

Forest Fuels and Management Considerations at the Willey Conservation Easement, Colorado

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Introduction

Changing disturbance regimes and climate are poised to reshape many of Earth's forested ecosystems (Buma & Wessman, 2013; Overpeck et al., 1990; Seidl et al., 2017). In the American West, increasing wildfire activity and climate change are driving major forest reorganization (Coop et al, 2020; Davis et al., 2019; Johnstone et al., 2016), with consequences to wildlife habitat, air and water quality, infrastructure and human lives (Western Forestry Leadership Coalition, 2010). Monitoring and managing forest fuels can reduce wildfire risk, sustain key understory and overstory species, and support biodiversity and ecosystems services (Schwilk et al., 2009, Prichard et al., 2010).

The Willey Conservation Easement (WCE) is a 160-acre property in the Rocky Mountains of southwestern Colorado, a region that has recently experienced unprecedented wildfires, forest beetle outbreaks, and substantial warming. A report generated by Bio-Environs (2015) suggested that the approximately 100-acre forest and 16-acre irrigated hayfield on the WCE had not experienced notable natural disturbance or direct ecological management in the recent past, and forest fuels were not quantified in the report. This lack of data means the health and potential resiliency of the forest to intensifying environmental change is unknown (Dr. Ian Billick, personal communication, February 2021). Consequently, there is a pressing interest in determining forest conditions, in particular with regards to the potential role of prescribed fire as a useful management tool for the property. The objective of this study was to quantify live and dead fuels at sites on the property, such that the resulting data could be used to model likely wildfire patterns and severity. Additional data on forest regeneration and understory composition were also noted to provide a current baseline of key ecological indicators of resilience. Finally, potential management strategies were outlined which might be considered in order to reduce wildfire risk and increase forest resilience.

Methods

The WCE consists of 160 acres in Hinsdale County, Colorado, and includes a hay field, a portion of Cebolla Creek, a forested hillside with two distinct aspects and attendant forest vegetation types, and a dry mesa grassland. Data were collected by from nine plots for this preliminary analysis, with the goal of informing a WCE fuels and fire management plan.

