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Determining Fire Severity of the 2017 Santa Rosa, CA Fire

John Cortenbach[1], Richard Williams[1], Buddhika Madurapperuma[2*]

ABSTRACT—This study examines the 2017 Santa Rosa wildfire using remote sensing techniques to estimate the acreage of burned areas. Landsat 8 imagery of the pre- and post-fire areas was used to extrapolate the burn severity using two methods: (i) difference Normalized Burn Ratio (dNBR) and (ii) change detection analysis. We compared our analyses with data provided by the California Department of Forestry and Fire Protection (Cal Fire). The results of burn severity using both methods were on average 24% under-approximated in comparison to Cal Fire values. When comparing our acreage burn analysis to Cal Fire data, our results were on average 76 ± 8% accurate in identifying burn severity. Of the two methods, the change detection using an iso-clustered unsupervised classification scheme was more accurate. Landsat-based burn severity mapping provides cost–effective tools for forest managers to identify fire risk areas for wildfire planning and ecosystem management.

INTRODUCTION—Catastrophic wildfire is among the most common form of forest disturbance in the Pacific Northwest of the United States. In California and adjacent states there is fear that the recent spate of high-intensity fires that wipe out canopy trees, or stand-replacing fires, present a challenge for conservation of conifer forests. In the beginning of the 2017 fall season in northern California, large fires erupted and spread throughout Santa Rosa, Napa, and Sonoma Counties (Miller, 2017). The scars left by these wildfires, though terrible, provided an opportunity to investigate the impact they had on the affected areas mentioned above. Wildfires in California are frequent due to climatic conditions that are influenced by dry fuel accumulation, lightning, lengthening of the summer drought, and earlier spring snowmelt and runoff (Stewart et al., 2005; Westerling et al., 2006; Williams et al., 2010). It is suspected that high temperatures and fast winds, characteristic of the fall season, fueled the rapid spread of the wildfire across counties in northern California.

In 2017, a multitude of fire outbreaks occurred throughout the state of California. One of the most extreme was the Santa Rosa fire across Sonoma and Napa Counties, which put many homes at risk and rendered the air quality hazardous throughout much of that summer. These fires caused severe damage to structures and destroyed many wine-cultivating areas.

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Tubbs and Nuns fire. The 2017 wildfires in northern California burned through and destroyed whole neighborhoods in and adjacent to the city of Santa Rosa, Sonoma County (Madsen et al., 2018). Two blazes, namely the Tubbs and Nuns fires, ravaged huge swaths of Sonoma County. The Tubbs fire began on 8 Oct 2017 and burned portions of Napa, Sonoma, and Lake Counties during October that year. It was estimated that over 36,807 acres had burned by 31 Oct 2017. The escalation of the fire was heavily attributed to the peak wind gusts ranging between 20 and 40 miles per hour that pushed the fire from the northeast. According to Watkins et al. (2017), the fire spread approximately 12 miles in the first three hours of its outbreak. The Nuns fire, on the other hand, was located east and north of the city of Sonoma and spread to both Sonoma and Napa Counties. This fire also began on

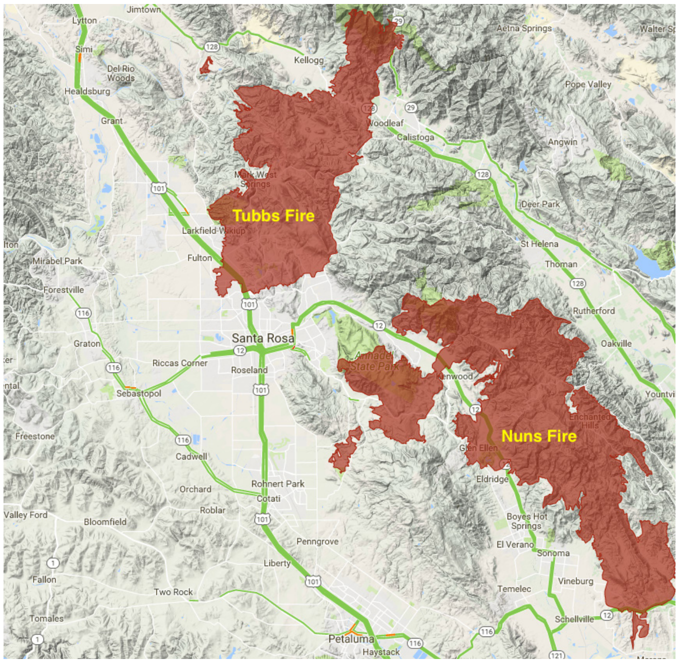

FIGURE 1. Google map of the Tubbs and Nuns fires after their destructive barrage over Sonoma County (Nor Cal Fires, n.d.).

