RE-GREENING TREES:

ASSESSING POST-FIRE CHANGES TO INDIVIDUAL TREE HEALTH AND MORTALITY AT THE CALWOOD EDUCATION CENTER

AUTHORS: Lauren E. Lad, Wade T. Tinkham,
Camille S. Stevens-Rumann

COLORADO FOREST RESTORATION INSTITUTE
COLORADO STATE UNIVERSITY

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CSU Land Acknowledgment: Colorado State University acknowledges, with respect, that the land we are on today is the traditional and ancestral homelands of the Arapaho, Cheyenne, and Ute Nations and peoples. This was also a site of trade, gathering, and healing for numerous other Native tribes. We recognize the Indigenous peoples as original stewards of this land and all the relatives within it. As these words of acknowledgment are spoken and heard, the ties Nations have to their traditional homelands are renewed and reaffirmed. CSU is founded as a land-grant institution, and we accept that our mission must encompass access to education and inclusion. And, significantly, that our founding came at a dire cost to Native Nations and peoples whose land this University was built upon. This acknowledgment is the education and inclusion we must practice in recognizing our institutional history, responsibility, and commitment.

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Photo Credit: Moderate severity burn patch from the Calwood Fire at Columbine camp 5. Photo by Rafael Salgado

Authors: Lauren E. Lad[1], Wade T. Tinkham[2], Camille S. Stevens-Rumann[1]

1. Colorado Forest Restoration Institute, Department of Forest and Rangeland Stewardship, Colorado State University, Fort Collins, CO

2.Rocky Mountain Research Station, USDA, US Forest Service

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Colorado State University
Colorado Forest Restoration Institute
Department of Forest & Rangeland Stewardship
Mail Delivery 1472
Fort Collins, Colorado 80523
(970) 491-4685 • www.cfri.colostate.edu

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Introduction

The 2020 fire season was particularly impactful for Colorado forests featuring several record-breaking fires in both extent and cost. One fire that burned during a wave of late season ignitions was the Calwood Fire. The Calwood Fire burned from October 17 to November 14, 2020, though most acres burned in the first three hours of the fire and burned approximately 600 acres on the Calwood Education Center (CEC) property and ~10,000 acres in total. The area burned on the CEC property affected forests comprised of primarily ponderosa pine (*Pinus ponderosa*), with some Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*). The fire burned at varying intensities and trees on the CEC property experienced gradients of burn severity from low to high, with more than 40% of the fire exhibiting high severity effects.

The dominant species on the site, ponderosa pine, is a fire-adapted species that is resistant to low-severity fires but has also demonstrated the ability to recover after high severity fires (Fitzgerald, 2005). Specifically, the open crown, thick bark, and deep root system help these trees retain moisture and disperse heat during fires (Fitzgerald, 2005). Additionally, bundles of needles have shown recovery following scorch when meristematic tissue remains protected, as in situations of high intensity fire where high winds reduce the time that flames spend in direct contact with branch tips (Fitzgerald, 2005). However, the suppression of fire during the 20th century in these forests has increased tree density and fuel continuity, which is exacerbated by climate change to promote increased fire intensity (Rodman et al., 2019).

The ponderosa pine-dominated forests around the CEC's Columbine and Mica Mine camps experienced a fire severity gradient with a range of tree crown scorch and consumption (Figure 1a). The area surrounding Columbine camp experienced these high intensity flames during a period of high winds, facilitating heat dispersal and potentially allowing the survival of meristems, even on highly scorched bundles. Among the partially consumed individuals, many appeared to be dead and were thinined to reduce their risk of falling in the camps. However, some trees with high levels of crown scorch (>80%) were observed to have damaged needles re-greening (Figure 1b) and new buds opening in the summer following the fire, prompting questions on the health of the remaining trees. Since the Columbine camp is surrounded by mostly mature trees, it was a priority for the CEC to retain as many healthy individuals as possible.

The primary goal of this project was to assess and track the health of the remaining moderately burned trees. To accomplish this, unmanned aerial system (UAS) image collections were conducted in the 6.5 acres surrounding the Columbine camp in fall 2021 and summer 2022. The multispectral imagery provided a snapshot of individual tree health, allowing us to track health through time. The initial UAS survey was conducted in July 2021 to examine the fire severity pattern and to map the extent of the study area. Then, in September and October 2021, we conducted a combination of UAS surveys and a field data subsample of the study area to provide imagery and estimates of tree conditions approximately 1-year post-fire. The processed imagery from September 2021 was used as our baseline tree condition to which subsequent flights were compared. In the summer of 2022, UAS flights were conducted in June and July. The imagery from these flights were compared to the baseline to determine if individual trees were recovering, declining, or maintaining their health.

