Spatial Variability of Surface Fuels in Dry Ponderosa Pine Forests

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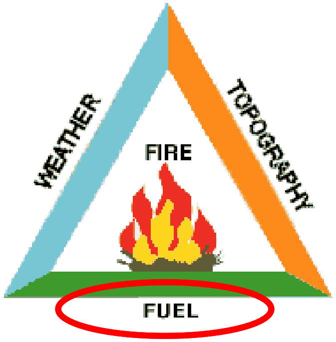
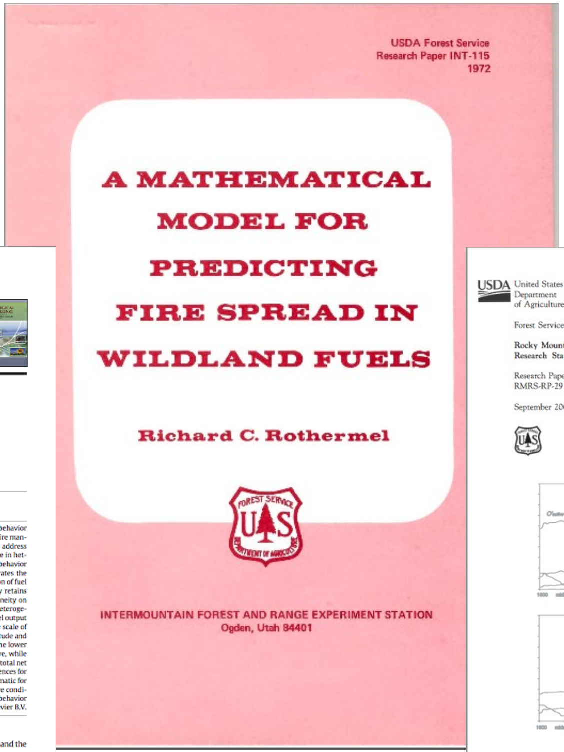
Overview

- Importance of fuel variability
- Current state of knowledge
- Our question
- Study design
- Results
- Implications
- Future research recommendations

Fine Scale Fuel Distributions

Characterizing fuels is important



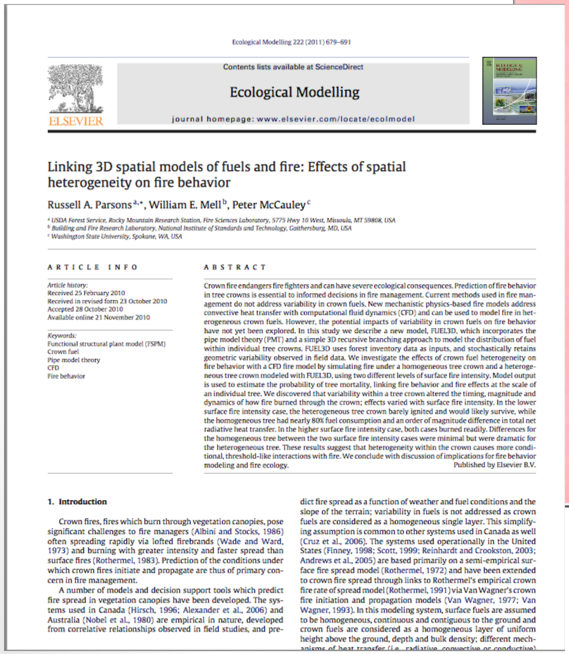


USDA Forest Service
Research Paper INT-115
1972

A MATHEMATICAL MODEL FOR PREDICTING FIRE SPREAD IN WILDLAND FUELS

Richard C. Rothermel

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401



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Linking 3D spatial models of fuels and fire: Effects of spatial heterogeneity on fire behavior

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ABSTRACT

Crown fire endangers fire fighters and can have severe ecological consequences. Prediction of fire behavior in tree crowns is essential to informed decisions in fire management. Current methods used in fire management do not address variability in crown fuels. New mechanistic physics-based fire models address convective heat transfer with computational fluid dynamics (CFD) and can be used to model fire in heterogeneous crown fuels. However, the potential impacts of variability in crown fuels on fire behavior have not yet been explored. In this study we describe a new model, FUEL3D, which incorporates the pipe model theory (PMT) and a simple 3D recursive branching approach to model the distribution of fuel within individual tree crowns. FUEL3D uses forest inventory data as inputs, and stochastically retains geometric variability observed in field data. We investigate the effects of crown fuel heterogeneity on fire behavior with a CFD fire model by simulating fire under a homogeneous tree crown and a heterogeneous tree crown modeled with FUEL3D, using two different levels of surface fire intensity. Model output is used to estimate the probability of tree mortality, linking fire behavior and fire effects at the scale of an individual tree. We discovered that variability within a tree crown altered the timing, magnitude and dynamics of how fire burned through the crown; effects varied with surface fire intensity. In the lower surface fire intensity case, the heterogeneous tree crown barely ignited and would likely survive, while the homogeneous tree had nearly 80% fuel consumption and an order of magnitude difference in total net radiative heat transfer. In the higher surface fire intensity case, both cases burned readily. Differences for the homogeneous tree between the two surface fire intensity cases were minimal but were dramatic for the heterogeneous tree. These results suggest that heterogeneity within the crown causes more conditional, threshold-like interactions with fire. We conclude with discussion of implications for fire behavior modeling and fire ecology.

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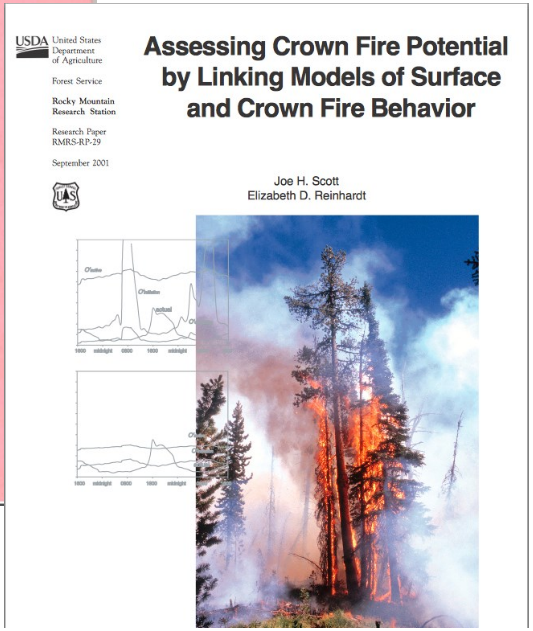
1. Introduction

Crown fires, fires which burn through vegetation canopies, pose significant challenges to fire managers (Albini and Stocks, 1986) often spreading rapidly via lofted firebrands (Wade and Ward, 1973) and burning with greater intensity and faster spread than surface fires (Rothermel, 1983). Prediction of the conditions under which crown fires initiate and propagate are thus of primary concern in fire management.