8 Oct 2017 and spread across an estimated 54,000 acres. On its spread path, it merged with other fires, such as the Adobe, Pressley, and Norrbom fires, absorbing them and creating one massive fire (Watkins et al., 2017). Due to limited fire outbreak datasets, this study was constrained and dependent on two pre- and post-fire Landsat datasets of the Tubbs and Nuns fires that were collected in Nov 2017 (FIG 1). It is important to note that these two images did not span the same region of interest since the two fires did not overlap (FIG 1).

The scope of this study is to determine the severity of the Tubbs and Nuns fires by estimating the acreage of burned areas within Sonoma County using the following specific objectives: (i) determine which fire had the highest severity by comparing the difference Normalized Burn Ratio (dNBR) between the Tubbs and Nuns fires; (ii) estimate the burn acreage within the two fire regions with change detection using a pixel-over-pixel comparison of an iso-clustered unsupervised classification; and (iii) estimate the actual burned acreage values and a degree of error associated with the estimation of burned acreage.

METHODS—*Delineate burned area*. Due to the recent occurrence of the northern California fires, specifically in Santa Rosa, the preliminary analysis was limited to 2017 Landsat 8 imagery that was obtained on 9 Sept and 5 Nov 2017 from the United States Geological Survey (USGS, 2017). These two images reflected the pre- and post-fire states, respectively. FIG 2 displays the Landsat images used for this analysis with true color band combinations used to enhance the contrast (band 6, 5, 4 combinations for red, green, and blue, respectively). These three band combinations were of shortwave one and two composite (SWIR1, SWIR1, SWIR2) and a SWIR1, near infrared (IR), and red bands. Such burned areas are dependent on an accurate region of interest (ROI), which is then created in near IR and red bands. These bands are assigned to the blue, green, and red bands. These band combinations helped to discriminate burned and unburned areas, hence creating an ROI.

After the ROI was identified, as shown in FIG 2, the overall workflow used to achieve the objectives consisted of two methods: (i) difference Normalized Burn Ratio (dNBR) and (ii) change detection using an iso-cluster unsupervised classification. The workflow for these analyses is presented in FIG S1.

difference Normalized Burn Ratio (dNBR). In image preprocessing, digital numbers were converted to Top of Atmosphere (ToA) reflectance using ArcMap© (Rozario et al., 2018). Dark object subtraction was performed to remove the effect of atmospheric scattering on the reflectance of dark objects, such as water pixels, using ENVI® (Rozario et al., 2018). The reflectance bands of the pre- and post-fire images were used to derive Normalized Burn Ratio (NBR).

The NBR formula uses near IR (NIR) and the shortwave infrared (SWIR-2) wavelengths as shown in Equation (1).

$$NBR = (NIR - SWIR) / (NIR + SWIR) \quad (1)$$

Then, difference Normalized Burn Ratio (dNBR) was computed by subtracting the post-fire NBR from the pre-fire NBR as shown in Equation (2).

$$dNBR = NBR_{pre} - NBR_{post} \quad (2)$$

The dNBR analysis was conducted partially in ENVI®, to manipulate bands, create ROIs, and clean up the data. The images were then imported into ArcMap© to run the NBR indexing for the pre- and post-fires images, followed by the dNBR.

