Surface and canopy fuels vary widely in 24-yr old, post-fire lodgepole pine forests

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Climate change and young forests

Changes in global temperature and moisture regimes at mid to high latitudes are expected to increase wildland fire occurrence due to more frequent weather conditions that promote wildfire. An increased frequency of wildfire will lead to a younger vegetation age mosaic across forested landscapes and forecasted decreases in fire frequency will have to be realized by the combustion of young forest stands. Young forests are believed to have lower fire risk and behavior than mature forests due to differences in their fuel loads and conditions, but a landscape-wide assessment of young forest fuels has until now been lacking. In this study, we provide a detailed analysis of forest fuels across 24 year old lodgepole pine (*Pinus contorta* var. latifolia) forests in Yellowstone National Park.

Research questions

1. How do surface fuel characteristics change with time-since-fire?
2. How do canopy and surface fuels vary across the Yellowstone landscape 24 years post fire?

Methods

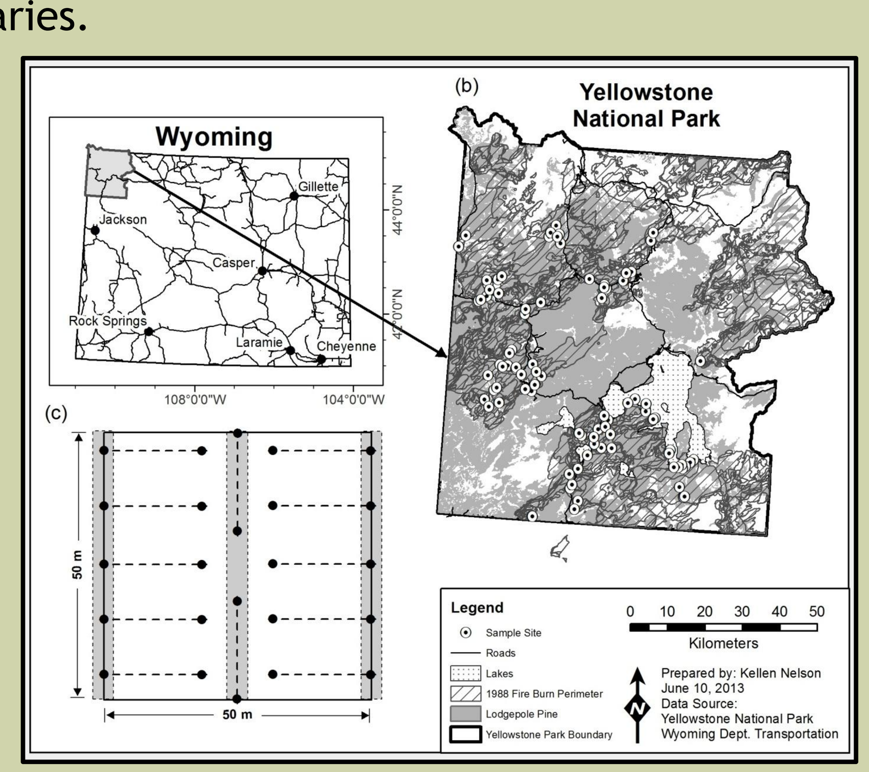
During the summer of 2012, we re-measured surface fuels in 11 sites that were established in 1996 (8 years post fire) and measured canopy, surface, and herbaceous fuels in 82 sites distributed across the Yellowstone National Park post-1988 fire landscape.

Surface fuels

- 12 planar intercept (aka Brown's) transects were sampled at each site.
- Woody particles that intersected each transect were tallied in each of the following diameter size classes: <0.64, 0.64–2.54, 2.54–7.62, and >7.62 cm. Transect lengths for each class included 3 m, 3 m, 10 m, and 20 m, respectively.
- Litter and duff depth were assessed at 3 locations—2 meters apart.
- Herbaceous fuels were visually estimated (0-5%, 5-10%, 10-20%, etc.) by cover class within thirty 0.25 m^2 micro-plots located at 5 meter increments along the east, center, and west plot boundaries.

Canopy fuels

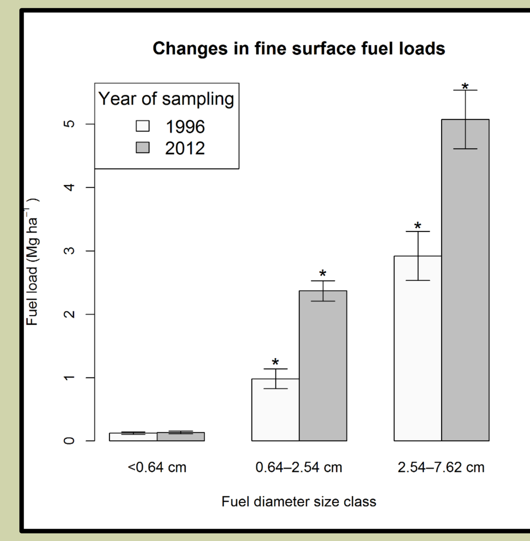
- Canopy fuels were characterized by assessing tree density in three belt transects and measuring a subsample of tree sizes in each plot.
- Canopy fuel loads were calculated using locally developed allometric equations from tree size measurements, then scaled to the stand level using tree density estimates.