A number of models and decision support tools which predict fire spread in vegetation canopies have been developed. The systems used in Canada (Hirsch, 1996; Alexander et al., 2006) and Australia (Nobel et al., 1980) are empirical in nature, developed from correlative relationships observed in field studies, and predict fire spread as a function of weather and fuel conditions and the slope of the terrain; variability in fuels is not addressed as crown fuels are considered as a homogeneous single layer. This simplifying assumption is common to other systems used in Canada as well (Cruz et al., 2006). The systems used operationally in the United States (Finney, 1998; Scott, 1999; Reinhardt and Crookston, 2003; Andrews et al., 2005) are based primarily on a semi-empirical surface fire spread model (Rothermel, 1972) and have been extended to crown fire spread through links to Rothermel's empirical crown fire rate of spread model (Rothermel, 1991) via Van Wagner's crown fire initiation and propagation models (Van Wagner, 1977; Van Wagner, 1993). In this modeling system, surface fuels are assumed to be homogeneous, continuous and contiguous to the ground and crown fuels are considered as a homogeneous layer of uniform height above the ground, depth and bulk density; different mechanisms of heat transfer (i.e., radiative, convective or conductive)



USDA United States Department of Agriculture

Forest Service

Rocky Mountain Research Station

Research Paper RMRS-RP-29

September 2001

Assessing Crown Fire Potential by Linking Models of Surface and Crown Fire Behavior

Joe H. Scott
Elizabeth D. Reinhardt

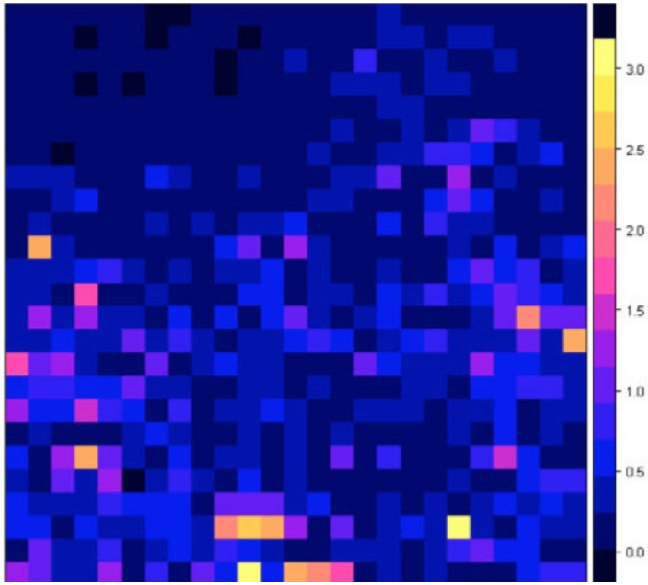
Fine Scale Fuel Distributions

There is often a scale mismatch between our fuel measurements and the response variables of interest

CU Burning Issues http://www.colorado.edu/geography/boulderfires/

Fine Scale Fuel Distributions

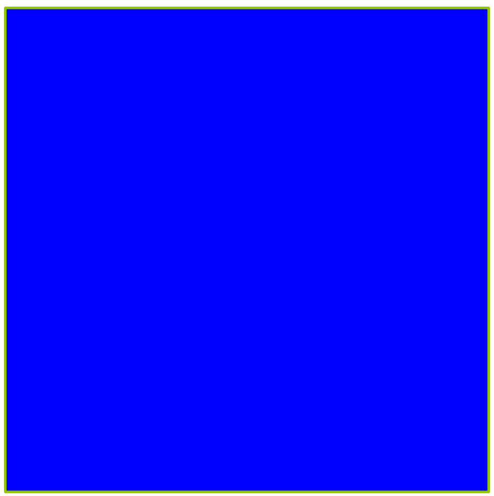
Characterizing fuels is important, and we're bad at it.

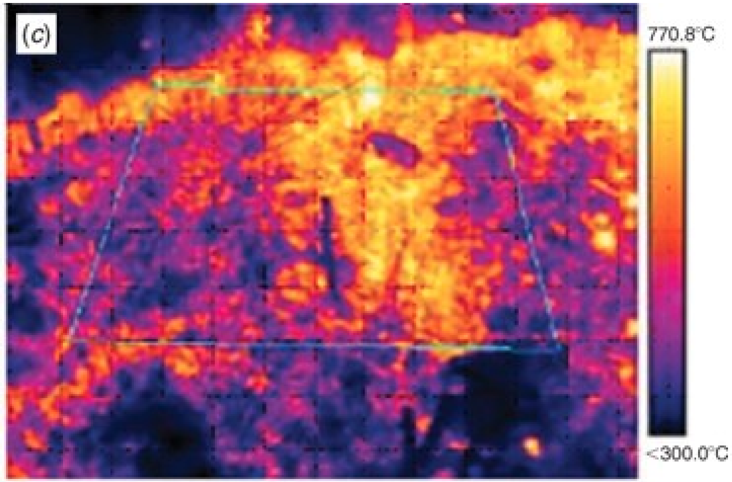


Keane et al. 2012

Fine Scale Fuel Distributions

How We Model Fuels vs. How Fire Behaves





Hiers et al 2009

Treatment responses matter, too

- Accurate inventories before and after fuel treatments are essential to assessing effectiveness
  - Change in loading
  - Change in predicted rate of spread, crowning index, etc.
- Are we measuring treatment results at the appropriate scale?

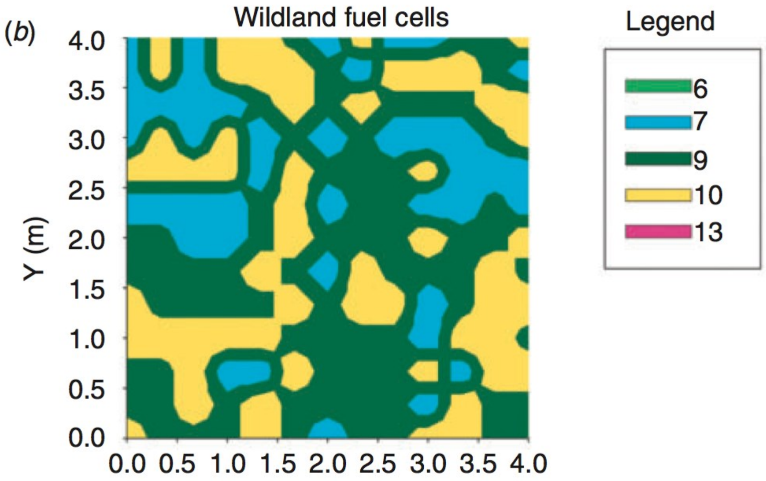
Treatment responses

What are the effects of overstory treatment on understory fuels?

What do we know?

Not much, but we think the scales are small.

- Hiers et al. 2009
- Keane 2012



Fuel Class	Range (m)
1h	16.3
10h	4.95
100h	4.56
1,000 h	22.01
Duff/Litter	1.29

Spatial distributions and treatment effects

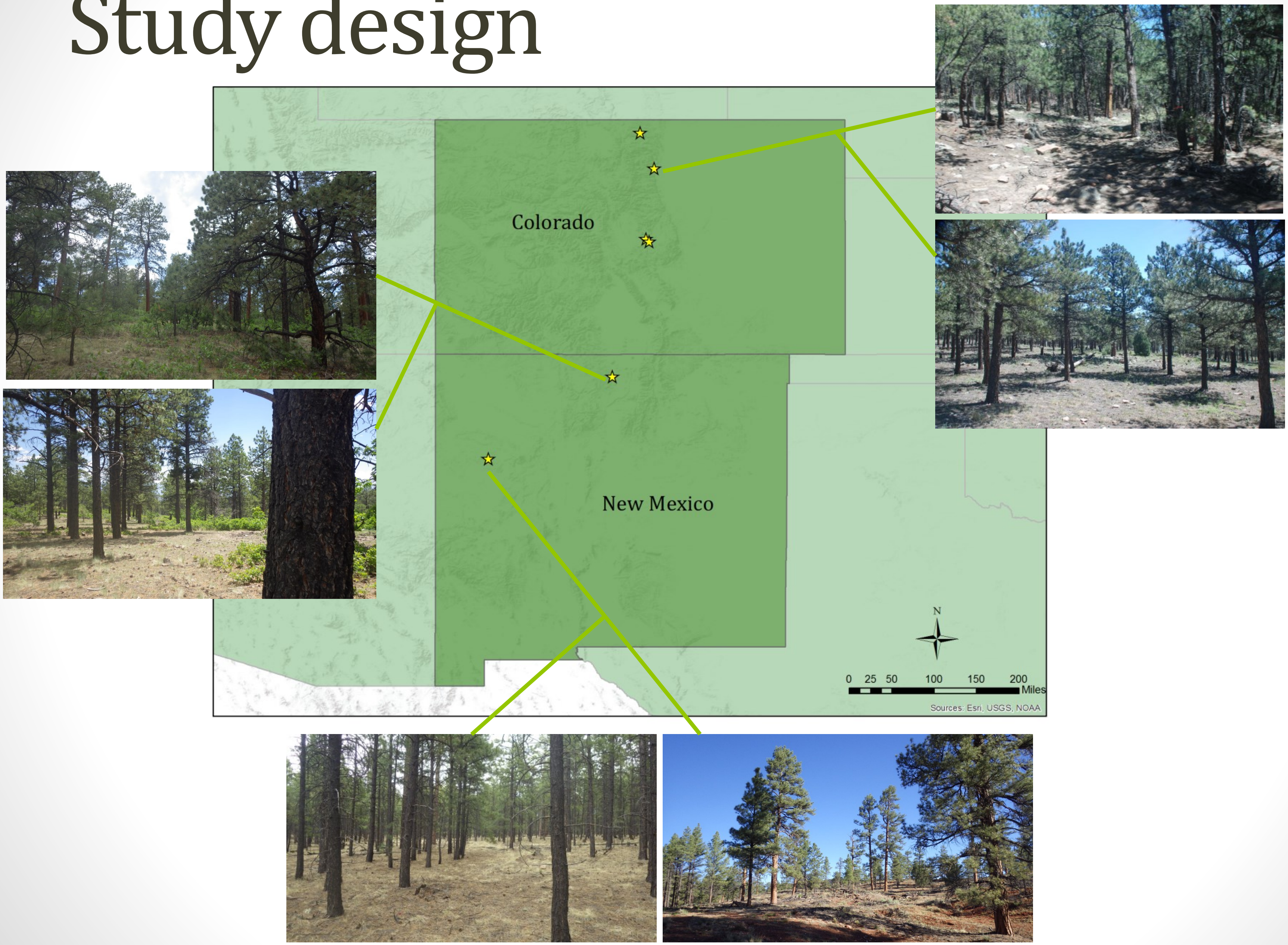
We expanded on results of Keane 2012 to focus on ponderosa pine forest types and how they were affected by treatments

