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A systematic study of the reliability of fire pattern indicators used in wildland fire investigation

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Abstract

This work presents the preliminary results obtained from the first set of six field experiments conducted within the scope of a project focused on systematically evaluating the reliability of fire pattern indicators used in wildland fire investigation. The field experiments were conducted in the Pinelands National Reserve (NJ, USA) during the conduction of prescribed burns. This allowed studying the generation of fire pattern indicators in a realistic scenario and under controlled conditions. During the experiments, a series of sensors were used to determine the heat exposure that induces the appearance of fire pattern indicators over planted supporting elements. The preliminary results suggest that fire pattern indicators are a valuable and valid tool for the determination of the area of origin of a fire if they are used holistically. Further results and analysis to be presented in the full version of this work include fire spread and the characterization of the heat exposure that generates the fire pattern indicators observed in the complete experimental campaign.

1. Background and Motivation

The increased frequency of catastrophic wildfire events is projected to continue over the next century causing dramatic impacts to human and ecological systems (e.g., loss of life, health impacts, property, and economic losses, lost ecological function, and resilience) (NIFC, 2022; Sample et al., 2022). The rapid expansion of the wildland-urban interface and the effects of climate change have increased the frequency and intensity of these events, highlighting a specific need for fire behavior and effects research, where human and ecological systems intersect to understand anthropogenic roles in unwanted wildland fire ignitions (Maranghides & Mell, 2013; Hammer et al., 2007). Scientific gaps in the basis for standard approaches used for studying ignitions in the field limit our understanding of the reliability and scientific integrity of these approaches and justify a need for new science to either support existing methods or guide improvements.

Field studies of unwanted wildland fire ignitions focus on identifying and evaluating physical fire pattern indicators (FPIs) within a fire's footprint as a forensic means of locating a fire's exact point of origin and ignition source. From this perspective, ensuring the accurate determination of the origin and causes of wildland fires is paramount, and thus standardized methods are provided to fire investigators. In the United States and worldwide, the National Fire Protection Association's Guide for Fire and Explosion Investigations (NFPA, 2021) and the Guide to Wildland Fire Origin and Cause Determination of the National Wildfire Coordinating Group (NWCG, 2016) are the primary documents that provide a systematic method for the conduction of this type of investigation and rely on fire pattern indicators. As per this guide, indicators are commonly divided into two classes: macroscale and microscale FPIs (NWCG, 2016). Macroscale FPIs are associated with large objects and are easily noticeable, for example, the angle of the charring displayed by a tree trunk. On the other hand, microscale FPIs are only observable by getting up close to an object, such as the protection shown behind a

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pinecone. The interpretation of microscale FPIs typically becomes more important as investigators work closer to the area of ignition.

Very few scientific studies have attempted to assess the reliability of FPIs systematically, despite their primary importance in fire investigations (Simeoni et al., 2017). To begin addressing this gap, we present a project to develop a novel experiment-based dataset that will be used to assess the reliability of FPIs related to fire behavior and local fire conditions.

To generate a statistically robust dataset, experiments will be conducted in two different settings: field and laboratory. In the field, prescribed burns will be used to study the creation of FPIs in realistic but controlled fire conditions (Mueller et al., 2017). In this setting, it will be possible to observe the generation of most indicators, paying attention to the macroscale FPIs that appear on vegetation and landscape features. Furthermore, microscale FPIs will be identified, and the thermal exposure conditions needed to produce them will be quantified. After the field experiments, laboratory experiments will be conducted using the information gathered in the field. A wind tunnel will be used to study the effects of wind, slope, and vegetation layout on the creation and reliability of FPIs. The combination of the experiments conducted in these two settings will establish a robust and statistically representative dataset centered on the reliability of FPIs within the range of the tested conditions.

The work presented herein showcases the approach and preliminary results obtained from the first set of six field experiments conducted within the scope of this project.

2. Methodology

2.1. Study site and burn plot characteristics

The field experiments were conducted in March 2022 at the Pineland National Reserve (PNR), located in New Jersey, United States. The PNR comprehends an area of ~ 445,000 ha, composed mainly of upland and wetland forests. The basic geography of the area is a relatively flat coastal plain with low-angle slopes and a maximum elevation of 63.5 m, with well-drained sandy loam as the primary soil type (Clark et al., 2015).

