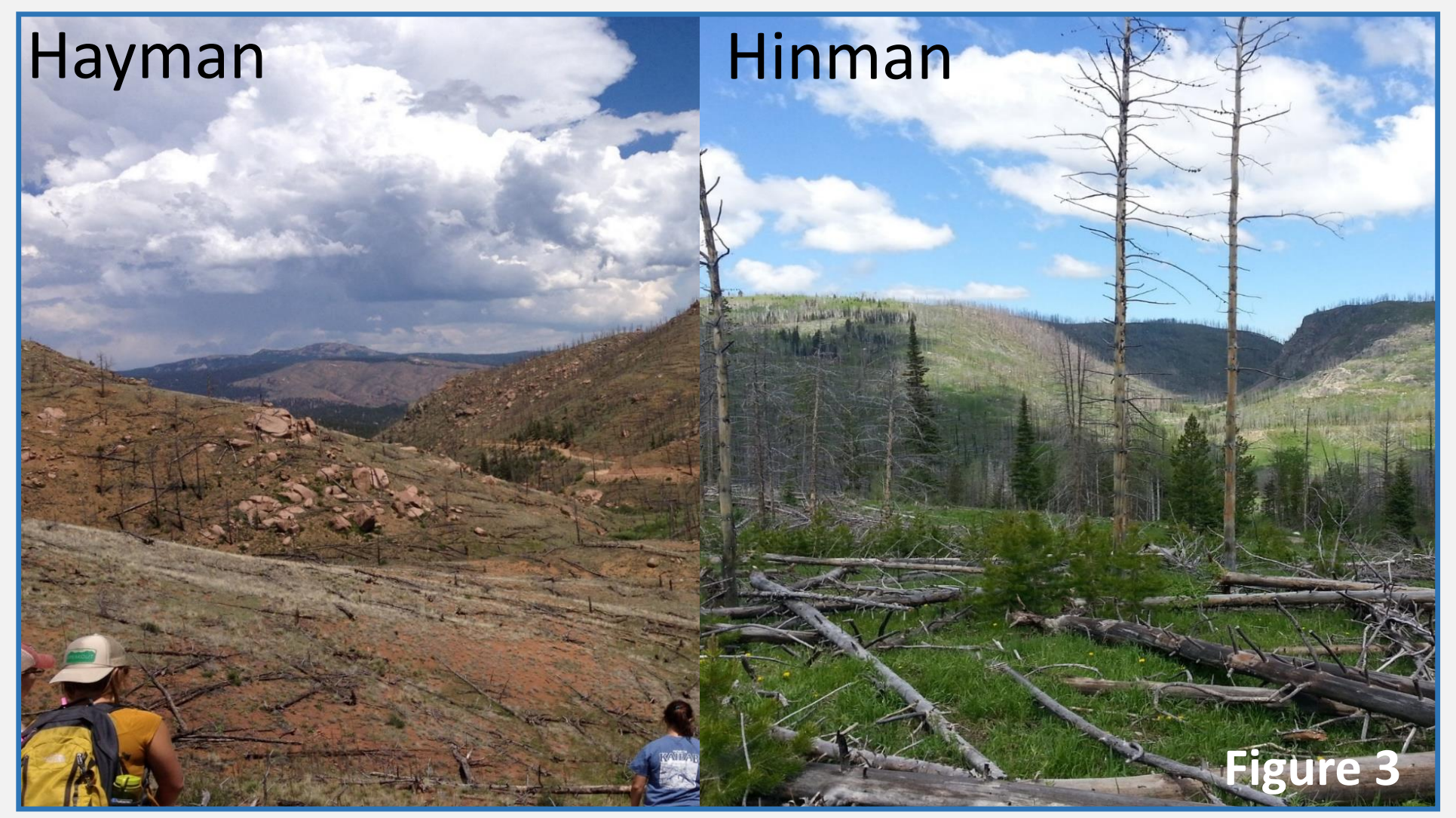


Figure 2: Location of three burn scars sampled during the summer of 2015. The **(a)** Hinman (subalpine) and **(b)** Hayman (montane) fires occurred in 2002, the Waldo Canyon fire (montane) in 2012. Soil samples from burned and reference plots were sampled from both montane and subalpine systems (red & white markers). Nine montane streams (3 reference, 6 burned, blue markers) were sampled weekly throughout the summer. Soil and vegetation plots were co-located within watersheds along a geomorphic transect **(c)**.