- Thin only
  - Restoration minded, groupy-clumpy prescriptions
- Thin-and burn
  - 6-8 year old burns

Hypotheses

- We expected range values to be positively correlated with fuel particle diameters
- We expected patch size to decrease and between-patch variability to increase with thin treatments
- We expected variability in thin-and-burn stands to more closely resemble the unmanaged stands

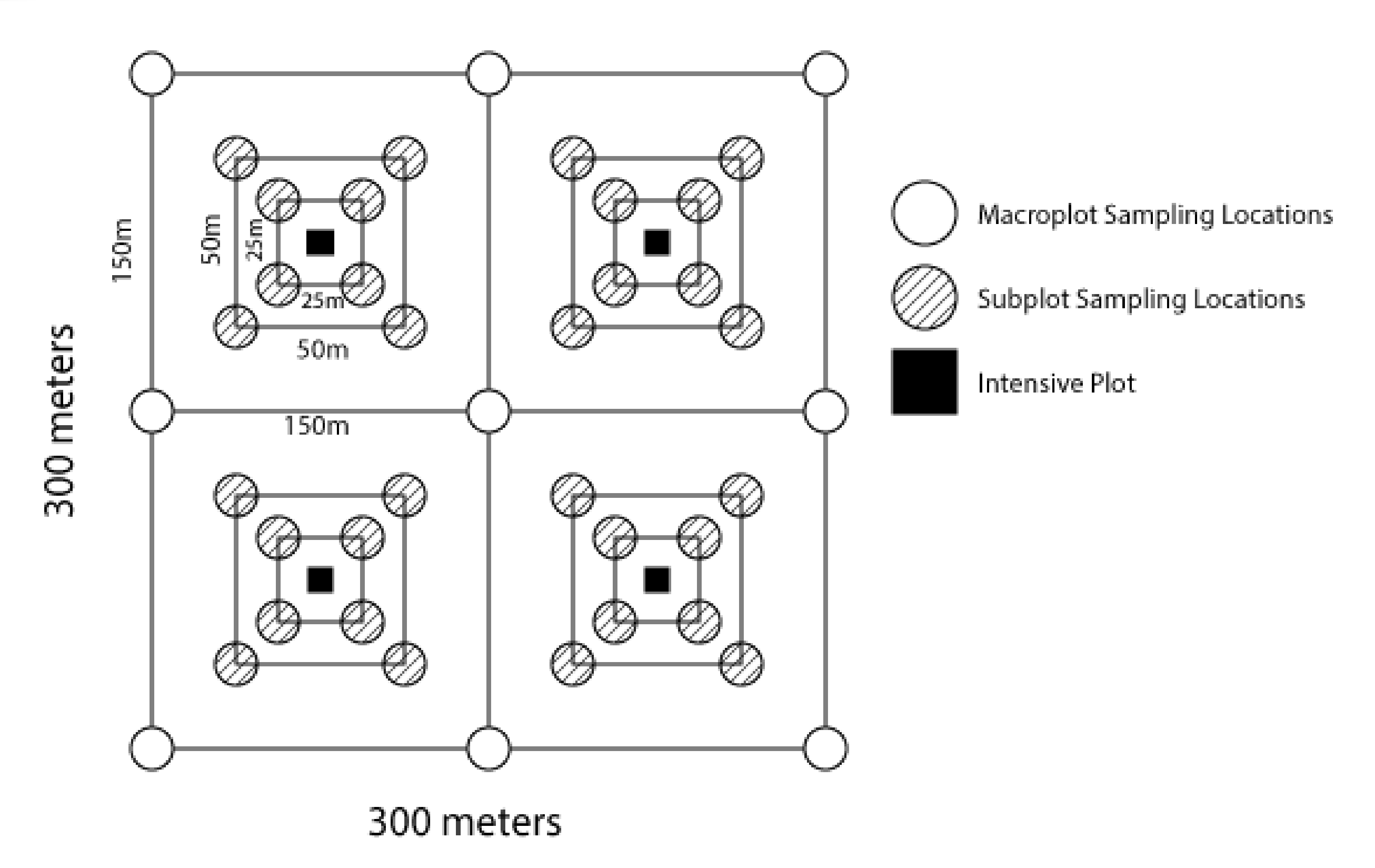
Study design



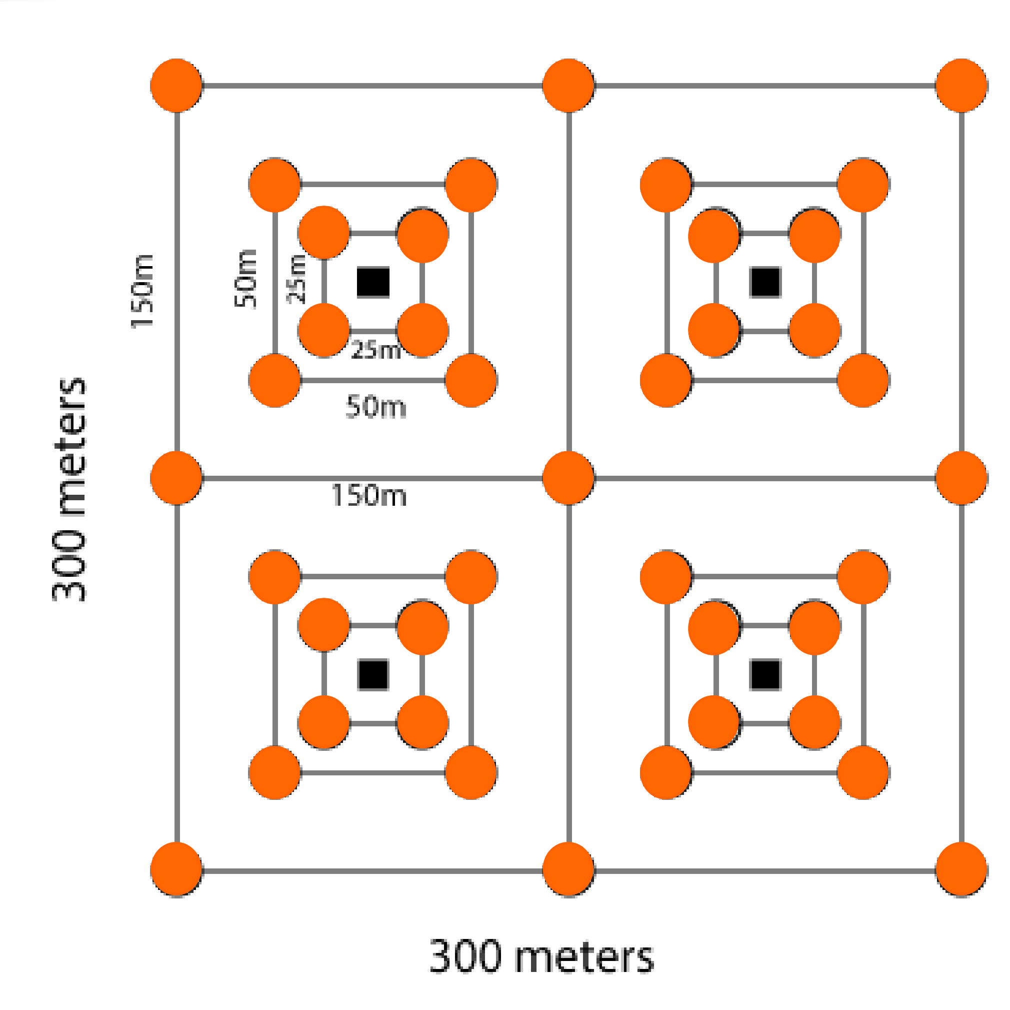
Study design

- Trees per acre decreased between 60% and 81%, with an average decrease of 68%
- Basal area decreased up to 68% but at one site was actually 8% higher in the untreated plot. The average decrease was 39%

Study Design



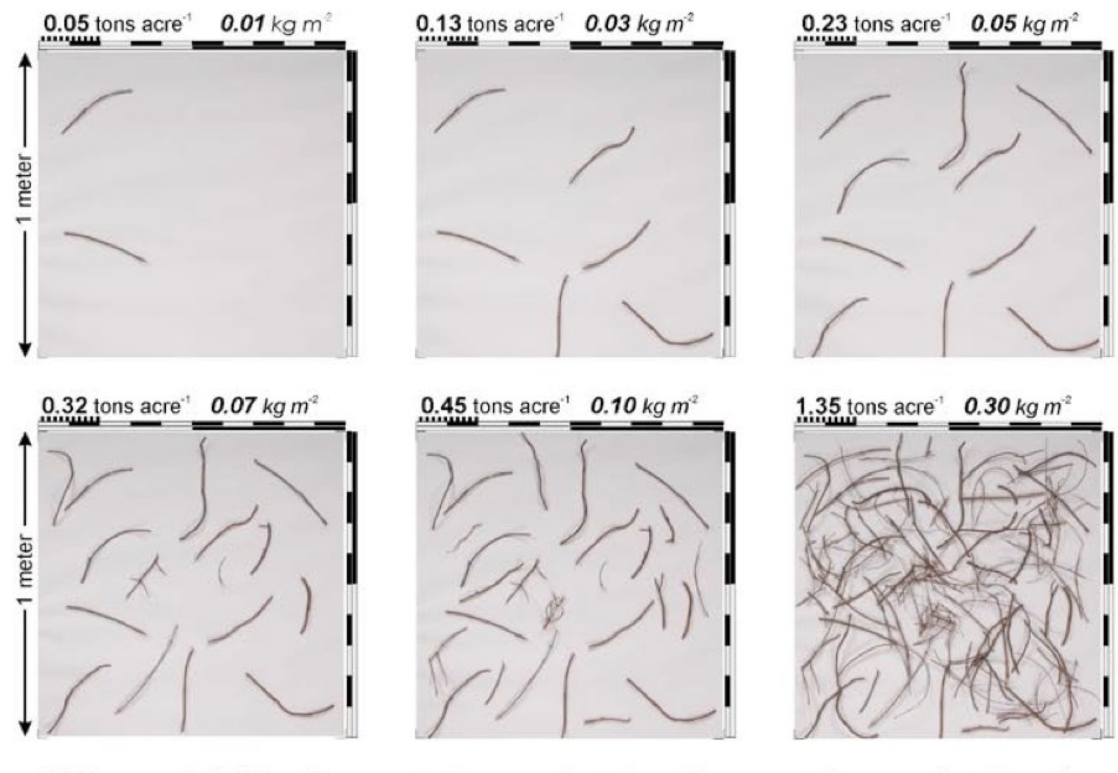
Study Design



- Variable radius plots for tree species, height, dbh
- 1,000 hour fuels measured for end diameters and length in 200m^2 fixed plots
- Separation distances from 25m to 425m
- 41 sample locations per site

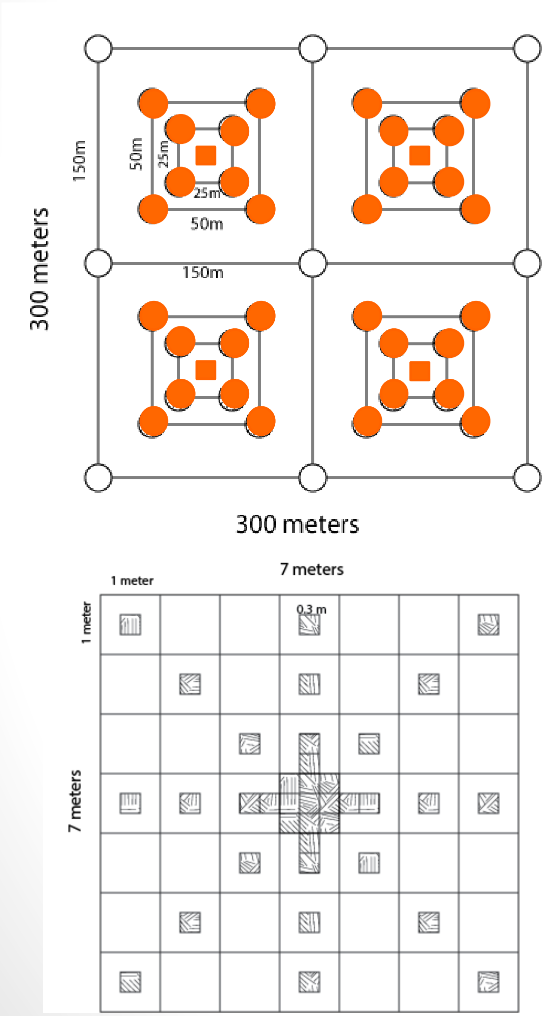
Study Design

- Fine woody debris (1-hour, 10-hour, and 100-hr fuels) sampled using photoload technique



(Keane and Dickinson 2007)