Change detection. ENVI's Image Change workflow was

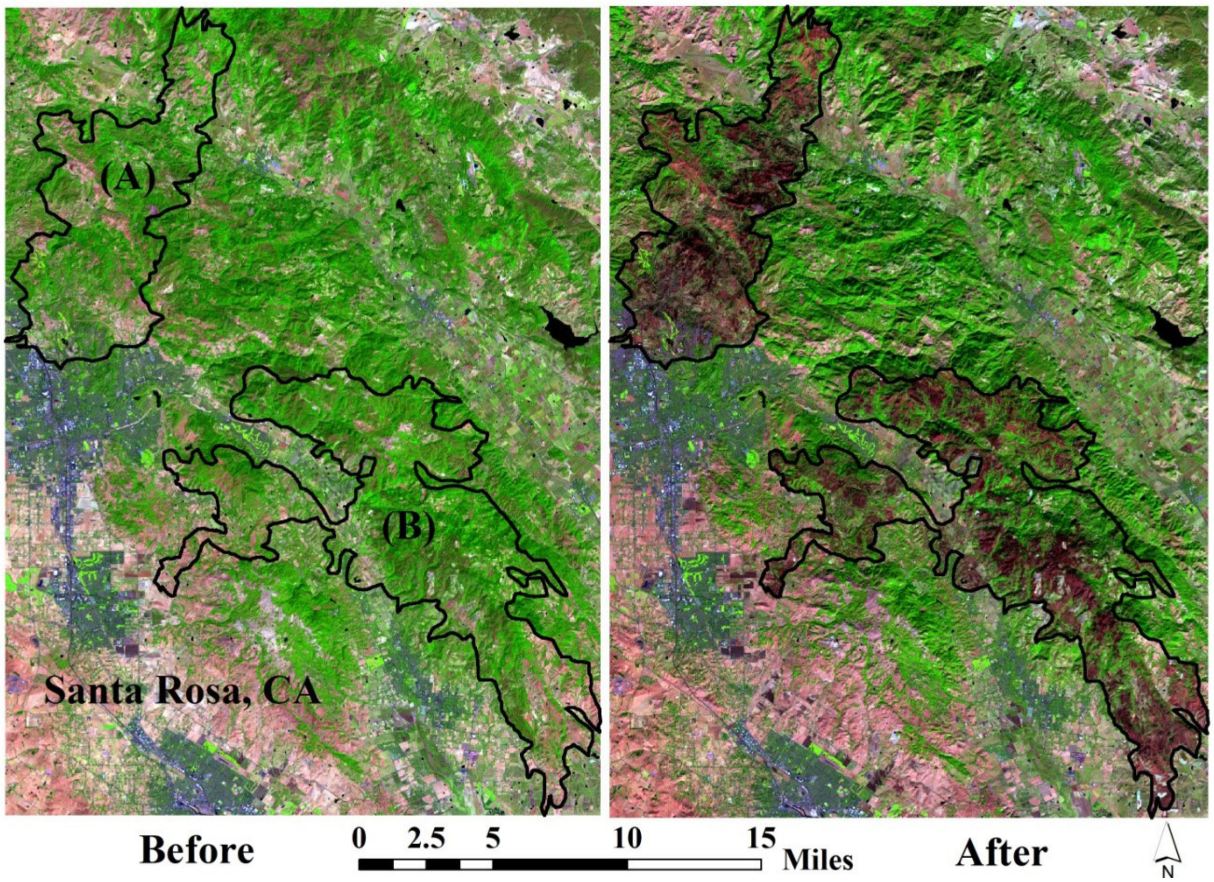

FIGURE 2. Santa Rosa, California 2017 burn severity study area pre-fire (left) and post-fire (right). Tubbs (A) and Nuns (B) fires are to the north and west of the city, respectively. The image appearance is set to a true color 6, 5, 4 Landsat band combination. The black outline ROI indicates the area used for the analysis.

used to determine burn areas (Exelis, 2015). The Image Change workflow compares spectral differences of two images of the same geographic region and different time steps, and also identifies differences between them. The difference can be computed on a thermal band corresponding to the temperature difference between pre- and post-fire. Burn extent and severity classes were created by taking the difference between pre- and post-NBR layers.

We estimated burned acreage using dNBR and change detection methods. Since the area estimation from the above methods was based on remote sensing methods, we utilized Cal Fire burn acreage data to compare the results. Cal Fire estimated burned acreage by compiling various dataset shared from partners such as USDA Forest Service, Bureau of Land Management, National Park Service, US Fish and Wildlife Service, and numerous local agencies (https://frap.fire.ca.gov/data/statewide/FGDC_metadata/fire18_1_metadata.xml). Various data sources of Cal Fire resulted in multi-methods for burn acreage estimation.