How do carbon stocks recover, post fire?



	Hayman Fire	Hinman Fire
elevation (m)	2000 (montane)	2600 (subalpine)
spatial extent (ha)	55,893	12,500
dominant species	Ponderosa – Douglas Fir	Lodgepole – Subalpine Fir
climate	MAT 9.4°C MAP 52 cm, 19% snow	MAT 4.2°C MAP 90 cm, 31% snow

By comparing ecosystem carbon pools in the Hayman and Hinman burns (Figures 3 & 4) it is clear that they are different recovery trajectories. There is significantly more regrowth in the Hinman burn scar as compared to the Hayman. There are a number of factors which could drive these differences, including different mean annual temperature & precipitation, forest type, and severity of disturbance (both fires are classified as "severe," however the Hayman fire was much larger) (Figure 3).

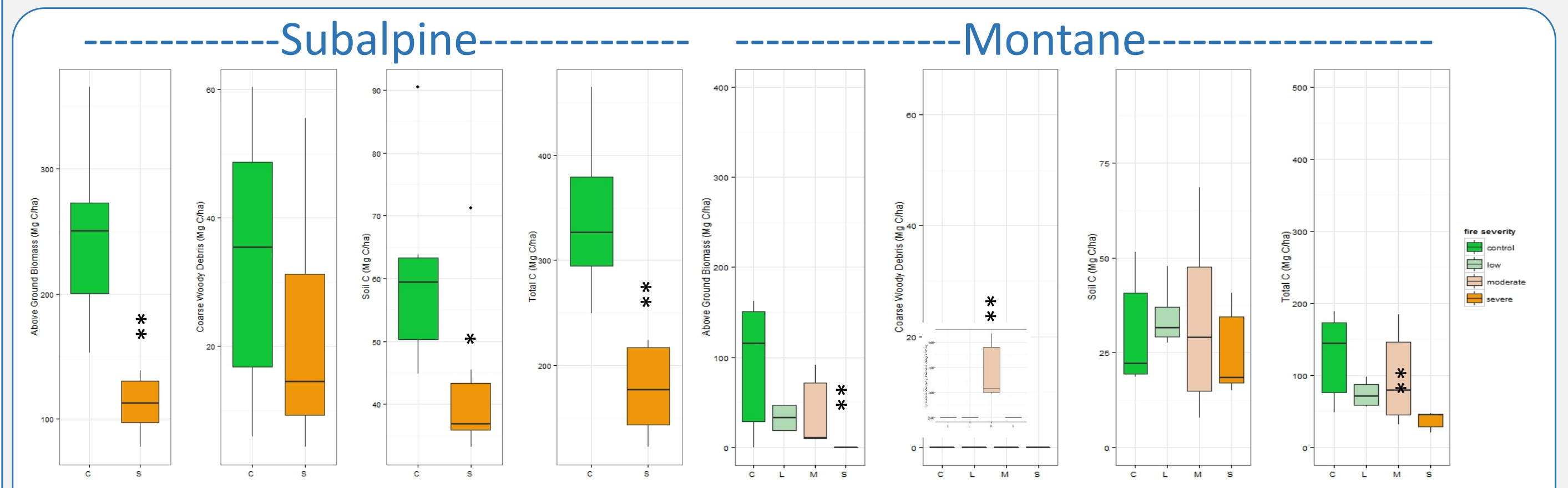


Figure 4: Total C in above ground biomass, coarse woody debris, and soil pools in subalpine (n=5 per treatment) and montane (n=3 per treatment, except low severity) ecosystems. The low severity burn sites burned in 2012, all other sites burned in 2002. Significant differences from control plots are indicated with asterix, * p<0.10, ** p<0.05.

Examining differences between control plots illustrates factors that likely affect recovery trajectory.
For example:

1. Soil moisture was significantly greater for all the subalpine soils (p<0.0001), an indicator of the system's greater precipitation and later snow melt
2. Fire reduced the soil % carbon by ~ 50% in both montane and subalpine environments. However, unburned subalpine soils had ~2x greater C content than montane soils (average %C in control plots: 4.4% vs. 10.7%).

How does fire affect the bioavailability of soil carbon?