Data Analysis

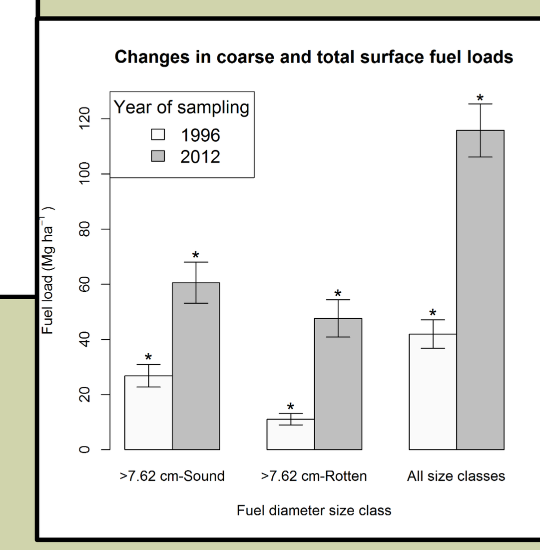
- Changes in surface fuel loads between 1996 and 2012 were assessed by computing the ratio of change and comparing means using paired t-tests.
- Canopy fuel loads and continuity were investigated by creating vertical profiles of canopy bulk density and relating canopy cover and tree density.
- To address drivers of fuel loads, we fit multiple linear regression models predicting specific fuel loads with variables related to pre and post-fire stand structure, topography, and productivity.

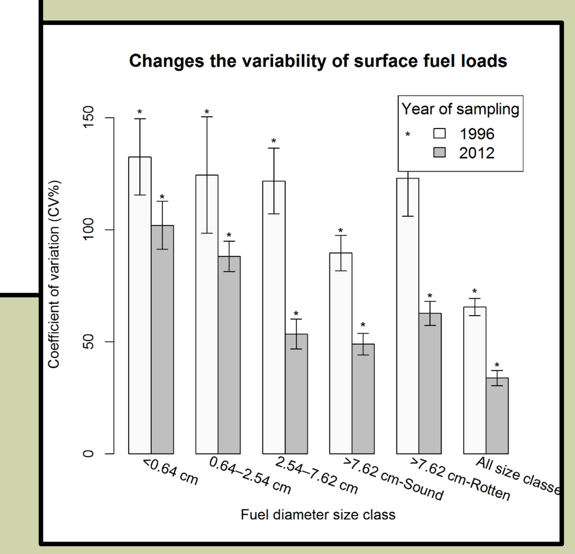
Changes in surface fuels from 1996 to 2012



Asterisks denote significant differences (α=0.05).

- Surface fuels <0.64 cm diameter did not change between 1996 and 2012, but all other fuel classes increased by a factor of two or three.





- Variation in fuel loads within stands decreased significantly between 1996 and 2012.

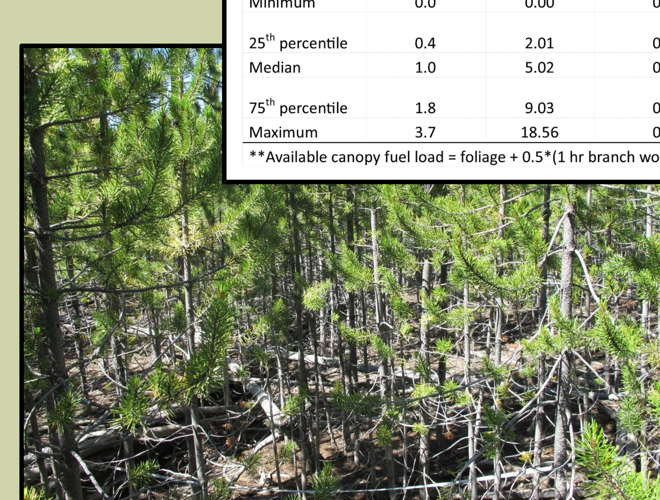
Variability in fuel loads

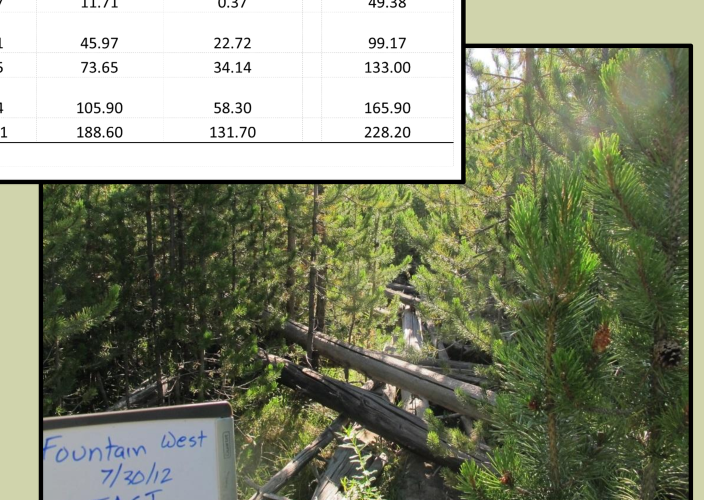
- Post-fire tree density spanned six orders of magnitude and produced a tremendous range in available canopy fuels.
- Litter and herbaceous fuels made up the greatest share of fine surface fuels.
- Coarse fuels composed the largest share of total fuel loads.