Study Design



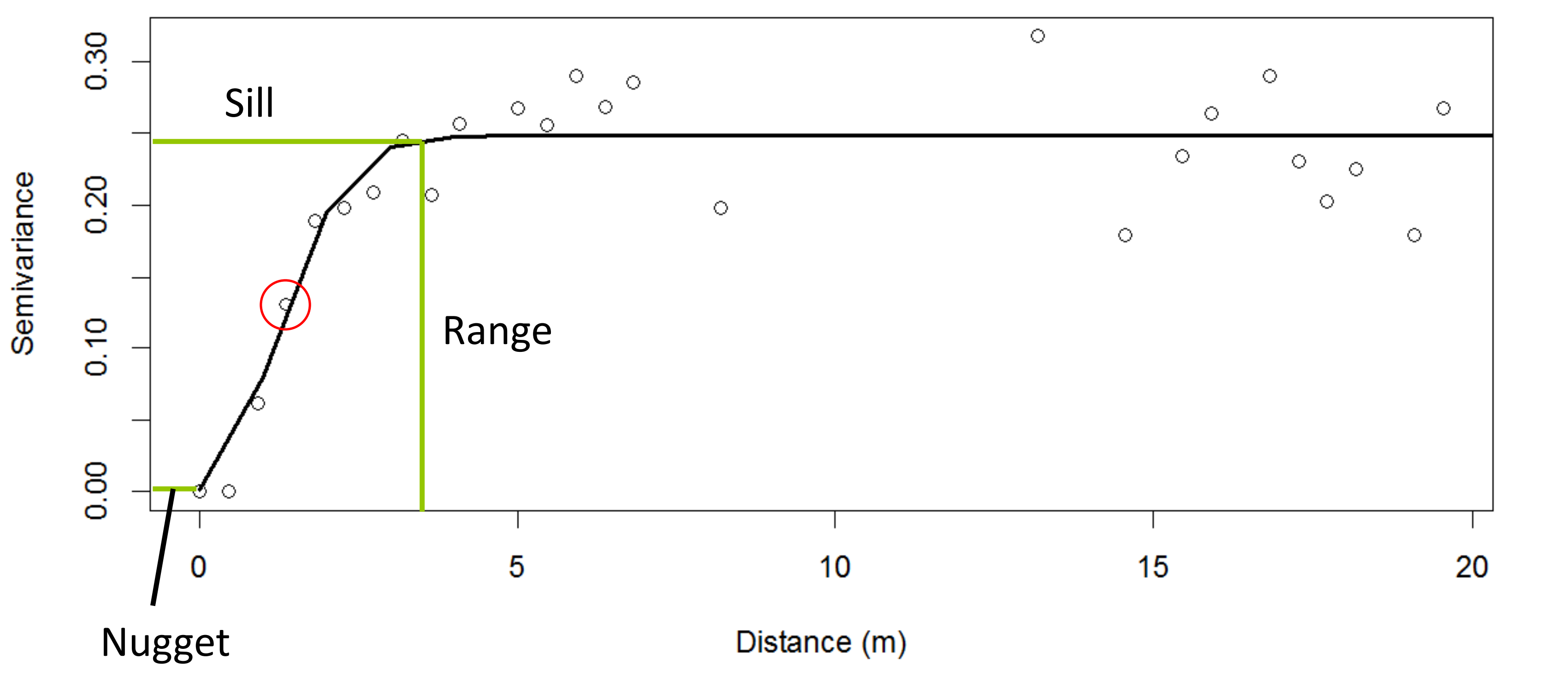
- Shrubs and herbaceous plants were clipped, dried, and weighed meter by meter within a 7 by 7 meter intensive plot and at the subplot level
- We also collected, dried, and weighed all fine woody fuels on 20% of these plots
- Litter and duff were sampled in 0.1 square meter plots at the subplot level and as shown on this intensive plot diagram
- 180 sample locations for litter and duff
- 228 sample locations for fine woody fuels, shrubs, and herbs
- Separation distances from .35m to 280m

Study Design

- Each site produced 1541 point measurements of surface fuels, plus overstory descriptive data. Over all sites this adds up to over 18,000 data points.

- Across all 12 sites we collected a total of 9,000 samples with a combined dry weight of over 1,600 pounds.

