University of Wyoming National Park Service Research Center Annual Report

Volume 37 Article 10

1-1-2014

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Recommended Citation

Nelson, Kellen N. and Tinker, Daniel B. (2014) "Evaluating the Effects of Projected Climate Change on Forest Fuel Moisture Content," *University of Wyoming National Park Service Research Center Annual Report*: Vol. 37 , Article 10.
Available at: http://repository.uwyo.edu/uwnpsrc_reports/vol37/iss1/10

EVALUATING THE EFFECTS OF PROJECTED CLIMATE CHANGE ON FOREST FUEL MOISTURE CONTENT

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✦ OVERVIEW

Understanding how live and dead forest fuel moisture content (FMC) varies with seasonal weather and stand structure will improve researchers' and forest managers' ability to predict the cumulative effects of weather on fuel drying during the fire season and help identify acute conditions that foster wildfire ignition and high rates of fire spread. No studies have investigated the efficacy of predicting FMC using mechanistic water budget models at daily time scales through the fire season nor have they investigated how FMC may vary across space. This study addresses these gaps by (1) validating a novel mechanistic live FMC model and (2) applying this model with an existing dead FMC model at three forest sites using five climate change scenarios to characterize how FMC changes through time and across space. Sites include post-fire 24-year old forest, mature forest with high canopy cover, and mature forest affected by the mountain pine beetle with moderate canopy cover. Climate scenarios include central tendency, warm/dry, warm/wet, hot/dry, and hot/wet.

✦ YEAR 1 ACTIVITIES

Our first year progressed well and our work is on track. Field data from 2014 have been entered and checked for accuracy. Laboratory work related to the moisture content of foliar and surface dead fuel particles is being completed by student workers at the University of Wyoming and will be complete by June 2015. Kellen Nelson will fully analyze these data this year. We augmented our sampling design and field data collection methods to address several additional objectives: (1) With the help of NPS staff (Stacey Gunther and Roy Renkin), we selected three 1x1 km study sites on the Yellowstone Plateau that reflect important forest development stages to demonstrate the effects of forest development and stand structure on live and dead fuel moisture. Targeted forest development stages include 24 year post-fire, mature forest with high canopy cover, and mature forest affected by the mountain pine beetle with moderate canopy cover. (2) We added several fuel components including dead surface woody fuel particles, litter, and duff fuel and live understory plant fuels (herbs and graminoids) to investigate how changing weather conditions may alter these fuel components and expand the impact of the study. (3) 15 low-cost, open-source weather stations were developed by Kellen Nelson. These stations reduce costs by ~10 times of commercial systems while maintaining accuracy and reliability. Weather stations were deployed across the three study sites. Designs will be published in an appropriate peer-reviewed journal and assembly instructions will be available on Kellen Nelson's website. (4) Erick Larsen, a field crew member and student at the University of Washington, completed an independent study project that met the requirements for a senior thesis that investigates how stand structure influences seedling recruitment and growth in the three development stages mentioned in the objectives.

To accomplish the study objectives outlined in the proposal and support the additional objectives mentioned above, the Boyd Evison Fellowship was supplemented with grants from the UW/NPS Research Station (AMK Ranch—Research Station) and the American Alpine Club. Additionally, Kellen N. Nelson (student PI) and Daniel B. Tinker (faculty PI) have been awarded a 'Graduate Innovation grant' from the Joint Fire Sciences Program to expand the extent of this study to the entire Yellowstone Plateau. Research funded by the 2014 Boyd Evison fellowship (and other 2014 grants) provide the foundation for this new investigation and will enable us to be the first investigators to fully incorporate feedbacks and interaction between climate, vegetation, and fire across the Yellowstone Plateau landscape.

✦ RESULTS TO DATE

Weather station development

Weather stations were developed using the Arduino open-source prototyping platform and designed to measure the most relevant meteorological factors affecting forest fuel drying (Figure 1). An Arduino pro microcontroller was paired with an Adafruit Datalogger shield and powered using an AA battery pack. Data was logged to an SD card. Sensors were soldered directly to the Adafruit Datalogger shield and included temperature/humidity (SHT-15/75 sensor), soil water potential (Watermark 200ss), and soil and litter temperature (Vishay NTC Thermistor--NTCLE100E3). Measurements were logged during the fire season at 15 minute intervals.