	Stand density (stems ha^{-1})	Mean crown base height (m)	Available canopy bulk density (kg m^{-3})	Canopy Fuel Load ($Mg\ ha^{-1}$): Foliage	Canopy Fuel Load ($Mg\ ha^{-1}$): 1-hour branch wood	Canopy Fuel Load ($Mg\ ha^{-1}$): Total available canopy fuel	Live Surface Fuel Load ($Mg\ ha^{-1}$): Herbaceous	Live Surface Fuel Load ($Mg\ ha^{-1}$): Woody (shrub) fuels
Mean	19508±5645	0.42±0.03	0.369±0.045	6.59±0.69	2.28±0.24	7.73±0.81	1.29±0.07	0.16±0.02
Minimum	0	0.02	0.001	0.00	0.00	0.00	0.12	0.00
25th percentile	1500	0.20	0.102	1.94	0.61	2.24	0.98	0.03
Median	4000	0.36	0.281	5.48	1.89	6.43	1.29	0.09
75th percentile	12,666	0.62	0.490	8.91	3.10	10.38	1.73	0.24
Maximum	344,067	1.17	2.49	39.86	13.55	46.63	2.65	0.74

	Litter depth (cm)	Dead Surface Fuel Load ($Mg\ ha^{-1}$): Litter	1-hour	10-hour	100-hour	1000-hour -Sound-	1000-hour -Rotten-	Total surface fuel load ($Mg\ ha^{-1}$)
Mean	1.1±0.09	5.61±0.46	0.17±0.01	2.28±0.09	5.08±0.22	78.55±4.31	41.90±2.98	133.60±5.01
Minimum	0.0	0.00	0.03	0.55	1.97	11.71	0.37	49.38
25th percentile	0.4	2.01	0.08	1.65	3.91	45.97	22.72	99.17
Median	1.0	5.02	0.14	2.14	4.85	73.65	34.14	133.00
75th percentile	1.8	9.03	0.21	2.78	6.04	105.90	58.30	165.90
Maximum	3.7	18.56	0.55	4.89	13.81	188.60	131.70	228.20

**Available canopy fuel load = foliage + 0.5*(1 hr branch wood)

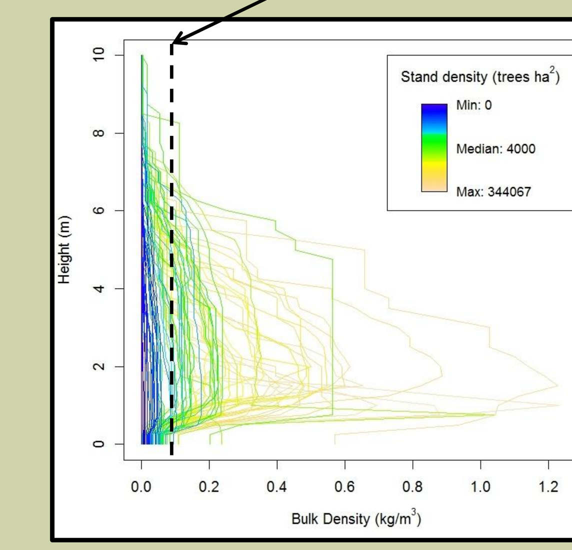




Drivers of fuel load

- Canopy bulk density was positively related to live stand density but negatively related to canopy height.
- Crown continuity measured as crown cover (%) was positively related to stem density (R^2=0.80).
- Available canopy fuel load was positively related to live stand density, an interaction between precipitation and temperature, and annual solar radiation (R^2=0.72).
- Crown base height was positively associated with live tree density but negatively associated with slope (R^2=0.64).

0.1 kg ha^{-1} is recognized as a threshold for crown fire propagation.



- Litter fuel load was positively related to crown base height, live tree density, and herbaceous fuel load, but negatively related to precipitation (R^2=0.46).
- Fine fuel load (<0.64 cm dia.) was positively related to crown base height, precipitation, temperature, and aspect (R^2=0.47).
- Coarse fuel load (>2.54 cm dia.) was positively related to late-seral, pre-fire structure but negatively related to temperature and precipitation (R^2=0.24).

Conclusions

- Fuel loads in young forests are highly variable yet appear to become less so with time.
- Our data indicate that that much of the forest that regenerated after the 1988 fire has adequate canopy fuel to carry wind driven crown fire but insufficient surface fuels to sustain fire under moderate conditions.
- Should fire occur in these young forests, substantial heterogeneity in canopy, surface, and total fuels suggest variability in fire behavior and severity.
- Fuel mosaics in young forests will increasingly influence fire activity in western forests as climate continues to warm and fire rotation lengths decline.

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