Analysis– Semivariograms

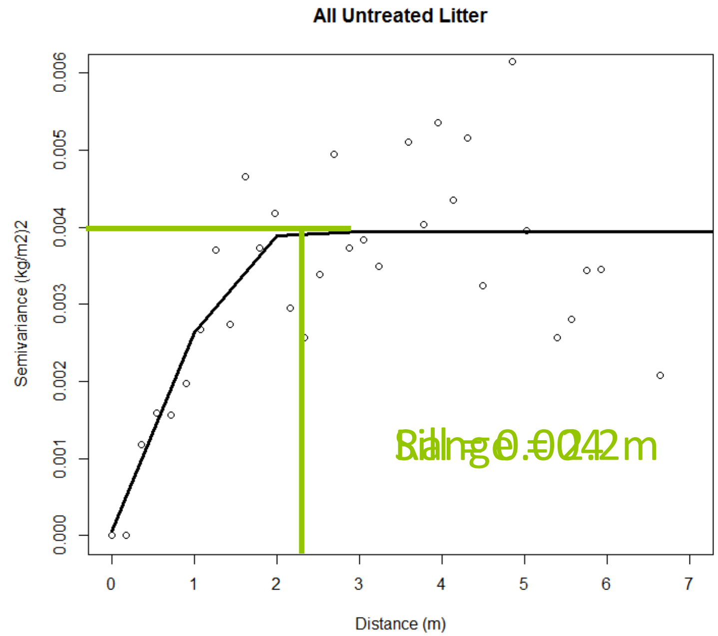


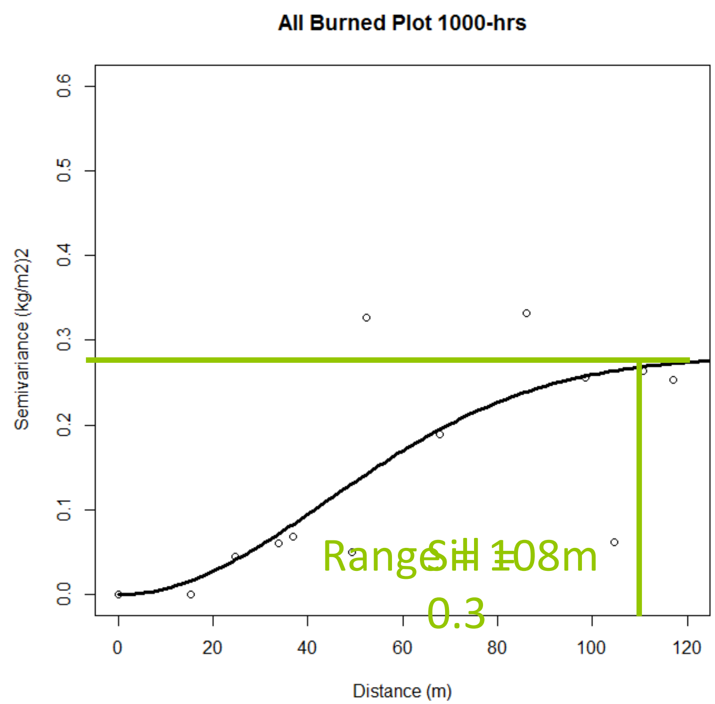
Results

- Results are preliminary
- Herbaceous, shrub, duff data not analyzed yet

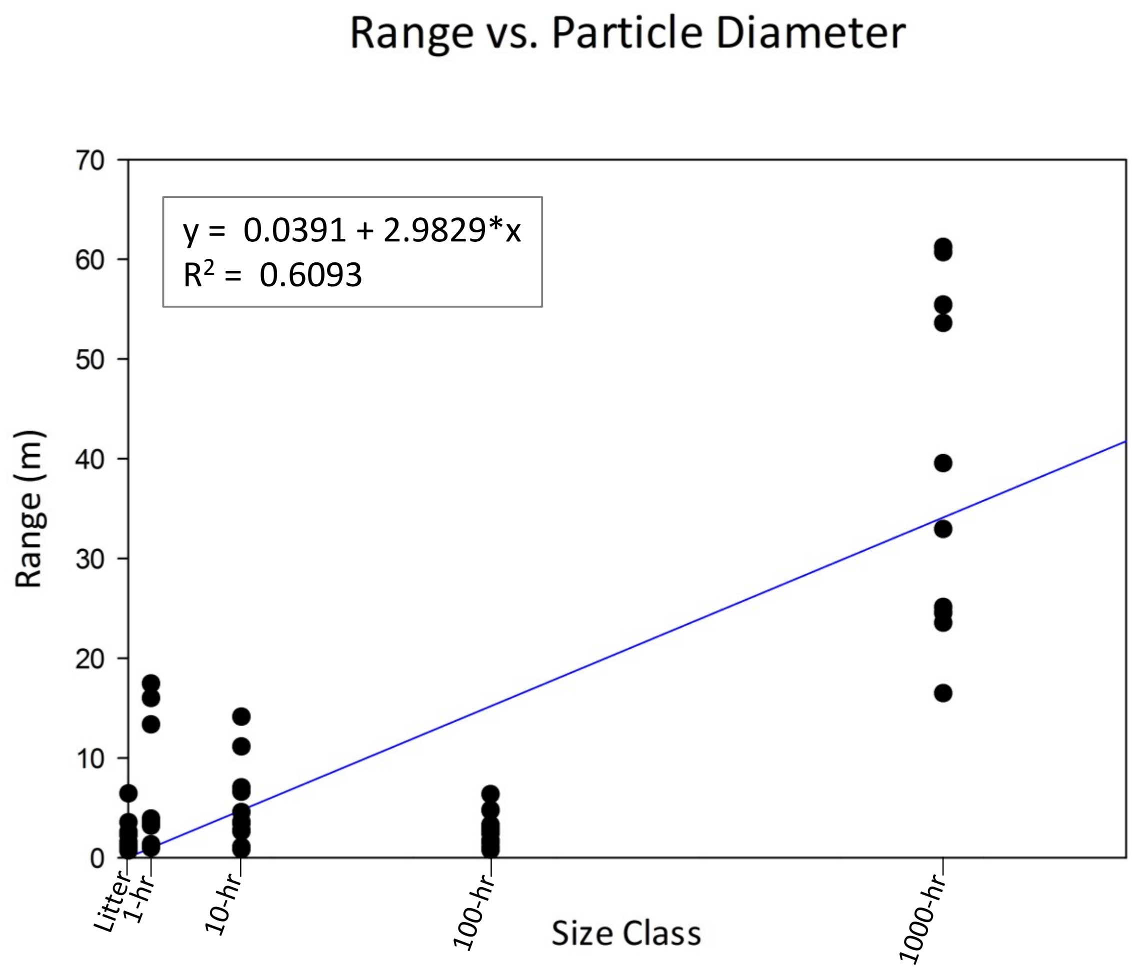
Results

- High variation in sill values
  - 0.002 to 0.4 $(kg/m^2)^2$
  - This equates to standard deviations between 0.2 and 2.8 tons/acre
- Ranges almost all under 4 meters
- No consistent treatment responses on burned sites
- Sills tended to increase in thin-only treatments



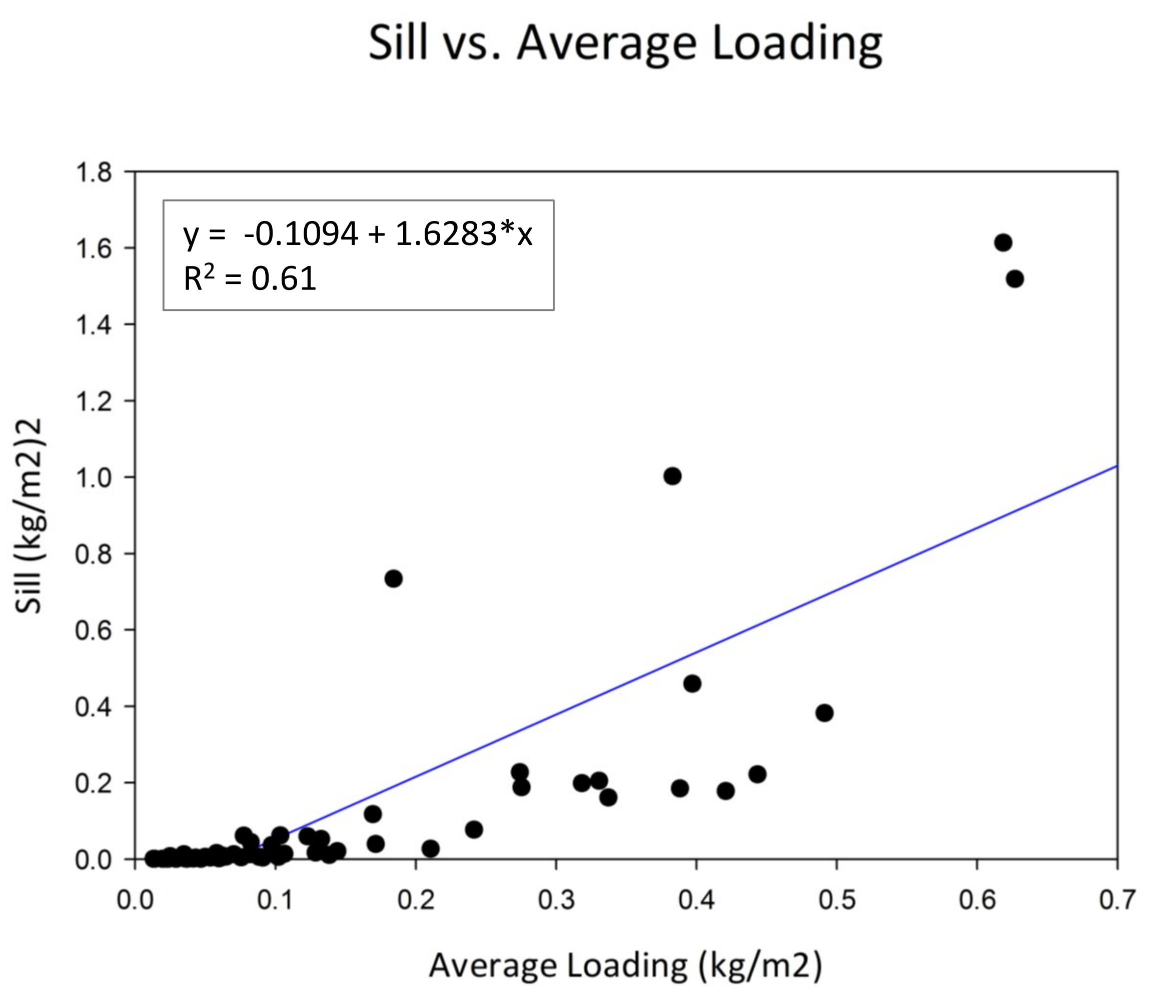


Results



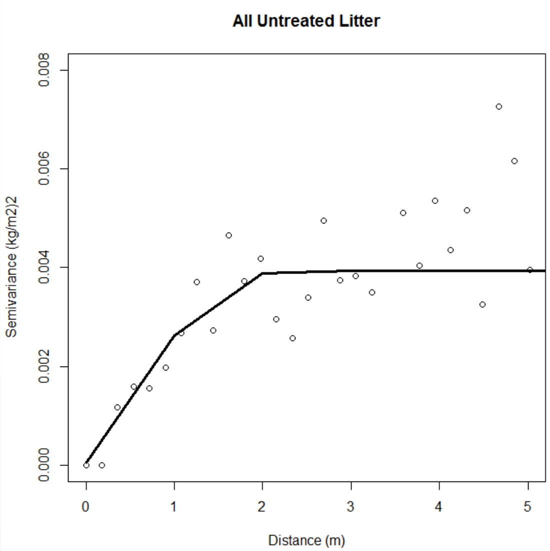
Range vs. Particle Diameter
y = 0.0391 + 2.9829*x
R2 = 0.6093
Range (m)
70
60
50
40
30
20
10
0
Litter
1-hr
10-hr
100-hr
1000-hr
Size Class