As presented by Clark et al. (Clark et al., 2015), the upland forests represent roughly 60% of the forested areas in the PNR, with many closed-canopy stands of approximately 60–90 years of age. In general terms, it is composed of the following three major communities: oak-pine, pine-oak, and pine-scrub oak (Skowronski et al., 2007). For all communities, understory vegetation comprises mainly Scrub oaks and Ericaceous shrubs such as huckleberry and blueberry.

The experiments reported here were conducted in small plots of ~0.5 ha, with low-intensity fires that replicate the conditions near the point of origin of a fire. Supporting elements to study the generation of FPIs were planted in clusters of ~9 m^2 to study the generation of micro-scale FPIs.

To replicate the initial conditions of a fire incident as close as possible, single-point ignition was conducted using a typical isobutane lighter. The location of the point of ignition was varied according to the fire spread scenario to be represented and current wind conditions.

2.2. Diagnostics

2.2.1. Fuel characterization

Vegetation samples were collected from randomly-sampled 1 m^2 destructive harvest subplot areas within each burn unit. As prescribed fires rarely reach the more highly decomposed organic layers of the ground, a collection depth that reaches the litter layer of the forest floor was sufficient (Clark et al., 2015).

The material collected was sorted in-situ as detritus and vegetative material. These materials were then dried for a minimum of 48 hours at 70°C and sorted into fuel particle and time-lag components (e.g., downed wood, stems, fine fuels; 1-, 10-, 100- hour time-lag classes).

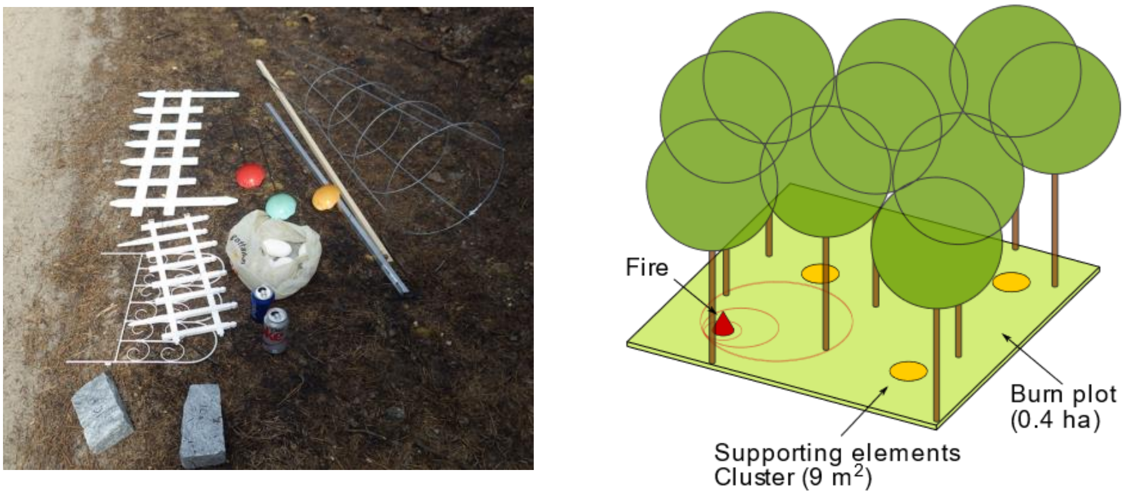
Terrestrial laser scans (TLS) were conducted at each plot before and after the fire to obtain a 3D survey of the vegetation, indicators, and equipment to estimate the initial and final vegetation bulk density and fuel consumption.

2.2.2. Fire spread

Protected conventional cameras mounted at elevated positions inside and in the vicinity of the fire perimeter were used to capture the fire spread from different angles and visualize the fire behavior near the indicators. In addition to these cameras, a weather station and 3D sonic anemometers placed outside the perimeter of the burn plot were used to characterize the environmental and air entrainment conditions before, during, and after the fire.

2.2.3. Generation of fire pattern indicators

Following the approach presented by Simeoni et al. (Simeoni et al., 2017), supporting elements that allow the appearance of microscale fire pattern indicators were used. Fig. 1(a) shows an example of the supporting elements used by Simeoni et al. in the past. As previously mentioned, the supporting elements were planted in clusters comprising an area of approximately 9 m^2 dispersed throughout the burn plot, as shown in Fig. 1(b). The clusters were distributed in the burn plot in a way that allowed to capture head, flank, and backing fire-induced fire pattern indicators.