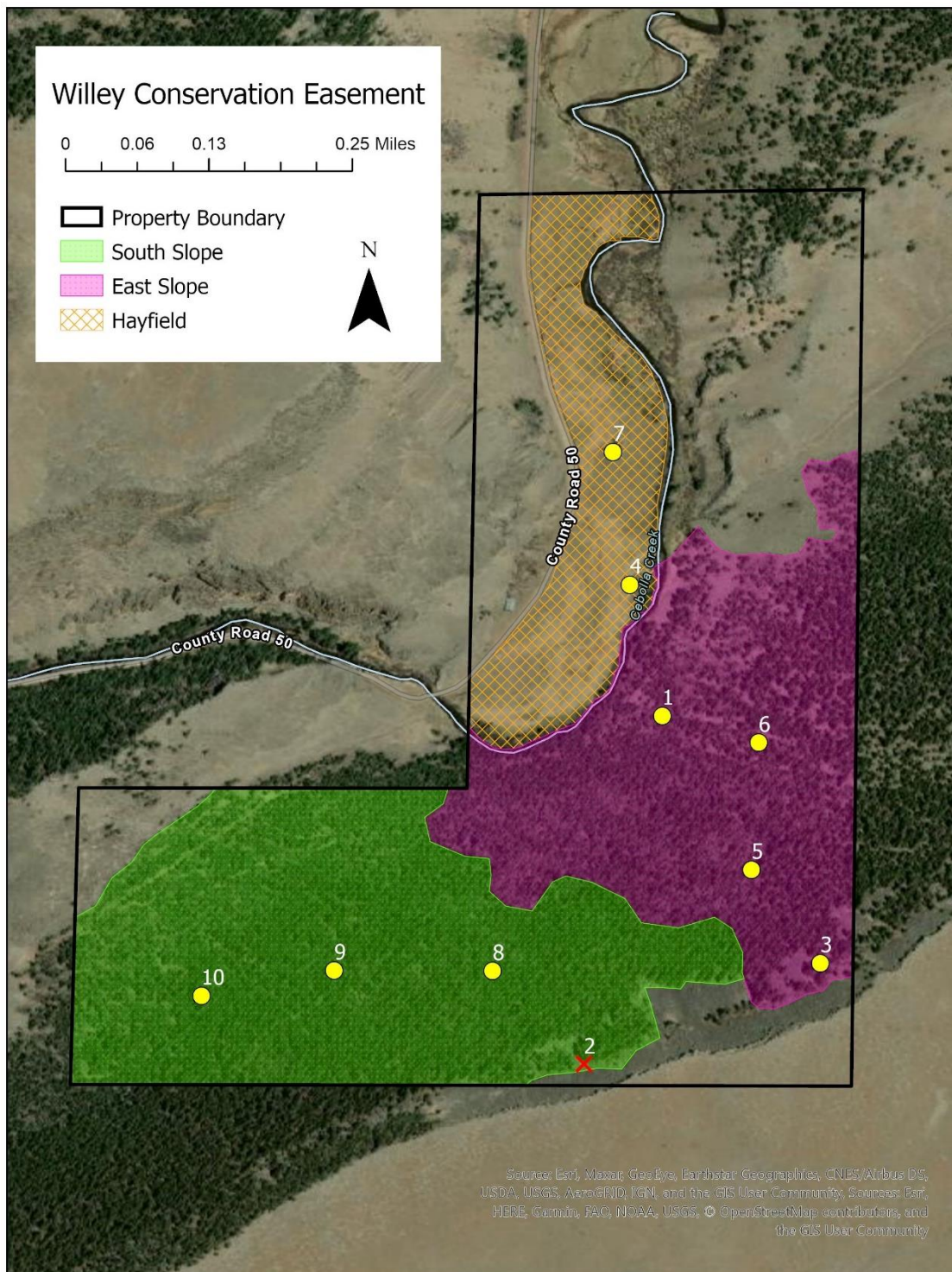


Figure 1. Sampling points in yellow, accompanied by their respective numbers. Site 2, which was omitted, is shown as a red X. The boundary between the Hayfield and the East Slope is Cebolla Creek. The boundary between the East and South Slopes is defined by a swath of spaced-out aspens abutting the tightly bunched growth of the South Slope.

Plot locations were randomly determined by generating 10 points within the bounds of the easement using ArcGIS Pro software, a property boundary shapefile, and aerial photographs of the property. Coordinates for each point were recorded and used as plot centers. No physical plot markers were to be placed on the easement; GPS coordinates of each plot center were recorded in the field using a high-precision Trimble Geo 7x GPS units on loan from the Rocky Mountain Biological Laboratory (RMBL) (see Appendix 1 for plot coordinates). One plot was omitted (Site 2) due to safety and logistical concerns arising from an extremely steep slope with loose substrate.

At the other nine sites, data were collected in 12.6-m radius plots. For all individual trees I recorded species, diameter at breast height (DBH), crown base height (CBH) and total height using a rangefinder, and health status (5 = long dead/missing bark and branches, 4 = recent dead/missing nearly all needles or leaves, 3 = crown half or more dead, 2 = crown less than half dead, 1 = healthy). These data were used to calculate standing biomass (a metric of canopy fuel loads) using the allometric equations of Ter-Mikaelian and Korzukhin (1997; Appendix 2).

Tree regeneration was measured in a 5.6-m radius subplot with the same plot center, and included species, height class (<10 cm, >10-20 cm, >20-40 cm, >40 -137 cm tall), and health (quantified in the same categories as above).

Foliar cover by understory vegetation (vascular plants) was visually estimated by four life-form classes (forbs, graminoids, shrubs, and tree regeneration) within 1-m² quadrats, three per plot, located at the midpoint of each transect. The height of each lifeform was also recorded, and each quadrat was photographed. Where known, species were noted.