RESULTS—The dNBRs for both the Tubbs and Nuns fires were analyzed and presented with respect to the city of Santa Rosa, as shown in TABLE 1 and FIG 3. Qualitatively it appears that the severity between the Tubbs and Nuns fires for both dNBR and change detection estimation methods is more or less similar. However, through close visual inspection of the zoomed-in images, it appears that there are more high-severity zones present in the Nuns ROI than the Tubbs area. From this dNBR analysis of the Landsat images, the severity files were reclassified into specific areas associated with low, medium, and high burn severities.

Both methods were very close in their approximations,

TABLE 1. Comparison of the approximated burned acreage between the Tubbs and Nuns fires using the dNBR and a change detection method.

Parameter	dNBR (acres)		Change Detection (acres)	
	Nuns	Tubbs	Nuns	Tubbs
Estimated	37,503	23,998	38,355	24,579
Actual	46,104	35,270	46,104	35,270
Accuracy	81%	68%	83%	70%

but were on average 24% under-approximated when compared to values supplied by California Department of Forestry and Fire Protection (Cal Fire, 2017). The errors in classification are detectable in FIG 3 where there are unburned areas in close proximity to high-severity burn areas. The shapefiles used to determine the areas, which were converted from raster to vector files, are shown in FIG 4. This image is overlaid on the burn areas so that overlap and non-overlap of the shapefiles can visually show where burned areas were not categorized. The imagery noise correction analysis, like reflectance, cloud cover, and air moisture, greatly improve the accuracy of the analysis.

A comparison of the two fires, with respect to burn severity, was conducted using ground truthing data to validate the remote sensing results (FIG 5). A field visit to Santa Rosa fire areas was made in mid-March 2018 to observe the impact of the fire as well as to validate our burn severity classification maps. A total of 60 ground-truthing points were tested for burn severity and 45 points were matched with dNBR analysis, resulting in 75% accuracy for classifying and references images.

FIG 6 summarizes the burn acreage of both Nuns and Tubbs fires in 2017 in Santa Rosa. These results showed that the Nuns fire had more total acreage burned than the Tubbs fire. However, the percentage burn for low, medium, and high burn severity classes for both fires was more or less similar. For example, of the total area of the Nuns and Tubbs fires, 3% and 4% were high severity, 22% and 25% were moderately burn, and 76% and 71% were low burn, respectively. Using Cal Fire records, it was identified that our analysis was moderately accurate (76 ± 8%) (Jenson, 2005).