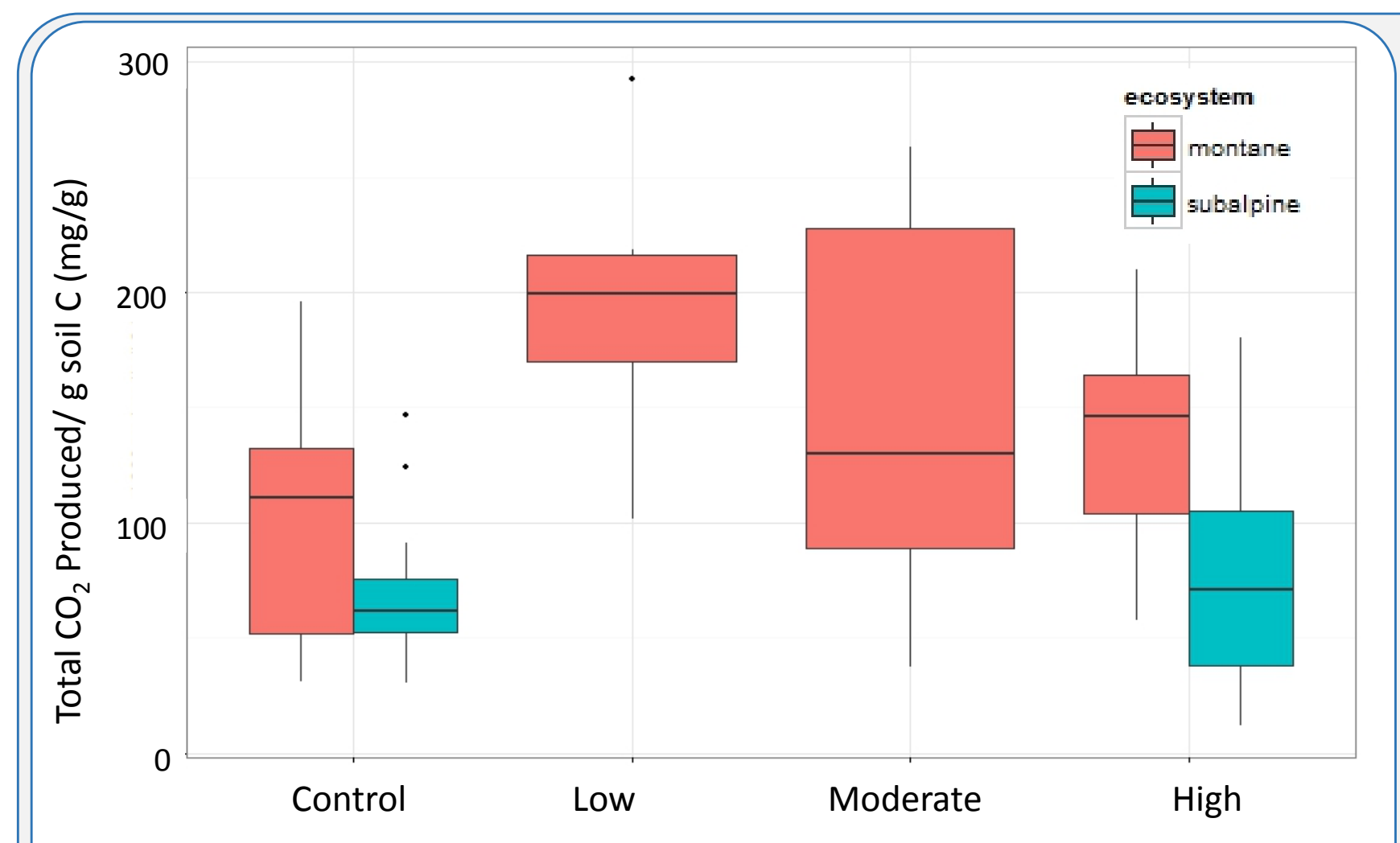


Figure 5: Cumulative CO_2 production from 7-week laboratory incubation experiments, 3 soils per plot (3 plots per treatment – ecosystem pairing.

Laboratory incubations allow us to compare the amount of CO_2 produced, normalized to soil C, to determine the relative bioavailability of soil C at each site. Soils in burned areas tend to be more bioavailable (Figure 5), however most of these relationships are not statistically significant, likely due to system heterogeneity. Montane soil C is significantly more bioavailable than subalpine soil C, in burned sites (p=0.001). This is likely one driver responsible for the differences in recovery trajectories between sites.