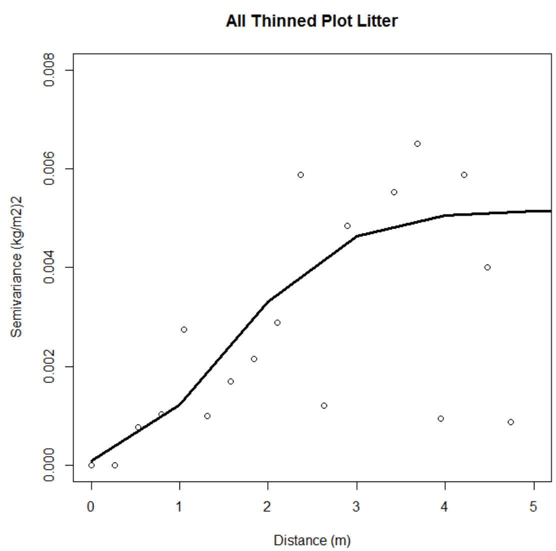
Results

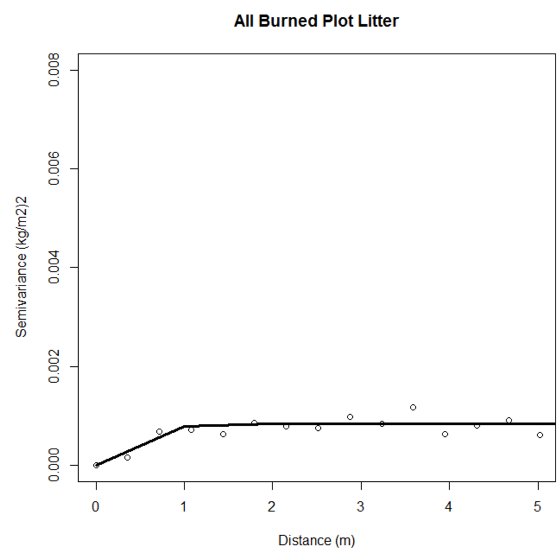


Sill vs. Average Loading
y = -0.1094 + 1.6283*x
R2 = 0.61
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Sill (kg/m2)2
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Average Loading (kg/m2)