Surface fuels were sampled along each of the three transects as follows. Duff and litter were measured to the nearest 0.5 cm using a ruler at three sites (four, eight, and twelve m from plot center), and downed woody fuels were measured using a go/no-go to determine 1-, 10-, 100-, and 1000-hour fuels crossing the same transects. 1000-hr fuels were measured along the entire transect, with the diameter and condition (sound vs. rotten) recorded for each. 100-hour fuels were measured along the last five meters, and both 10-hour and 1-hour fuels were measured along the last two meters. Fuels were counted using methods and quantified using equations described in Brown (1974; Appendix 3).

Data were subjected to summary statistics using Microsoft Excel to determine the average number of trees per acre, the average tree basal area (ft²/acre), the average crown-base height of the canopy (ft), the average aboveground tree biomass (tons/acre), the average tons of 1-hour fuels/acre, the average tons of 10-hour fuels/acre, the average tons of 100-hour fuels/acre, the average tons of 1000-hour fuels/acre, and the average tons of duff and litter/acre throughout each of the three sampling areas, named as follows: the Hayfield, the East Slope, and the South Slope (see a map of boundaries and sampling points in Figure 1.). Note that fuels measures are provided using English rather than metric units as these are more commonly used by practicing foresters and fire managers, and fire behavior models.

Summary Statistics and Photographs

Table 1. Average fuel loads by site type. There were two sites (4, 7) in the Hay Field, four sites on the East Slope (1, 3, 5, 6), and three sites on the South Slope (8, 9, 10). Decimals are rounded to two places and standard deviations are shown in parentheses.

Site Type	Average Trees/Acre	Average Basal Area (ft ² /Acre)	Average Crown-Base Height (ft)	Average Aboveground Tree Biomass (Tons/Acre)	Average Tons of 1-Hour Fuels/Acre	Average Tons of 10-Hour Fuels/Acre	Average Tons of 100-Hour Fuels/Acre	Average Tons of 1000-Hour Fuels/Acre	Average Tons of Duff and Litter/Acre
Hay Field	32.46 (± 45.90)	28.89 (± 40.86)	0.46 (± 1.71)	155.41 (± 219.78)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.00 (± 0.00)	0.11 (± 0.15)
East Slope	770.82 (± 478.28)	70.48 (± 12.92)	2.53 (± 4.04)	218.94 (± 61.80)	9.17 (± 4.66)	15.13 (± 5.68)	14.95 (± 10.59)	22.57 (± 15.79)	16.62 (± 11.66)
South Slope	1003.41 (± 121.80)	120.00 (± 30.65)	4.56 (± 3.97)	454.22 (± 203.13)	15.94 (± 4.33)	14.74 (± 3.02)	63.04 (± 16.53)	10.02 (± 7.92)	19.14 (± 15.79)

Table 2. Comparison of total live and dead tree counts, and live and dead aboveground biomass (AGB) from trees across site types. Live trees had recorded health scores of 1, 2 or 3, and dead trees had recorded health scores of 4 or 5. Decimals are rounded to two places and standard deviations are shown in parentheses.

Tree Status	Total Count	Hay Field AGB (Tons/Acre)	East Slope AGB (Tons/Acre)	South Slope AGB (Tons/Acre)
Live	493	15.24 (± 21.55)	22.20 (± 7.58)	50.15 (± 24.75)
Dead	330	3.91 (± 5.53)	4.79 (± 3.56)	5.83 (± 0.04)



Figure 2. A photograph from Site 7 in the hay field. Much of this area was under standing water for several months starting in April.

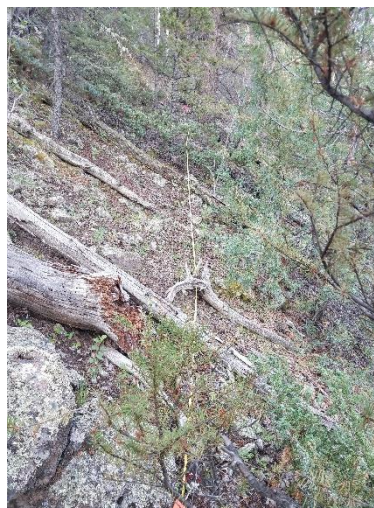


Figure 3. A photograph from Site 5 on the East Slope. Plots on this section contained more grasses and tree seedlings than those on the South Slope.