Fuel moisture across three stages of forest development

Dead FMC varied through the season depending on the fuel particle and the stand development stage (Figure 2). Understory vegetation increased in FMC in the young stand but did not change in the mature stands. Duff FMC trended upward through the season in the mature stands but did not change appreciably in the young stands—perhaps because very little duff was observed at this site. Litter FMC was higher in the mature stands early in the season but all stands had similar FMC at the end of the season. One-hour fuel particle (woody material <0.25" diameter) FMC increased in the young forest site but did not in the mature sites. Ten-hour fuel particle (woody material 0.25"—1.00" diameter) FMC trended positively through the season.

Preliminary analysis of live FMC shows differences in FMC with needle age (Figure 3). From this preliminary analysis, there does not appear to be any statistical differences between sites; however, only one-third of the data has been processed in the lab.

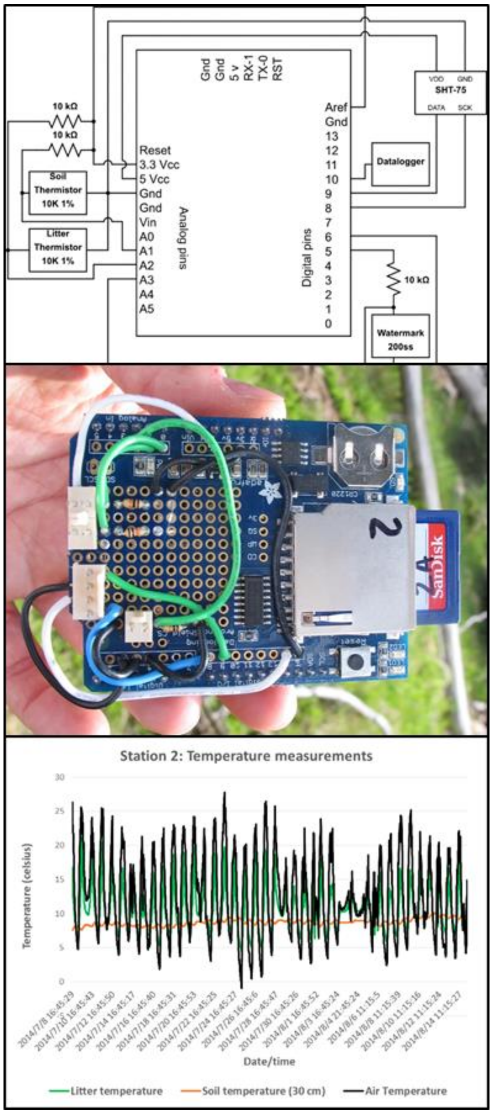
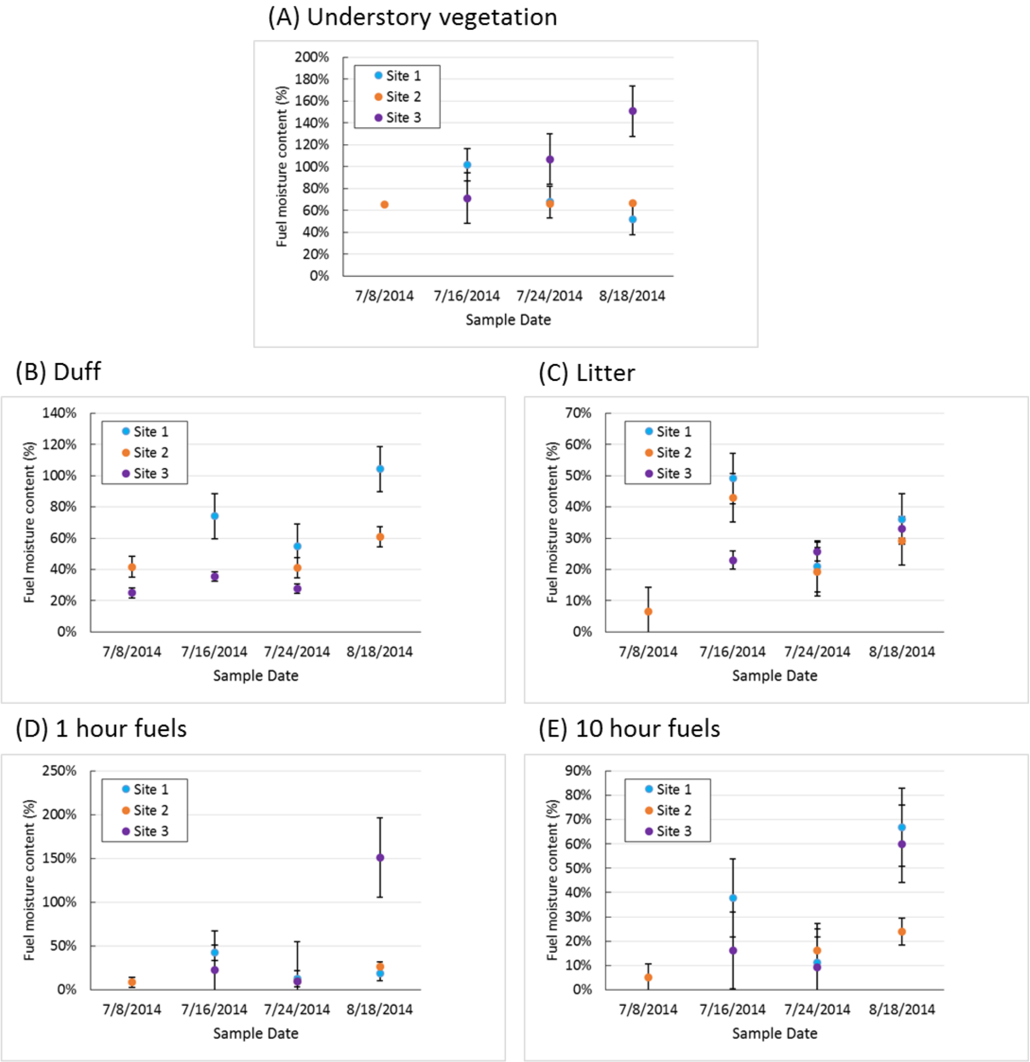