The fraction of carbon respired was also related to soil characteristics that vary systematically between sites, such as soil moisture (Figure 6a), soil C:N and soil extract C:N (Figure 6b).

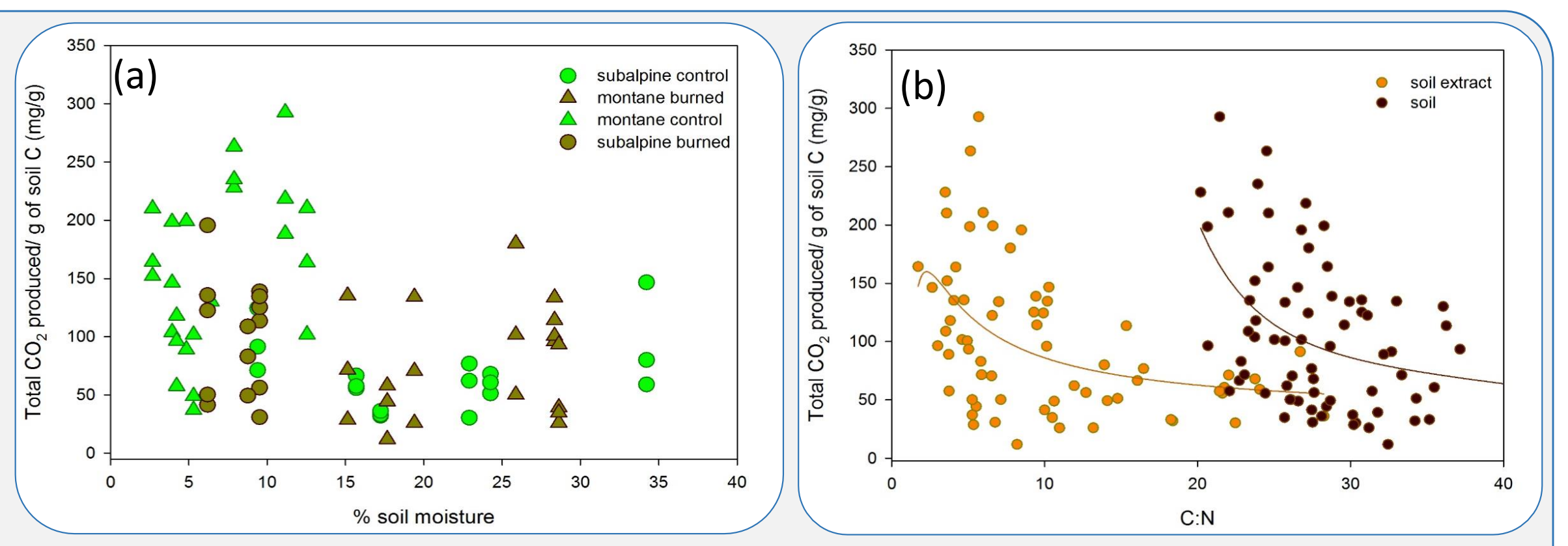
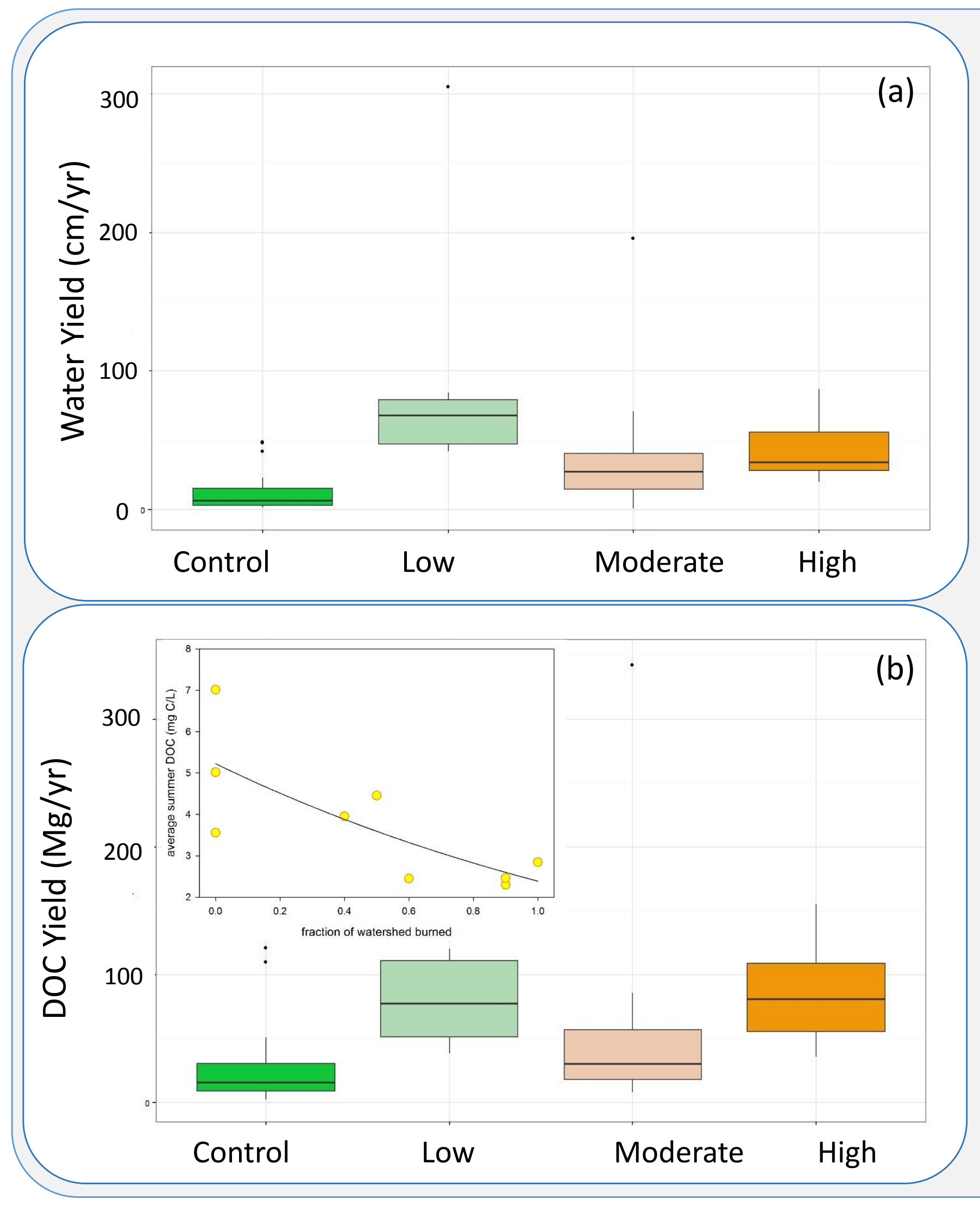