Figure 4. A photograph from Site 10 on the South Slope. Plots on this section contained most of the Douglas fir (*Pseudotsuga menziesii*) captured in this data set.

Findings and Management Implications

Below, I will describe the general characteristics of each of the three sampling areas (the Hayfield, the East Slope and South Slope forests), and management considerations. In the Hayfield, there is very little accumulated duff, litter, or woody fuels to remove (see Table 1.: no woody fuels were recorded at either site 4 or 7), and the existing irrigation system left much of the soil in this section very wet or under standing water starting in April. Consequently, the Rocky Mountain Biological Laboratory (RMBL) and Colorado Open Lands (COL) may wish to focus the majority of their management efforts and resources for this property on the sloped, forested portions of the easement east and south of Cebolla Creek. However, there may be opportunities for riparian vegetation restoration along Cebolla Creek, which was not sampled here. In particular, field observations suggest substantial recent dieback of alder (*Alnus incana* var. *tenuifolia*). Further sampling might be useful to determine the extent of this dieback vs. regeneration, and whether or not protection from browsing (by elk, deer, or livestock) could enhance juvenile growth and survival.

The highest concentration of duff, litter, downed woody fuels, and aboveground biomass were all recorded on the South Slope, which contained the densest and youngest forests stands (Tables 1. & 2.). Note that high standard deviations across the majority of my average measurements reflect substantial variation between individual sites, and suggest that additional sampling would be useful. The densely-treed South slope contained most of the Douglas fir (*Pseudotsuga menziseii*) in the data set, some of which was noted to be affected by western spruce budworm. In contrast, the East Slope was more open, with larger and older trees, some of which displayed evidence of historical low-severity fire in the form of fire scars. Forest structure here likely reflects historical, stand-replacing fire. Both the ponderosa pines recorded in this data set were on the East Slope, also consistent with a warmer aspect that may have historically burned at low severity. Understory vegetation on the East Slope also included higher proportions of grasses.

On June 11th, I brought Bureau of Land Management Fire Management Specialist Brian Stevens, US Forest Service Fuels Specialist David Carr, and Western Colorado University Professor Jonathan Coop to the WCE to get their professional opinions on treatment options for the property and prospective costs. Based on existing scientific literature and the expertise of Mr. Stevens, Mr. Carr, and Dr. Coop, there are three primary strategies RMBL and COL might wish to pursue on the forested portion of the WCE to reduce fuels and/or enhance forest resilience, depending on management priorities and desired outcomes, and contingent on additional monitoring data. These include:: 1.) selective cutting; 2.) selective cutting and piling; and 3.) selective cutting and piling with pile burning. If any such treatment(s) are applied on this property, it would be beneficial to create replicate sites on both the south and east slopes. Mr. Stevens and Mr. Carr both advised against broadcast burning on the WCE due to the relatively small area, steep slopes, unstable soil, and the logistical difficulty of containing such a burn to the property boundaries.

Selective cutting could include felling of dead aspen (*Populus tremuloides*) trunks, unhealthy Engelmann spruce (*Picea engelmannii*), and budworm-infested Douglas firs, and leaving the downed trees where they fell. There would be no felling of healthy blue spruce

(*Picea pungens*) near Cebolla Creek, or any of the bristlecone pines (*Pinus aristata*). Selective felling would open the forest canopy and stimulate regeneration, particularly of shade-intolerant aspen (Krasnow & Stephens, 2015). Leaving the felled trees in place would deter deer and elk from eating the new aspen suckers, reducing browsing pressure and promoting regeneration of aspen. Increasing aspen may decrease long-term fire risk on treated areas, as it is generally less flammable than conifers. However, there would be a short-term increase in heavy surface fuels associated with the newly downed trees.