To assess individual tree health, we used individual tree Normalized Differenced Vegetation Index (NDVI) values and compared individual trees across our four flight dates. Through this analysis, we were able to detect individual

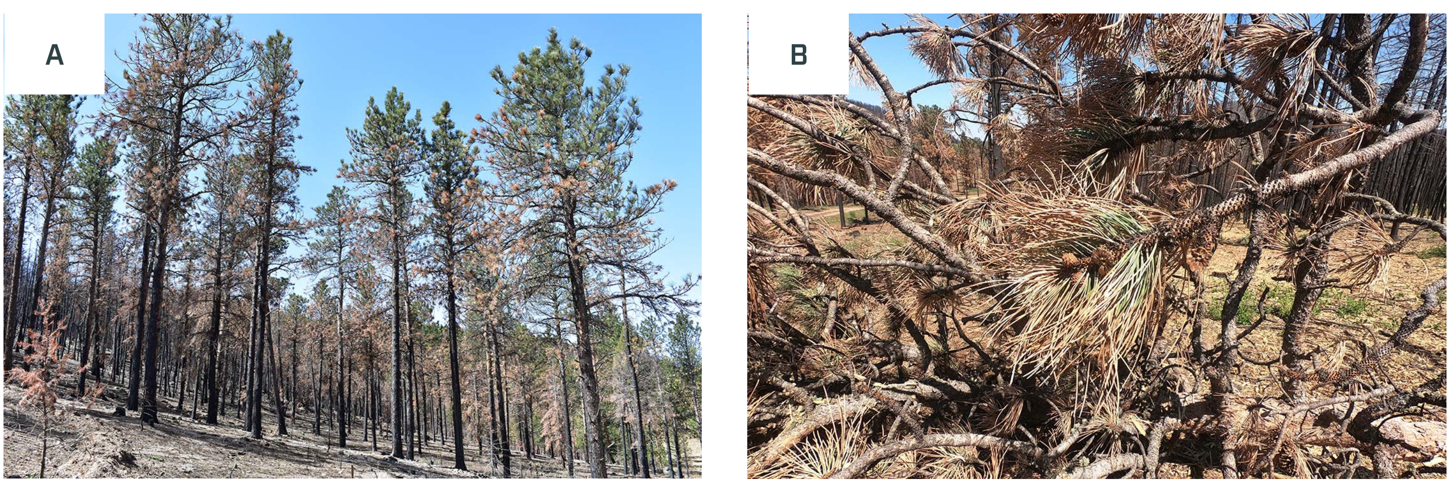

Figure 1: a) Photo displaying the gradient of fire severity across the Columbine camp with severity increasing from right to left across the photo. Photo by Rafael Salgado; b) Bundle of pine needles displaying the "re-greening" effect approximately 1-year post-fire. Photo by Lauren Lad

tree changes in health, as assessed by changes in the spectral reflection of the Near-Infrared (NIR) and Red bands. Common interpretations of NDVI can be seen below (Table 1). High NDVI indicates the existence of dense vegetation and NDVI has been found to perform well in characterizing post-fire net photosynthesis and physiological performance (Sparks et al., 2016). Low NDVI indicates a lack of vegetation (i.e., bare ground).

Table 1: Interpretations of NDVI values and categories (USGS).

NDVI Value	Category	Interpretation
-1.0-0.1	Low	Barren or low vegetation
0.1-0.5	Moderate	Sparse or unproductive vegetation
0.5-1	High	Dense or productive vegetation

The study area for this project was a 6.5-acre area within the Columbine camp at the CEC (Figure 2). The CEC is located in the foothills of the Rocky Mountains eastern front, slightly northwest of Boulder, CO.