Figure 1. Weather station circuit diagram (top), completed prototype board (middle), and soil, litter, and air temperature for July and August 2014 (bottom).


(A) Understory vegetation

(B) Duff

(C) Litter

(D) 1 hour fuels

(E) 10 hour fuels

Figure 2. Mean (±1 Standard Error) FMC for dead fuel particles.

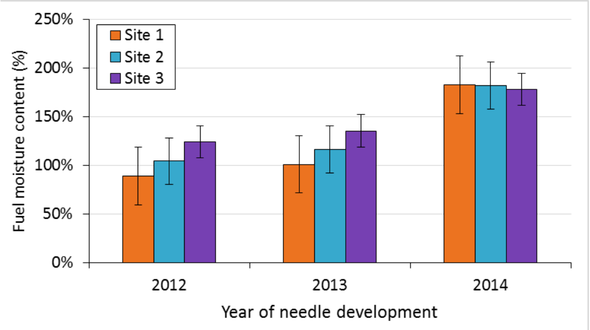


Figure 3. Mean live FMC on August 20—22 for each site by the year of needle development. Note: Results are preliminary and reflect approximately one-third of the data collected.

Stand structure across three stages of forest development

Tree density significantly differed between mature forest with high canopy cover, mature forest with moderate canopy cover, and the young post-fire forest. Sapling density, sapling basal area, total basal area, and all measures of quadratic mean diameter did not differ between the two mature study sites but did differ between the young, post-fire site and the two mature sites (Table 1). This data will be further analyzed and FMC models will be implemented during the next year.