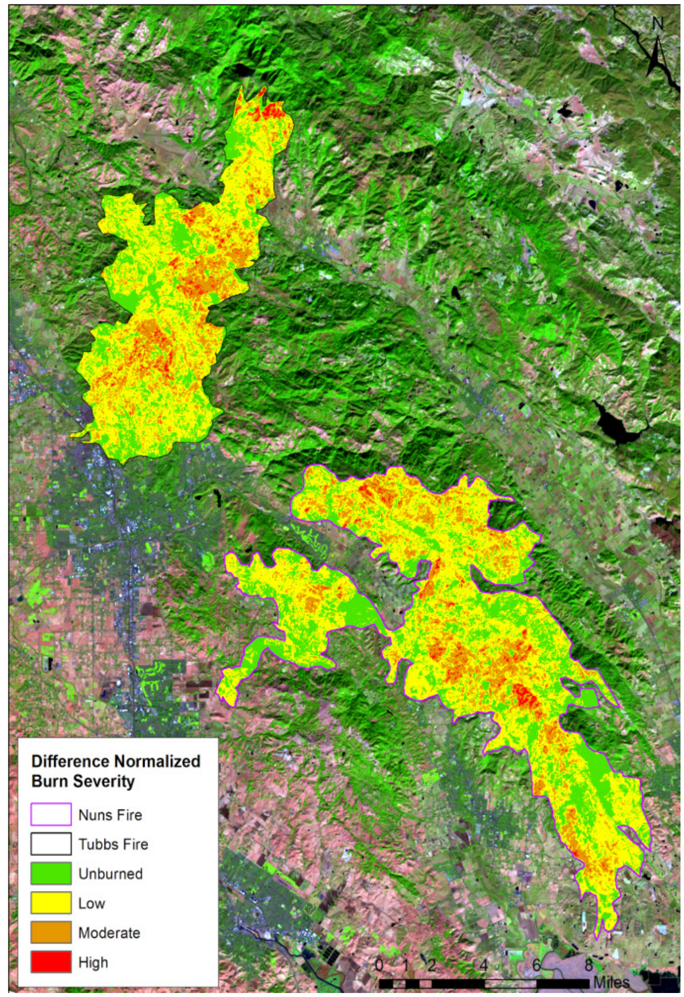

FIGURE 3. dNBR analysis for the Tubbs fire (top-left) and Nuns fire (bottom-right) using four main classes to categorize burn severity in the greater Sonoma and Napa County areas.

DISCUSSION—Wildfire in California has increased dramatically since 1970, and a large area of northern California forests has burned (Westerling et al., 2011; Schoennagel et al., 2017). The key factors contributing to increasing wildfires in the western United States are linked to anthropogenic climate change, e.g., increased fuel aridity (Abatzoglou and Williams, 2016), rising temperatures (Schoennagel et al., 2017), and increased drought (Westerling, 2016). Anticipatory climatic models predict a 100% increase in wildfire occurrence in northern California by 2085 (Westerling et al., 2011). Moderate to large increases in wildfires are predicted in wildland-urban interfaces in the next 20 years (Schoennagel et al., 2017; Moritz et al., 2014). Sonoma County is located at the high-risk

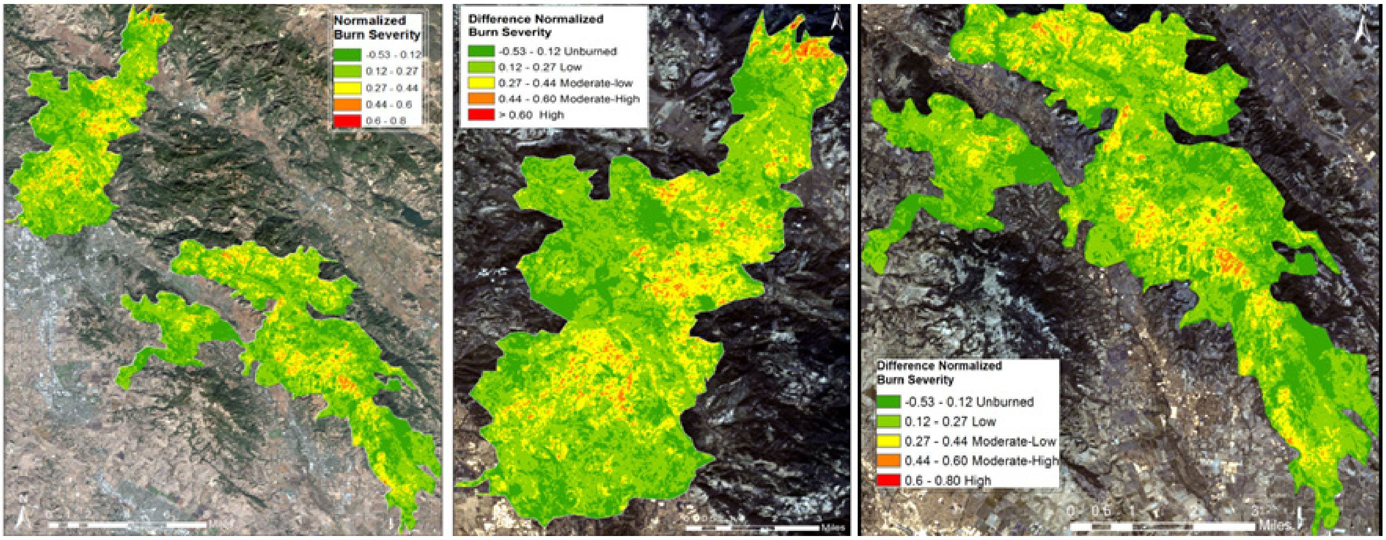

FIGURE 4. The image on the far left depicts the burn severities (e.g. unburned, low, moderate-low, and high burned) for both fires (Tubbs fire at top-left and Nuns fire at bottom-right) north and west of Santa Rosa. The middle image is a higher resolution view at the Tubbs fire and the burn severity distribution. The far right image is the Nuns fire and its associated burn severity results from the analysis. The burn acreage in each severity class was estimated by multiplying number of pixels in each category with pixel size (30 m × 30 m) in a raster calculator. These images serve as visual metrics to burn severity perceptions.