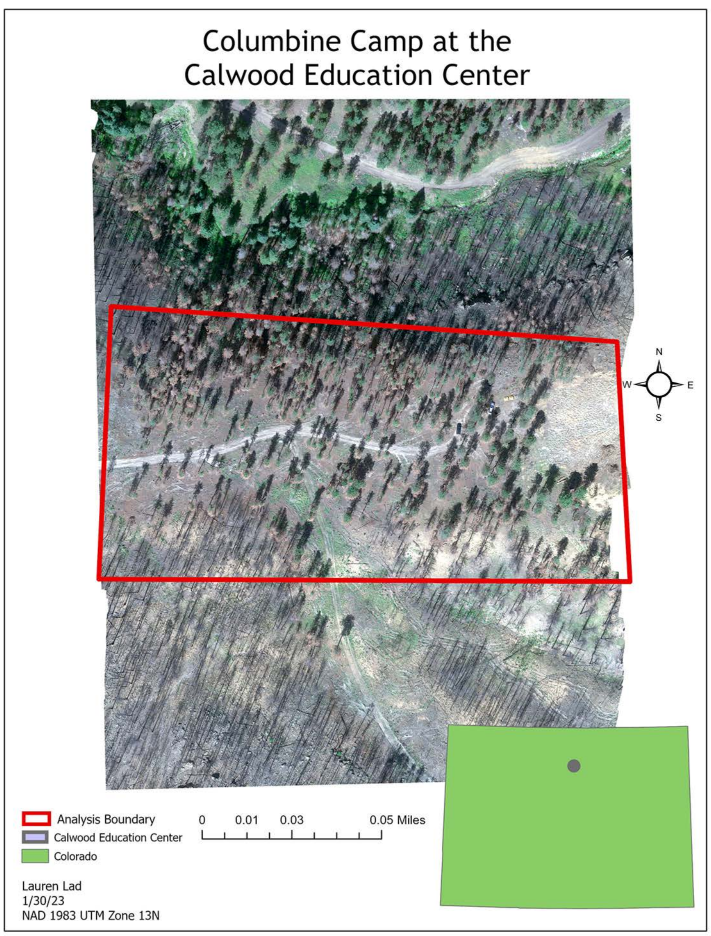

Figure 2: Study area map of the Columbine Camp

Data Collection and Processing

All UAV data were collected using a DJI Matrice 210V2 (DJI, Shenzhen, China) UAV equipped with a MicaSense 10-band Dual-Camera system (MicaSense, Seattle, WA, USA). The drone was flown in a serpentine pattern with 85% side overlap and 90% forward overlap at 90 m with a speed of 6 meters per second. The resulting multispectral imagery had a 6.3 cm resolution. For georeferencing the UAV images, 11 ground control points (GCPs) were placed around the Columbine Camp and had their coordinates collected with an Emlid reach real-time kinematic GPS (Figure 3). The GCPs allowed for spatial accuracy of 5.0 cm for each photo with an average error of 7.4 cm and ensured accurate alignment of imagery from different time points.

Figure 3: Example of bucket lid used as Ground Control Point (GCP). Each GCP has their coordinates collected using the Emlid GPS and is used to georeference flight images.

Flights were conducted on September 19 and October 1, 2021, and June 2 and July 8, 2022. Additional collection dates were cancelled due to unsafe flight conditions (i.e., high winds and/or low cloud cover). Following image collection, each flight date was processed in Metashape where we georeferenced all flight images, calibrated the spectral reflectance, and exported orthomosaics and point clouds, following the methods of Tinkham & Swayze (2021). Then, orthomosaics and point clouds were used to produce canopy height models in order to use the methods of Creasy et al. (2021) to extract individual trees. These canopy height models and individual tree locations provided crown outlines and tree points with which we spatially matched trees to examine changes in NDVI between collection dates. Within each tree crown polygon, we calculated NDVI at each collection date, then calculated the change in NDVI, or dNDVI, between each UAS acquisition and the preceding acquisition. The tree-level dNDVI values were summarized as three health status classes: declining (values less than -0.1), stable (values from -0.1-0.1), and improving (values greater than 0.1).

Results

The trees surrounding the Columbine camp had similar ranges in NDVI values during both the first (September 2021) and last (July 2022) UAS acquisitions, ranging from 0.123 to 1, with mean values of 0.477 (sd=0.177) and 0.511 (sd=0.185), respectively (Figure 4). Overall, most trees did not change substantially in their NDVI values throughout the monitoring period.