Results: Litter





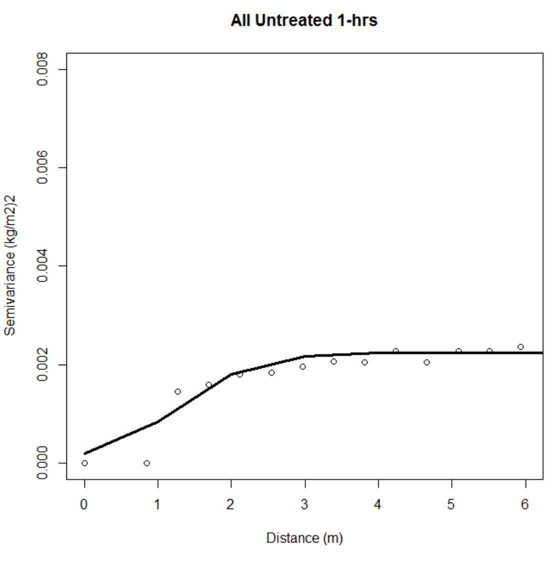


Sill = 0.0039
Range = 1.66 meters

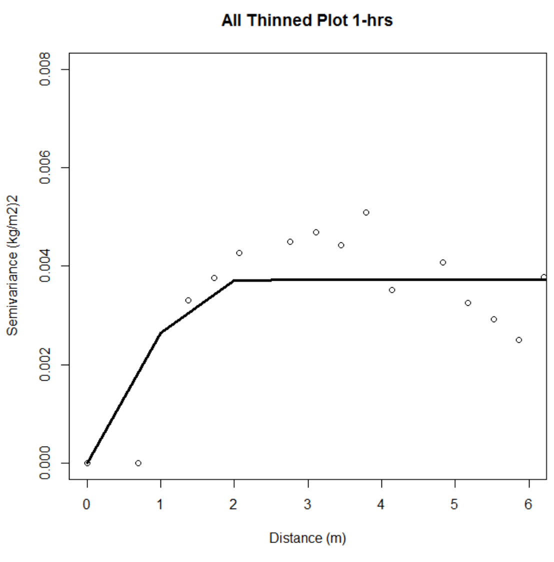
Sill = 0.0051
Range = 3.37 meters

Sill = 0.0008
Range = 1.05 meters

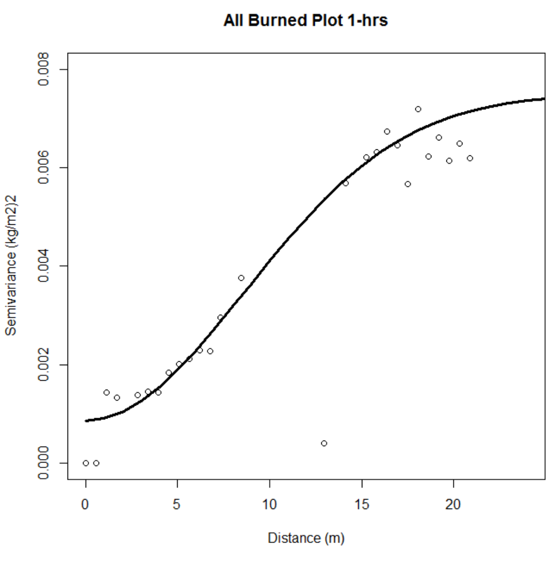
Results: 1-Hour Fuels



Sill = 0.0022
Range = 2.80 meters

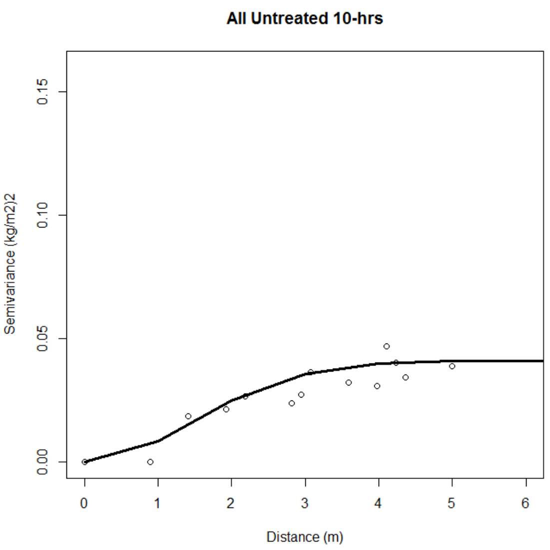


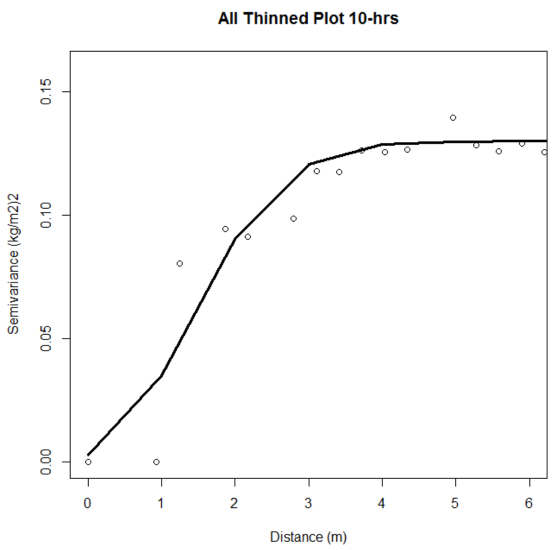
Sill = 0.0039
Range = 1.73 meters

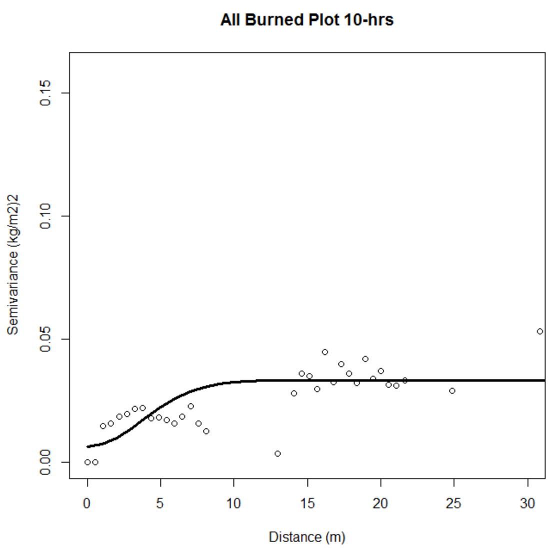


Sill = 0.0075
Range = 21.14 meters

Results: 10-hr Fuels





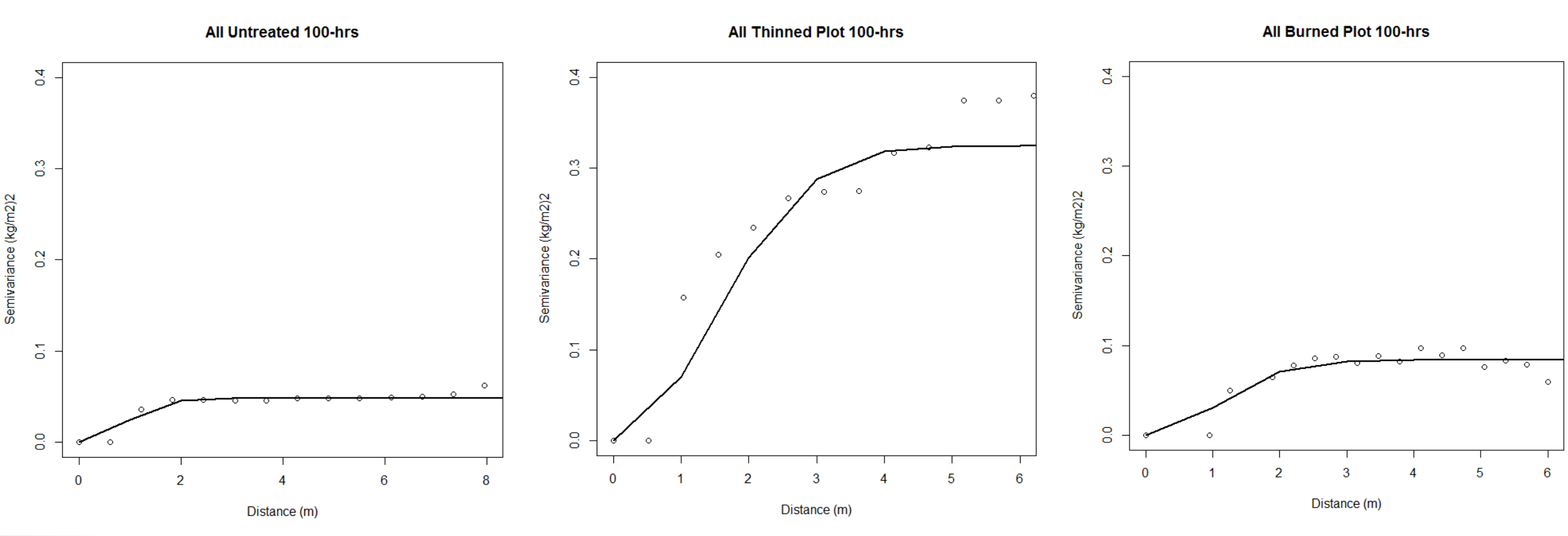


Sill = 0.041
Range = 3.60 meters

Sill = 0.130
Range = 3.22 meters

Sill = 0.033
Range = 9.09 meters

Results: 100-hr Fuels

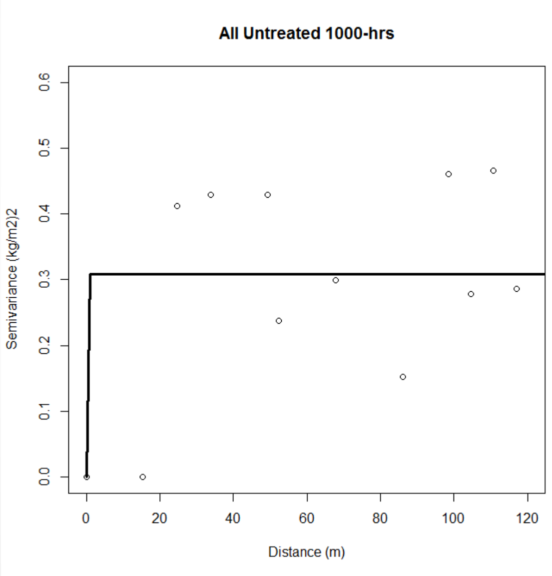


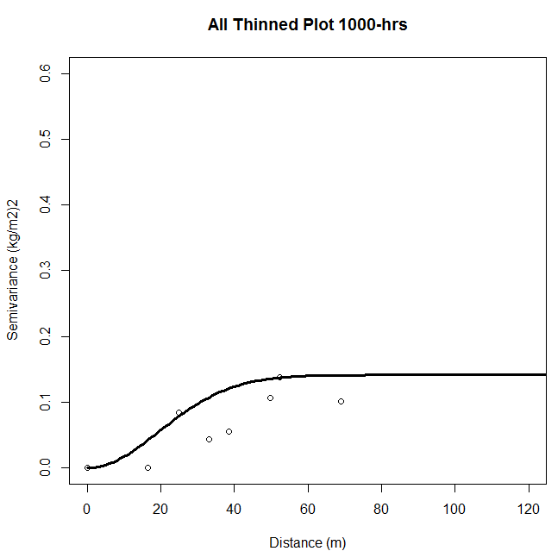
Sill = 0.048
Range = 2.05 meters

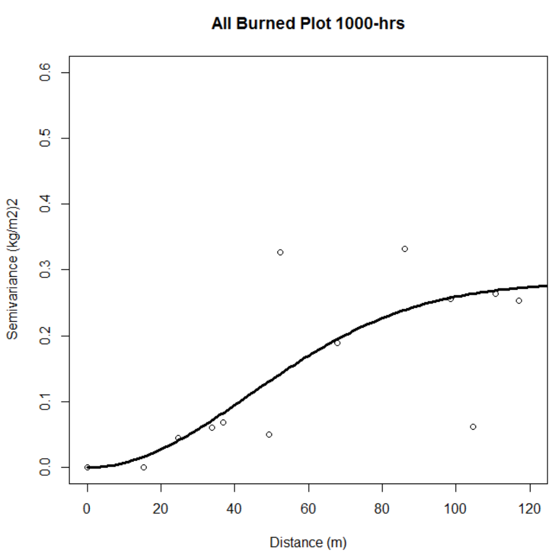
Sill = 0.325
Range = 3.52 meters

Sill = 0.084
Range = 2.54 meters

Results: 1,000-hr Fuels







Nugget = 0.316
Range = 0

Sill = 0.141
Range = 48.0 meters

Sill = 0.281
Range = 107.9 meters

Results– the good news

- Larger fuels vary at larger scales
- Sills are closely related to average loadings
- Patch sizes in untreated and thinned stands are similar in absolute terms– between 1 and 4 meters
  - The photoload technique is well-suited to this scale
- Sills of fine fuels are consistently increasing with thinning treatments

Results– the not-so-good news

- The magnitude of increase in variability is not consistent on thinned sites
- No consistent treatment responses on burned sites between fuel types
- Variability between patches is huge compared to average loading

Results- the not-so-good news

- Finding average loadings might not be so easy
- Thinned sites require more samples for the same level of accuracy
- Higher loadings require more samples for the same level of accuracy

So What?

- Current fuel assessment and mapping practices don’t correspond to the spatial scale of fuels variability.
  - Therefore, they cannot capture all fuelbed variability
- Variability is so high that standard practices likely don’t even capture the average fuel loading accurately

What's next?

- These results can be used to create more accurate fuel maps
  - Kriging
  - Pixel size in more advanced fire models
- 3-D modeling can determine how much difference this variability actually makes to fire dynamics

Acknowledgements

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Questions?