(a) *(b)*

Figure 1: Supporting items for the generation of micro-scale FPIs. (a) Example of the items used by Simeoni et al., (b) Positioning of the clusters of supporting elements within a burn plot.

Through close post-fire inspection of the supporting elements, the micro-scale FPIs generated were registered. Furthermore, to understand the generation of micro-scale indicators, the heat exposure over the supporting elements was characterized through the following instruments (Fig. 2(a)):

A set of four 1.5 mm-diameter type-K thermocouples (TC) and four thin-skin calorimeters (TSC) were placed near selected supporting elements in different cluster regions. Even though this number of TC+TSC pairs is insufficient to characterize the heat exposure over every planted element accurately, it does allow for an estimate of the time-resolved average effect of the fire within the cluster.

A set of three bi-directional velocity probes and differential pressure transducers were placed at the center of the cluster to register the average 3D wind and gas velocity within the cluster. Additionally, two protected conventional cameras were placed outside the cluster to record the progression of the fire front at perpendicular angles, as shown in Fig. 2(b). The objective of these cameras was to provide a detailed visual record of the fire progression and its effect on the supporting elements.

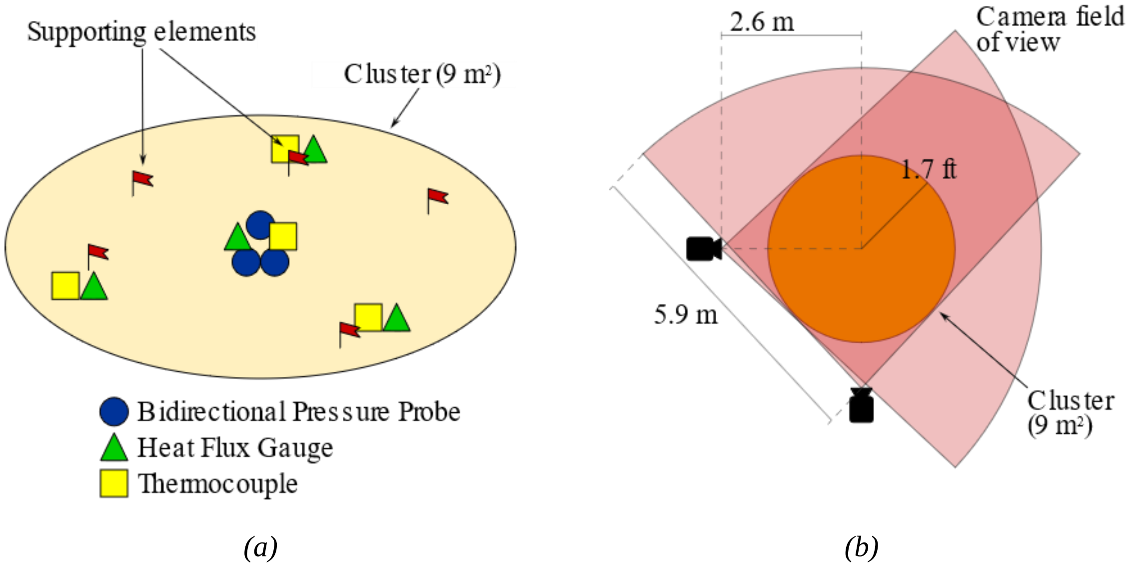


Figure 2: Instrumentation placing within a cluster of supporting elements. (a) Thermal exposure sensors placing, (b) near-cluster camera positioning.

Finally, the generation of macro-scale FPIs was evaluated through visual identification and documentation. Whenever possible, key elements within the burn plot (such as trees or shrubs) were targeted, and a detailed pre- and post-fire analysis (including ground-based LiDAR scanning) was conducted. By using the results obtained from this analysis along with the fire-spread footage registered, it is possible to identify the thermal exposure conditions that lead to the generation of the macro-scale fire pattern indicators observed in these key elements.