boundary zone within a wildland-urban interface and has experienced wildfire in the past. However, human settlement in this area has grown by 20% between 1990 and 2010 (Michels and Sagara, 2018). Despite records of this area's fire risk, human settlement in the area has grown by 20% between 1990 and 2010, indicating that people moving to the area tended to not know about the history of wildfire or were unaffected by the risk. Moreover, housing density in Sonoma County is predicted to grow from 1.81 houses/acre to 3.05 houses/acre between 2010 and 2050, respectively, resulting in future risk to settlements (Mann et al., 2014).

The burn severity maps for both Tubbs and Nuns fires are useful for forest managers to quickly glance at the area to determine priority areas for forest management. Estimation of wildfire size and fire risk zones are important for forest managers to implement thinning practices for fire-prone areas, fuel treatment, such as prescribed burning, and forest health assessment to facilitate recovery and resilience of conifer forests after fire disturbance. Generally, the extent of fire, location, and structural damage depicted in photo galleries are posted on federal web sites. Therefore, our findings are useful to the US Forest Service for the implementation of sustainable forest management practices of vulnerable areas.

This study suggests that of the two methods applied to the burn severity analysis, the method of change detection is superior. Using a pixel-over-pixel iso-clustered supervised classification scheme was more accurate than the dNBR approach. The use of manual classification and raster reclassified image (dNBR) is helpful with heat classifications.

We compared the burn acreage estimated through change detection and dNBR methods with Cal Fire estimation. Our results detected 24% less burned acreage than Cal Fire estimation. However, in terms of accuracy assessment, 75% agreement between Cal Fire and ground control data was obtained. Since we used moderate resolution Landsat data, it impacted accuracy. For example, our accuracy results were comparable with Fisher et al. (2017) land use classification accuracy, in which they obtained 75% for 30 m data and 82% for 1 m data. The fire risk map of Tubbs and Nuns is useful to fire and land managers to look for high-severity sites that are vulnerable to soil erosion and plant regeneration.

CONCLUSIONS & RECOMMENDATIONS—This analysis has drawn the following conclusions for the applied burn severity analysis on Tubbs and Nuns fires in Sonoma and Napa County.

- Change detection determined to be more accurate than the dNBR approach by itself possibly due to