Calculating the change in NDVI (or dNDVI) between the subsequent UAS acquisitions and from the start to the end of the monitoring period revealed that portions of the population were fluctuating in their health status (Figure 5). The overwinter period from October 2021 to June 2022 had the greatest variation in dNDVI values and may be attributed to local variation in the timing of

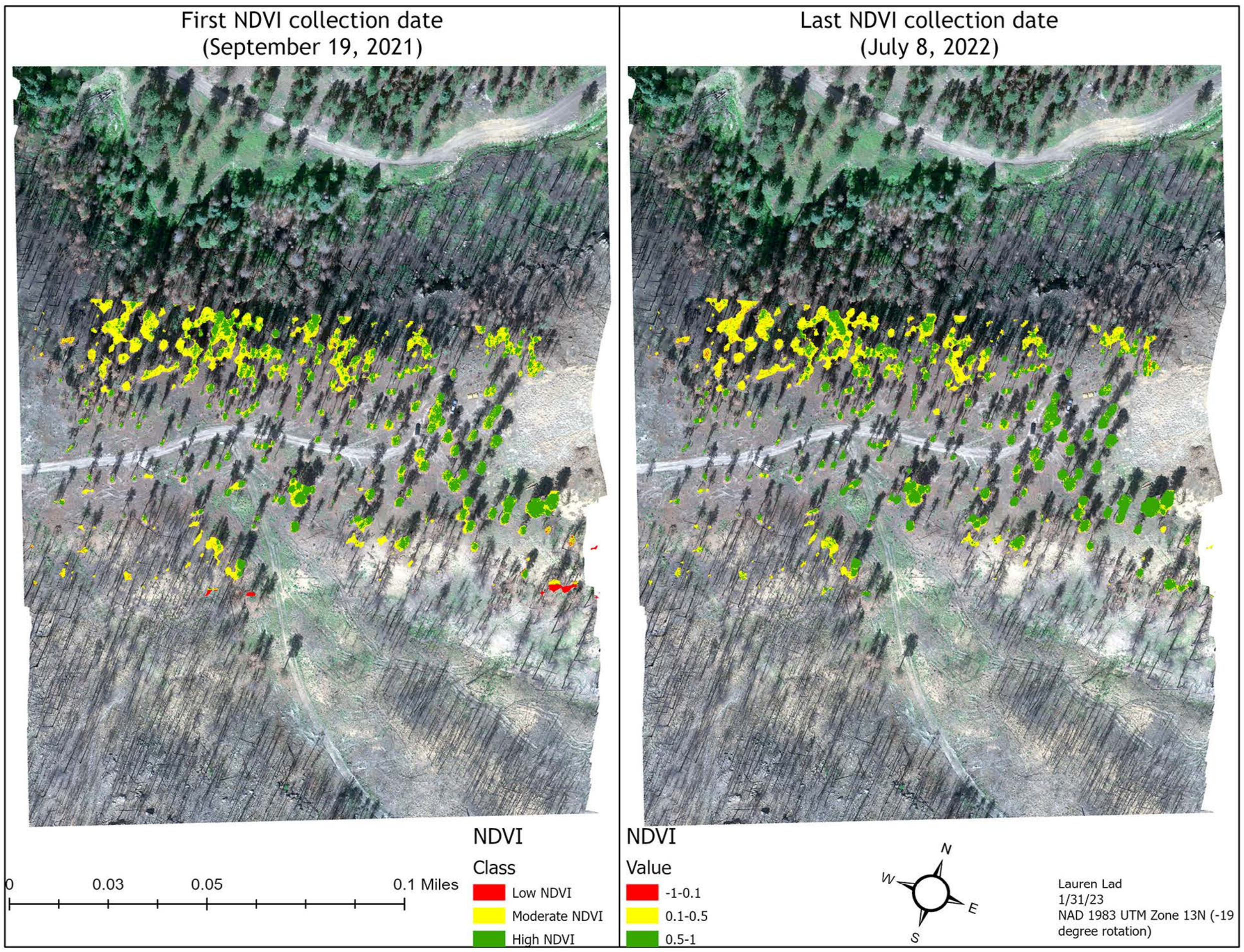

Figure 4: Map of NDVI on the first and last collection dates. The base map is RGB imagery from the 9/19/21 flight.