Table 1. Mean and 95% confidence intervals for a selection of forest structure by site

Stand Structure Attribute	**Site 1: Mature forest with moderate canopy cover**	**Site 2: Mature forest with high canopy cover**	**Site 3: 25 year old post-fire forest**
Tree density (ha^{-1})	725 (627-822)	1300 (1099-1500)	0 (0)
Tree basal area (m^2)	40 (34.5-45.5)	46.9 (38.9-54.8)	0 (0)
Tree quadratic mean diameter (cm)	25.8 (24.1-27.6)	23.1 (21.5-24.7)	0 (0)
Sapling density (ha^{-1})	2274 (1792-2755)	1991 (1417-2565)	7417 (5896-8938)
Sapling basal area (m^2)	2.1 (1.6-2.7)	2.8 (1.9-3.6)	13.3 (10.4-16.2)
Sapling quadratic mean diameter (cm)	3.0 (2.6-3.4)	4.0 (3.4-4.6)	5.2 (4.5-6.0)
Total basal area (m^2)	42.1 (36.7-47.6)	49.6 (41.5-57.7)	13.1 (10.4-16.2)
All quadratic mean diameter (cm)	14.7 (13.1-16.2)	15.4 (14.0-16.7)	5.2 (4.5-6.0)
Seedling density (ha^{-1})	11341 (7812-14871)	6343 (3614-9072)	8980 (5824-12135)

The density of seedlings, saplings, and trees varied by species and site (Table 2). Mature lodgepole pine (*Pinus contorta*) tree density was highest in the high canopy cover site and lowest in the young, post-fire forest site. Lodgpeole pine seedlings were highest on the moderate canopy cover site that was affected by the mountain pine beetle and lowest on the high canopy cover site. Subalpine fir (*Abies lasiocarpa*) trees and saplings were most dense on the moderate canopy cover site and absent from the post-fire site. Subalpine seedlings were highest on the high canopy cover site and decreased with reductions in canopy cover. White bark pine (*Pinus albicaulis*) trees were the same in both mature forest stands but were absent from the post-fire stand. Whitebark pine saplings and seedling density were highest on the moderate canopy cover site and lowest on the post-fire site. Englemann spruce (*Picea Englemannii*) tree, sapling, and seedling density was highest on the high canopy cover site and lowest on the post-fire site.

Table 2. Species specific stand structure by site

Site	**Species**	**Tree density (ha^{-1})**	**Sapling density (ha^{-1})**	**Seedling density (ha^{-1})**	**Basal area (ha^{-1})**
1—Mature, moderate canopy cover	*Abies lasiocarpa*	68.1±24.8	355.8±149.8	732.2±247.3	2.3±0.9
	Pinus albicaulis	5.6±4.1	714.6±143.1	1092.9±255.8	0.6±0.1
	Pinus contorta	619.6±58.3	1157.9±282.1	9354.5±2877.9	38.8±2.5
	Picea englmannii	37.5±11.3	57.4±27.2	278.9±125.9	0.9±0.3
2—Mature, high canopy cover	*Abies lasiocarpa*	67.4±25.4	279±116.4	1180.9±353.6	2±0.7
	Pinus albicaulis	5.6±5.6	214.1±63.9	512.2±106.1	0.3±0.1
	Pinus contorta	1101.1±203.5	1329.9±303	4329.5±2385.6	41.3±5.7
	Picea englmannii	125.5±37.6	168.2±54.3	320.9±111.3	6±2.2
3—young, post-fire low canopy cover	*Abies lasiocarpa*	0±0	0±0	7.6±5.2	0±0
	Pinus albicaulis	0±0	0±0	22.9±13.6	0±0
	Pinus contorta	0±0	7417.2±969.9	8934±2633.8	13.3±1.5
	Picea englmannii	0±0	0±0	15.3±6.9	0±0

The growth rate of seedlings and saplings varied with site (Figure 3). Linear models were fit for each site. The highest growth rate (~0.3 m yr^{-1}) occurred on the post-fire site with no surviving overstory trees ($R^2=0.62$, $p<0.001$). Mature forest were significantly lower than the post-fire stand. The mature forest site with moderate canopy cover had a growth rate of ~0.03 m yr^{-1} ($R^2 = 0.53$, $p<0.001$) and the high canopy cover site had a growth rate of ~0.02 m yr^{-1} ($R^2 = 0.35$, $p<0.001$).

✦ PRODUCTS

Senior thesis (independent study research paper): Erick Larsen. 2014. Drivers of tree regeneration and seedling success in Yellowstone National Park. University of Washington.