Selective cutting and piling would again focus on cutting down unhealthy aspens, Engelmann spruce, and Douglas fir, but would also include amassing the downed trees in piles. This would add approximately \$1100 per acre treated to the project cost, and potentially inhibit aspen regeneration by allowing elk access to the new sucker growth. (Baker, 1997).

Lastly, adding a pile burn component to the treatment would add approximately \$300-\$500 per acre treated to the project cost. This would decrease immediate fire risk from the felled fuels. Multiple studies have found this combination to be more effective at fostering new seedling growth and biodiversity than just cutting or burning alone (Schwilk et al., 2009, Prichard et al., 2010).

To supplement any treatments that RMBL and COL may choose to pursue, we recommend the establishment of Good Neighbor Agreements with the U.S. Forest Service and the Bureau of Land Management. Under these agreements, were either agency to conduct a burn on their adjacent property, they could also assume legal liability for extending the burn into the WCE. However, such agreements alone are not likely to serve as sufficient management for the forested portion of the WCE, as no work is currently being planned on public lands in the adjacent areas, and a prescribed burn would be unlikely from either agency within the next 15 years.

The WCE presents a unique monitoring and management opportunity for RMBL and COL to foster and document forest resilience in the face of climate change, drought, fire, insects, and traditional human land use. The data collected in this study can be used to inform those management decisions, to model potential wildfire behavior, and to serve as a baseline for future data collection. Since the property is not already subject to long-term observational studies as is the case near Gothic, it may lend itself very well to rigorous and replicated experimentation with a range of land management interventions. This is particularly relevant as the conservation easement goals include maintaining a scenic, natural space that provides high-quality wildlife habitat. Consequently, establishing management strategies that benefit the long-term health of the forested and riparian areas, and improve scientific knowledge of intervention efficacy, is both crucial and feasible.

Acknowledgements

I would like to thank Dr. Jonathan Coop for supervising this project, assisting in planning the data collection methods, visiting the WCE, providing professional insights and contributing to this report. I also thank the Western Colorado University Clark School of Environment and Sustainability and the Gunnison Field Office of the Bureau of Land Management for providing the tools necessary for data collection. Brian Stevens and David Carr visited the WCE and provided professional insights, and Shannon Sprott provided the WCE property shapefile and

protocols for using the Trimble Geo 7x GPS units, lent by RMBL. Access to the property was provided by RMBL and COL. Finally, I thank Dr. Ian Billick sparking my interest in this project.

Appendix 1: Sample Site Locations

Site Number	Date Sampled	Elevation (m)	Degrees Longitude	Degrees Latitude
1	7/17/2021	2760.838	38.077349102	-107.037180363
3	8/17/2021	2978.921	38.074234448	-107.035186038
4	7/16/2021	2727.271	38.078999534	-107.037588984
5	8/17/2021	2881.705	38.075410782	-107.036055499
6	8/9/2021	2821.923	38.077009424	-107.035962762
7	7/16/2021	2724.722	38.080668617	-107.037799965
8	8/21/2021	2880.238	38.074135153	-107.039317024
9	8/21/2021	2871.136	38.074141500	-107.041314344
10	7/16/2021	2846.943	38.073824240	-107.042988910

Appendix 2: Equations Used for Tree Biomass Calculations

These equations were selected from those compiled by Ter-Mikaelian and Korzukhin (1997). Original equation authors are noted after species names for clarity. Where multiple equations were available for the same species, I chose the equation with the greatest sample size and closest sampling location to Western Colorado. The following equations all yield results in kilograms from DBH measurements in centimeters. For this analysis, all results were later converted to tons.

Abbreviations

AB: total aboveground biomass, used for trees with a recorded Health score of 1, 2 or 3.

ST: stem biomass, used for trees with a recorded Health score of 4 or 5.

BR: branches' biomass, used for trees with a recorded Health score of 4 or 5.

DBH: diameter at breast height, measured in centimeters.