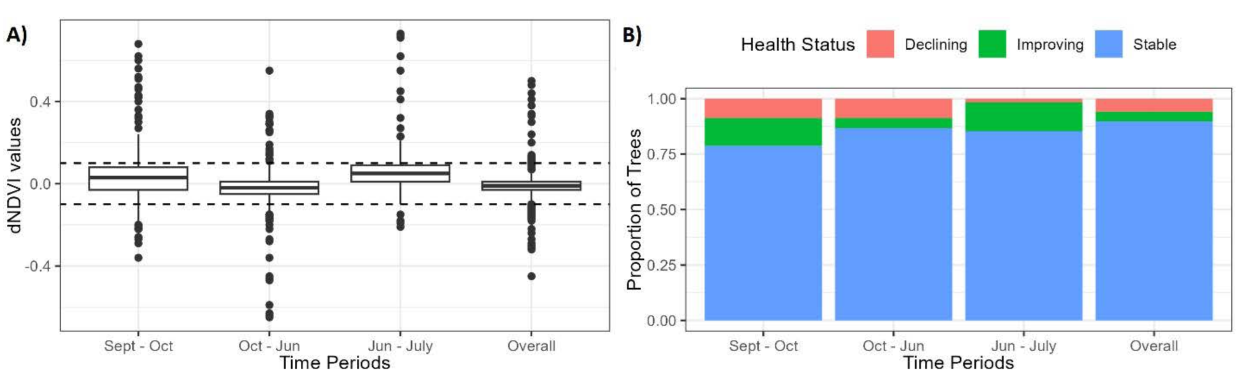

Figure 5: Summary of spectral reflectance values between subsequent time periods and overall, representing (A) the distribution of tree-level dNDVI values and (B) the health status of the population.

photosynthetic rates increasing between trees (Table 2). Overall, ~90% of monitored trees showed stable dNDVI values throughout the study (Figure 6), with about 5% of trees showing improving and ~5% of trees showing declining health between September 2021 and July 2022 (Figure 5). The strong positive increases in dNDVI seen in the spring and summer of 2022 can likely be attributed to the high moisture availability during the wetter than average growing season.