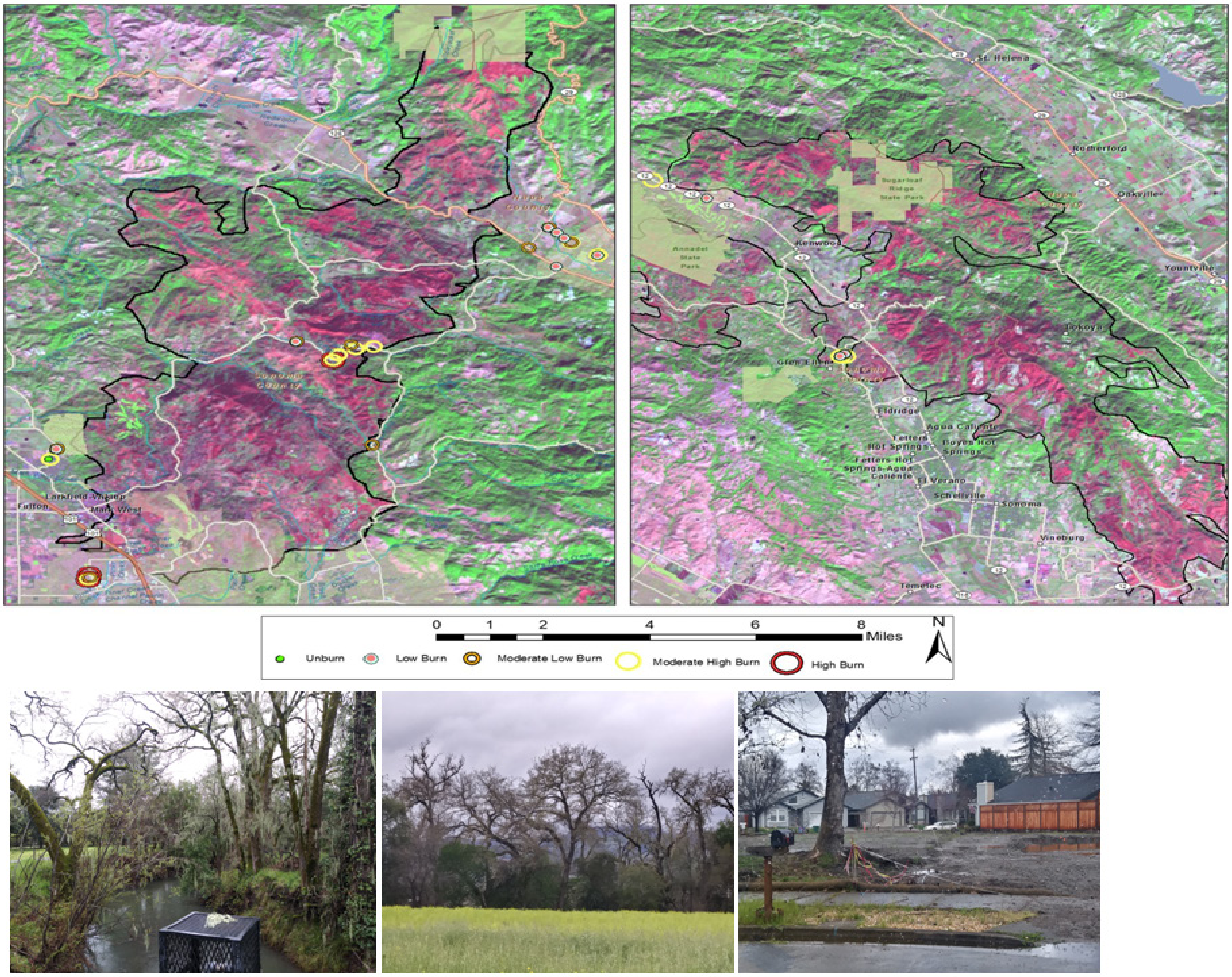

FIGURE 5. A land field survey (ground truthing) using a GPS Trimble Juno Geo 7X to mark the types of burn severities, while comparing a composite map layer of both Tubbs and Nuns fires and ground truthing survey sites. (left to right) Low burn [Geyserville: 38.594037N, -122.597456E], Moderate low burn [Geyserville: 38.710837N, -122.911748E], Moderate high burn [Santa Rosa: 38.472987N, -122.747941E].

the change detection usage of a pixel-over-pixel comparison approach.

- The change detection analysis results identified that the Nuns fire burned an estimated 38,355 acres, while the Tubbs fires burned 25,679 acres.
- A comparison to the actual acreage burned, provided by Cal Fire, indicated that this analysis was on average 76 ± 8% accurate in identifying burn severity on the basis of acreage burned.
- We recommended the use of high resolution images to find post-fire recovery of disturbed forest

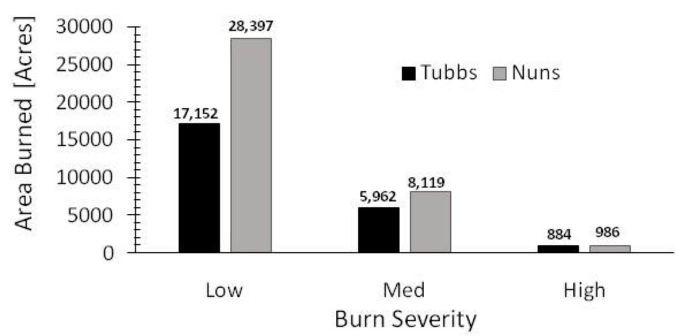

FIGURE 6. Comparison of fire burn severity on an acreage-burned basis for the Tubbs and Nuns fires.

utilizing the present findings as a baseline study to implement sustainable forest management practices.

ABOUT THE AUTHORS—John Cortenbach graduated from the Environmental Science Program at HSU in 2018. This paper was based on Cortenbach and his colleague's class project for GSP 326 advised by Dr. Madurapperuma. He is passionate about volunteering for social activities, hiking, and conducting GIS/remote sensing projects. The author is interested in applying remote sensing techniques for real life situations for wildfire mapping and invasive species habitat mapping.