Species and Equations

Abies concolor (White Fir) – Equations from Brown (1978) for *Abies lasiocarpa* were applied.

$$AB = ((.2513)*(DBH)^{1.5699})+((0.3894)*(DBH)^{1.2311})+((0.1926)*(DBH)^{1.5712})$$

$$ST = (.2513)*(DBH)^{1.5699}$$

$$BR = (0.1926)*(DBH)^{1.5712}$$

Alnus (Alder) – Equations from Young et al. (1980) for *Alnus rugosa*.

$$AB = (0.2612)*(DBH)^{2.2087}$$

Pinus aristata (Bristlecone Pine) – Equations from Gholz et al. (1979) for *Pinus contorta* were applied.

$$AB = ((0.0492)*(DBH)^{2.4287})+((0.0239)*(DBH)^{1.8362})+((0.0089)*(DBH)^{2.3533})$$

$$ST = (0.0492)*(DBH)^{2.4287}$$

$$BR = (0.0089)*(DBH)^{2.3533}$$

Picea engelmannii (Engelman Spruce) – Equations from Brown (1978).

$$AB = ((0.2844) * (DBH)^{1.3782}) + ((0.3346) * (DBH)^{1.2765}) + ((0.1687) * (DBH)^{1.5799})$$

$$ST = (0.2844) * (DBH)^{1.3782}$$

$$BR = (0.1687) * (DBH)^{1.5799}$$

Pinus ponderosa (Ponderosa Pine) – Equations from Brown (1978).

$$AB = ((0.2679) * (DBH)^{1.4726}) + ((0.1167) * (DBH)^{1.5774}) + ((0.0469) * (DBH)^{2.1315})$$

$$ST = (0.2679) * (DBH)^{1.4726}$$

$$BR = (0.0469) * (DBH)^{2.1315}$$

Picea pungens (Blue Spruce) – Equations for *Picea engelmannii* were applied.

Populus angustifolia (Narrowleaf Cottonwood) – Equations from Perala and Alban (1994) for AB and ST, and Freedman et al. (1982) for BR for *Populus gradidentata*.

$$AB = ((0.0785) * (DBH)^{2.4981})$$

$$ST = ((0.0426) * (DBH)^{2.5618}) + ((0.0333) * (DBH)^{2.2142})$$

$$BR = ((0.1368) * (DBH)^{1.751})$$

Populus tremuloides (Trembling Aspen) – Equations from Johnston and Bartos (1977).

$$AB = (0.1231) * (DBH)^{2.242}$$

$$ST = (0.1007) * (DBH)^{2.219}$$

$$BR = (0.112) * (DBH)^{2.495}$$

Pseudotsuga menziesii (Douglas Fir) – Equations from Marshall and Wang (1995) for AB and Brown (1978) for ST and BR.

$$AB = (0.0808) * (DBH)^{2.5282}$$

$$ST = (0.2168) * (DBH)^{1.7236}$$

$$BR = (0.2624) * (DBH)^{1.5464}$$

Appendix 3: Equations Used for Downed Fuel Biomass Calculations

Downed Woody Debris:

$$1, 10 \text{ hr size class: } 0\text{-}3 \text{ in: (tons/acre)} = (11.64 * n * d^2 * s * a * c) / Nl$$

$$100, 1000 \text{ hr size classes: } 3\text{+ inches: (tons/acre)} = (11.64 * \sum d^2 * s * a * c) / Nl$$

Where:

c = slope correction factor

n = total number of intersections over all sample points (for each of the 1-hr, 10-hr and 100-hr samples)

d² = squared average diameters

Diameter class (inches) :	0-0.25	0.25-1	1-3
d ² (inches ²):	0.0151	0.289	2.76

For 1000-hr fuels (3+ in), the actual diameters of each piece are squared and added together to get $\sum d^2$

s = specific gravity of the materials

Diameter class (inches) :	0-0.25	0.25-1	1-3	3+Sound	3+Rotten
Specific gravity :	0.48	0.48	0.40	0.40	0.30

a = the nonhorizontal angle correction factors

0 to 3 inches: 1.13

3+ inches: 1.00

Nl = the total length of the sampling line

Litter and Duff:

Litter and duff loadings were calculated by multiplying the average depth over all three transect measurements by the bulk density of litter (2.75 lbs/ft³) and duff (5.5 lbs/ft³). Results were then converted to tons/acre.