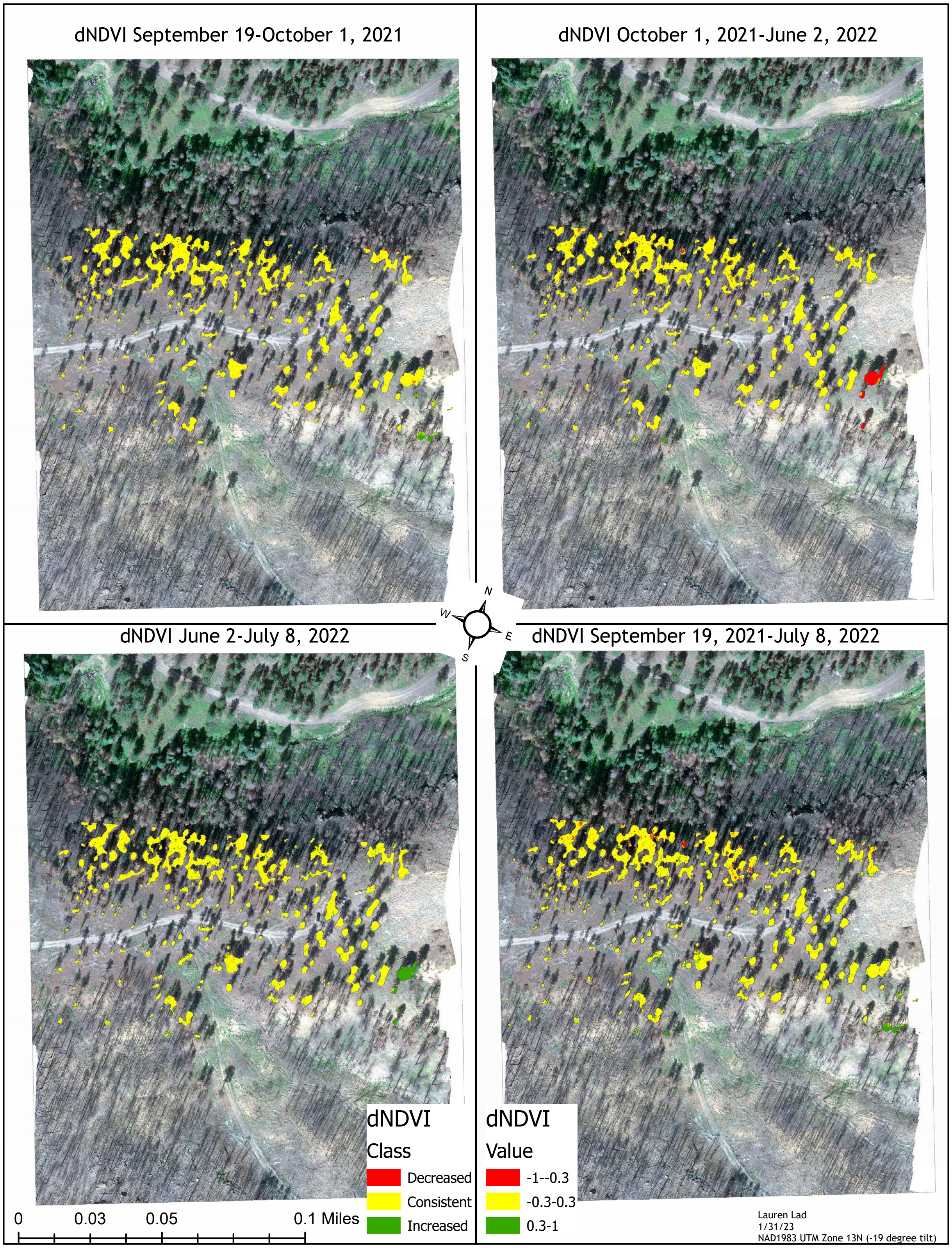

Figure 6: dNDVI maps show the change in NDVI between each collection date in chronological order starting in the upper left. The lower right image is dNDVI between the first and last collections. All base maps are RGB imagery from the 9/19/21 flight.

Table 2: Tree-level summary of dNDVI values between each collection date.

Pre-Date	Post-Date	Mean dNDVI	Median dNDVI	Minimum dNDVI	Maximum dNDVI
9/19/2021	10/1/2021	0.03	0.03	-0.36	0.68
10/1/2021	6/2/2022	-0.02	-0.02	-0.65	0.55
6/2/2022	7/8/2022	0.06	0.06	-0.21	0.73
9/19/2021	7/8/2022	-0.01	-0.01	-0.45	0.5

Conclusion

Overall, the trees surrounding the Columbine camp have had consistent NDVI values throughout the collection period and are stable in their health condition. Approximately 13% of trees showed improving health status in the early summer of 2022, indicating that they may be recovering, most likely due to higher-than-average precipitation in the summer of 2022. Approximately 5% of trees exhibited negative dNDVI between the September 2021 and July 2022 collections and these trees should be monitored for further changes and potentially removed to reduce hazard from trees falling. A shapefile of these tree locations accompanies this report (Supplemental 1). When removing trees from post-fire environments, there is potential for increased exposure of the remaining trees to wind, increased soil exposure to environmental conditions, and decreased protection for saplings and understory revegetation (McIver and Starr 2001). Best practices often point to removal of small tree patches to minimize subsequent tree loss to wind damage and to maintain some woody debris on the forest floor to stabilize soils and create micro-environments to promote plant establishment.

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Supplementary Files

1. Crowns7_8.shp: Tree crown polygons within the study area
2. dNDVI_all.pdf: Map seen in Figure 6
3. dNDVI_jun_july.tif: Raster file of the dNDVI between June and July 2022
4. dNDVI_oct_jun.tif: Raster file of the dNDVI between October 2021 and June 2022
5. dNDVI_sept_july.tif: Raster file of the dNDVI between September 2021 and July 2022
6. dNDVI_sept_oct.tif: Raster file of the dNDVI between September and October 2021
7. NDVI_crown_6_2_22.tif: Raster file of the NDVI within tree crowns from June 2, 2022
8. NDVI_crown_7_8_22.tif: Raster file of the NDVI within tree crowns from July 8, 2022
9. NDVI_crown_9_19_21.tif: Raster file of the NDVI within tree crowns from Sept. 19, 2021
10. NDVI_crown_10_1_21.tif: Raster file of the NDVI within tree crowns from Oct. 1, 2021
11. Points_7_8.shp: Individual tree points within the study area
12. Rgb_full_ortho.tif: True color raster of the entire Columbine camp
13. StartEndNDVIMaps.pdf: Map seen in Figure 4

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