Richard Williams graduated from the Environmental Resources Engineering Program at HSU. He collaborated with Cortenbach for GSP 326 project. Williams is interested in remote sensing application for renewable energy. He was president for the Renewable Energy Student Union (RESU) Club in 2016–2017 and was secretary in 2015–2016.

Dr. Buddhika Madurapperuma is a Lecturer/Research Associate in the Departments of Forestry and Wildland Resources and Environmental Science and Management. He is a major advisor for Cortenbach and William's class project. He teaches GIS, remote sensing, forest ecology, and dendrology classes at HSU. Dr. Madurapperuma conducts multidisciplinary research on remote sensing, i.e., hyperspectral remote sensing for invasive species detection and mapping, ecological studies on invasive species, and post-fire seedling recruitment and seed maturation schedule of CA conifer species.

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SUPPLEMENTARY MATERIAL

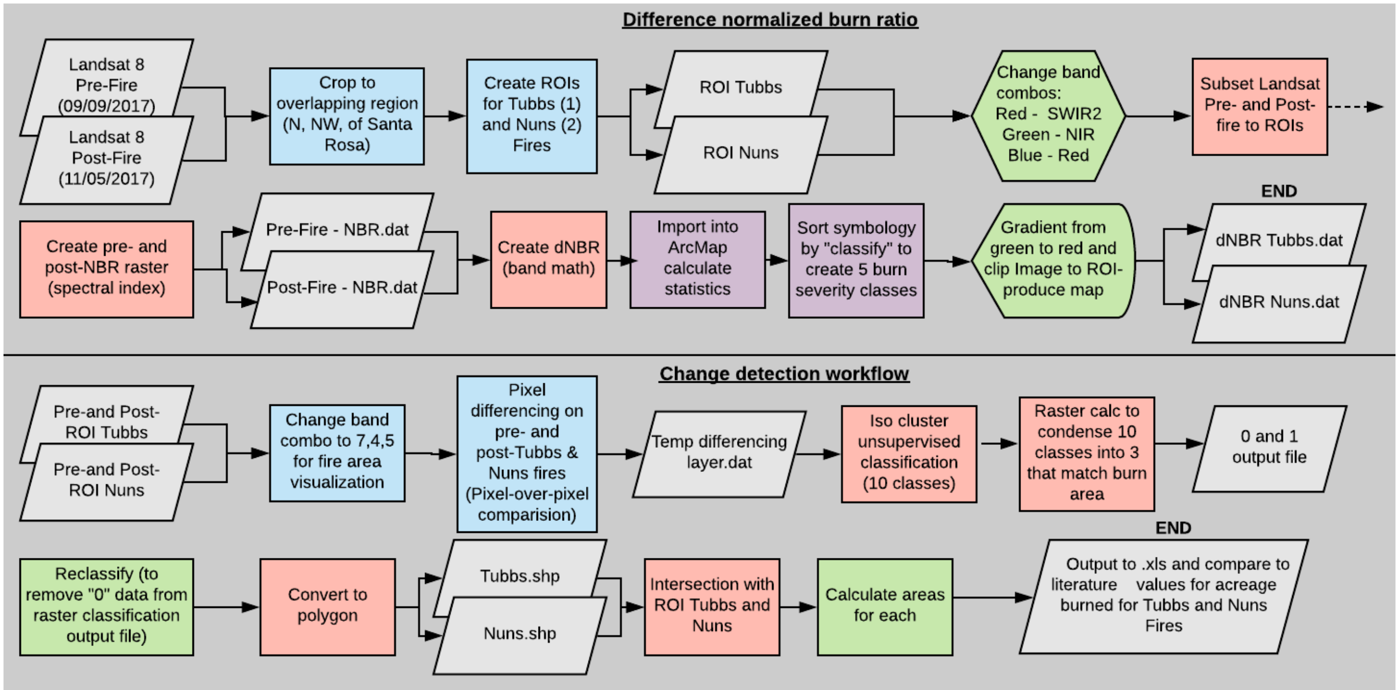

FIGURE S1. Workflow for the two main analyses conducted in order to determine acreage burned and burn severity for both the Tubbs and Nuns fires.