Literature Cited

- Baker, W.L., Munroe, J.A. and Hessel, A.E. (1997). The Effects of Elk on Aspen in the Winter Range in Rocky Mountain National Park. *Ecography*, 20: 155-165.
<https://doi.org/10.1111/j.1600-0587.1997.tb00358.x>
- Bio-Environs. (2015). The Cathedral Property / Willey 2106 Conservation Easement Present Condition Report.
- Brown, J.K. (1974). Handbook for Inventorying Downed Woody Material. USDA Forest Service General Technical Report INT-16.
- Buma, B., Wessman, C.A. (2013). Forest Resilience, Climate Change, and Opportunities for Adaptation: A Specific Case of a General Problem. *Forest Ecology and Management*, Volume 306: 216-225. <https://doi.org/10.1016/j.foreco.2013.06.044>.
- Coop, J.D., Parks, S.A., Stevens-Rumann, C.S., Crausbay, S.D., Higuera, P.E., Hurteau, M.D., Tepley, A., Whitman, E., Assal, T., Collins, B.M., et al. (2020). Wildfire-driven forest conversion in western North American landscapes. *BioScience* 70, 659–673.
- Davis, K.T., Dobrowski, S.Z., Higuera, P.E., Holden, Z.A., Veblen, T.T., Rother, M.T., Parks, S.A., Sala, A., and Maneta, M. (2019). Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. *Proceedings of the National Academy of Sciences*, pp. 6193–6198.
- Johnstone, J.F., Allen, C.D., Franklin, J.F., Frelich, L.E., Harvey, B.J., Higuera, P.E., Mack, M.C., Meentemeyer, R.K., Metz, M.R., Perry, G.L., et al. (2016). Changing disturbance regimes, ecological memory, and forest resilience. *Front. Ecol. Environ.* 14, 369–378.

- Krasnow, K. D., and S. L. Stephens. (2015). Evolving Paradigms of Aspen Ecology and Management: Impacts of Stand Condition and Fire Severity on Vegetation Dynamics. *Ecosphere* 6(1):12. <http://dx.doi.org/10.1890/ES14-00354.1>
- Overpeck, J.T., Rind, D., and Goldberg, R. (1990). Climate-induced changes in forest disturbance and vegetation. *Nature* 343, 51–53.
- Prichard, S.J., Peterson, D.L., and Jacobson K. (2010). Fuel Treatments Reduce the Severity of Wildfire Effects in Dry Mixed Conifer Forest, Washington, USA. *Canadian Journal of Forest Research*. 40(8): 1615-1626. <https://doi.org/10.1139/X10-109>
- Schwilk, D.W., Keeley, J.E., Knapp, E.E., McIver, J., Bailey, J.D., Fettig, C.J., Fiedler, C.E., Harrod, R.J., Moghaddas, J.J., Outcalt, K.W., Skinner, C.N., Stephens, S.L., Waldrop, T.A., Yaussy, D.A. and Youngblood, A. (2009). The National Fire and Fire Surrogate Study: Effects of Fuel Reduction Methods on Forest Vegetation Structure and Fuels. *Ecological Applications*, 19: 285-304. <https://doi.org/10.1890/07-1747.1>
- Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., et al. (2017). Forest disturbances under climate change. *Nat. Clim. Change* 7, 395–402.
- Ter-Mikaelian, M.T., Korzukhin, M.D. (1997). Biomass equations for sixty-five North American tree species. *Forest Ecology and Management*, 97.1: 1-24. [https://doi.org/10.1016/S0378-1127\(97\)00019-4](https://doi.org/10.1016/S0378-1127(97)00019-4).
- Western Forestry Leadership Coalition. (2010). The True Cost of Wildfire in the Western U.S.