Figure 6: Relationships between soil properties and the fraction of carbon respired during the 7-week incubation experiment. (a) Wetter soils had relatively more recalcitrant carbon and subalpine sites are significantly wetter than montane; there was no difference between burned and unburned plots. (b) Lower soil and soil pore water C:N is associated with greater soil carbon bioavailability.

How does fire affect carbon transport from terrestrial to aquatic ecosystems?



Weekly sampling of streams draining montane forests, both burned and unburned suggest that burned areas, on average, have higher and more variable water yields than nearby reference sites (Figure 7a). Greater water throughput leads to greater dissolved organic matter losses in fire impacted watersheds (Figure 7b). This relationship is driven by the shift in hydrology, the dissolved organic carbon (DOC) concentrations significantly decreased with increased extent of fire disturbance (p=0.01, Figure 7b inset).

Preliminary Conclusions:

Montane and subalpine systems' carbon pools respond differently to fire. Comparing estimated annual DOC leachate losses (Figure 7b) with terrestrial ecosystem carbon pools (Figure 4) suggests that burned montane ecosystems lose more carbon on an annual basis than they store: they are now a net C source. This shift in the net ecosystem C balance is likely due, in part, to the higher relative bioavailability of soil C in burned versus unburned montane systems.

Figure 7: Comparison of the (a) water yield (cm/yr) from nine montane watersheds near Colorado Springs, CO (3 control, 1 low, 2 moderate, 3 high) and (b) DOC yield (Mg/yr) from each system. The inset in (b) shows the inverse relationship between fraction of watershed burned and the average summer DOC concentration in the stream.

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