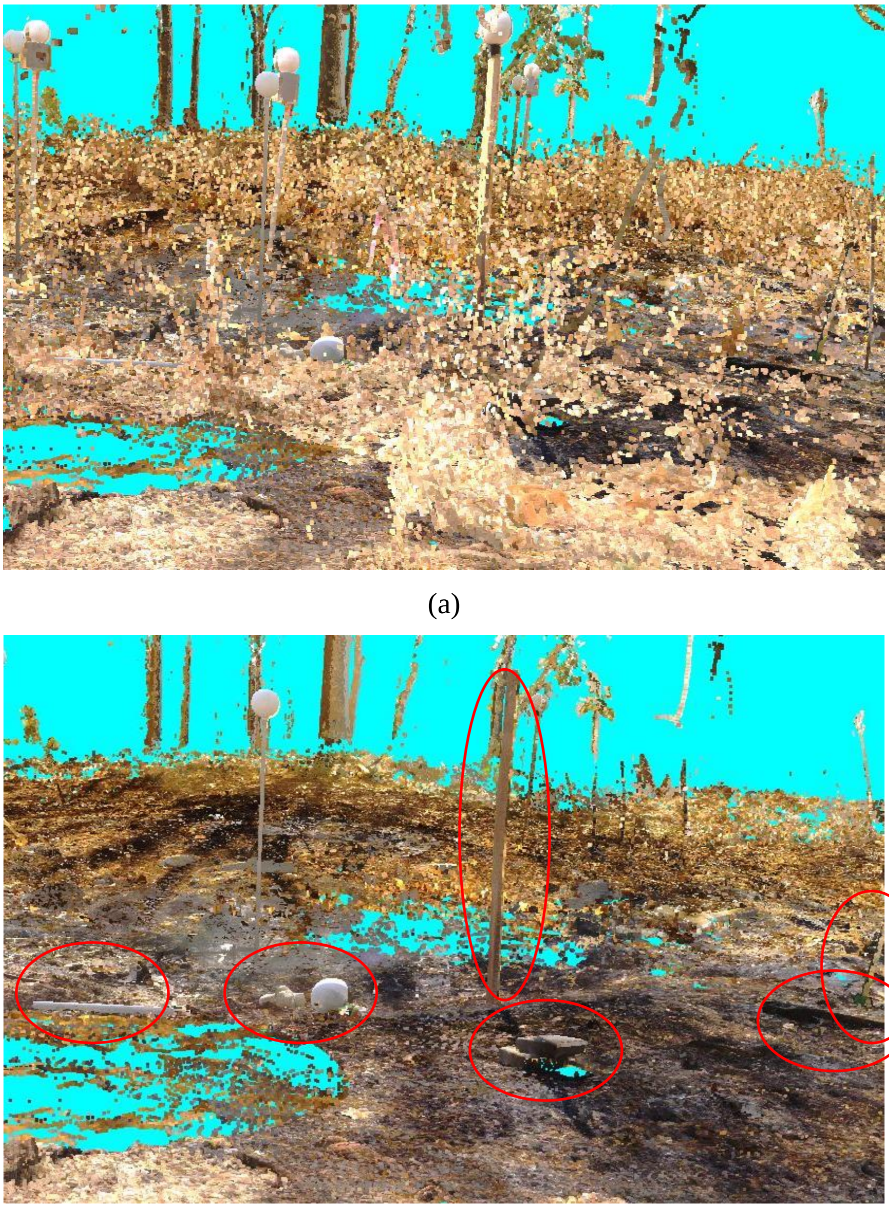
3. Results and Discussion

The preliminary results of some experiments are presented to illustrate the approach in practice. Pre- and post-burn TLS scans highlight the ability qualitatively evaluate fuel consumption within the plot as a first step in the approach (Figure 3). In addition to collecting fuel information, this step records the locations of the FPI materials while sonic anemometers collect data from outside the plot (idealized representation in Figure 4(a)). Figures 4(b) and (c) provide a before-and-after comparison of some of the planted elements to provide an example of the FPIs collected; mainly soot deposition and charring. Figure 4(d) displays the overall propagation of the fire derived from visual observations (red contour lines) as well as the propagation direction derived by the individual interpretation of the microscale FPIs (black arrows).

For three of the eight supporting elements, it was impossible to derive a fire propagation direction based on the damage displayed by the supporting element. It is also interesting to notice the apparent contradiction in the propagation direction derived from the FPIs displayed by the two top-most supporting elements, one of them being the galvanized steel cylinder shown in Fig. 4(b). This contradiction was caused by the collapse and the eventual burning of the branch where the supporting element was installed. These preliminary findings support those of Simeoni et al. (Simeoni et al., 2017); the consideration of a single fire pattern indicator can provide insufficient or potentially incorrect information regarding the evolution of a fire. To infer the real behavior of the fire, the information provided by all FPIs identified must be analyzed holistically.

4. Conclusions

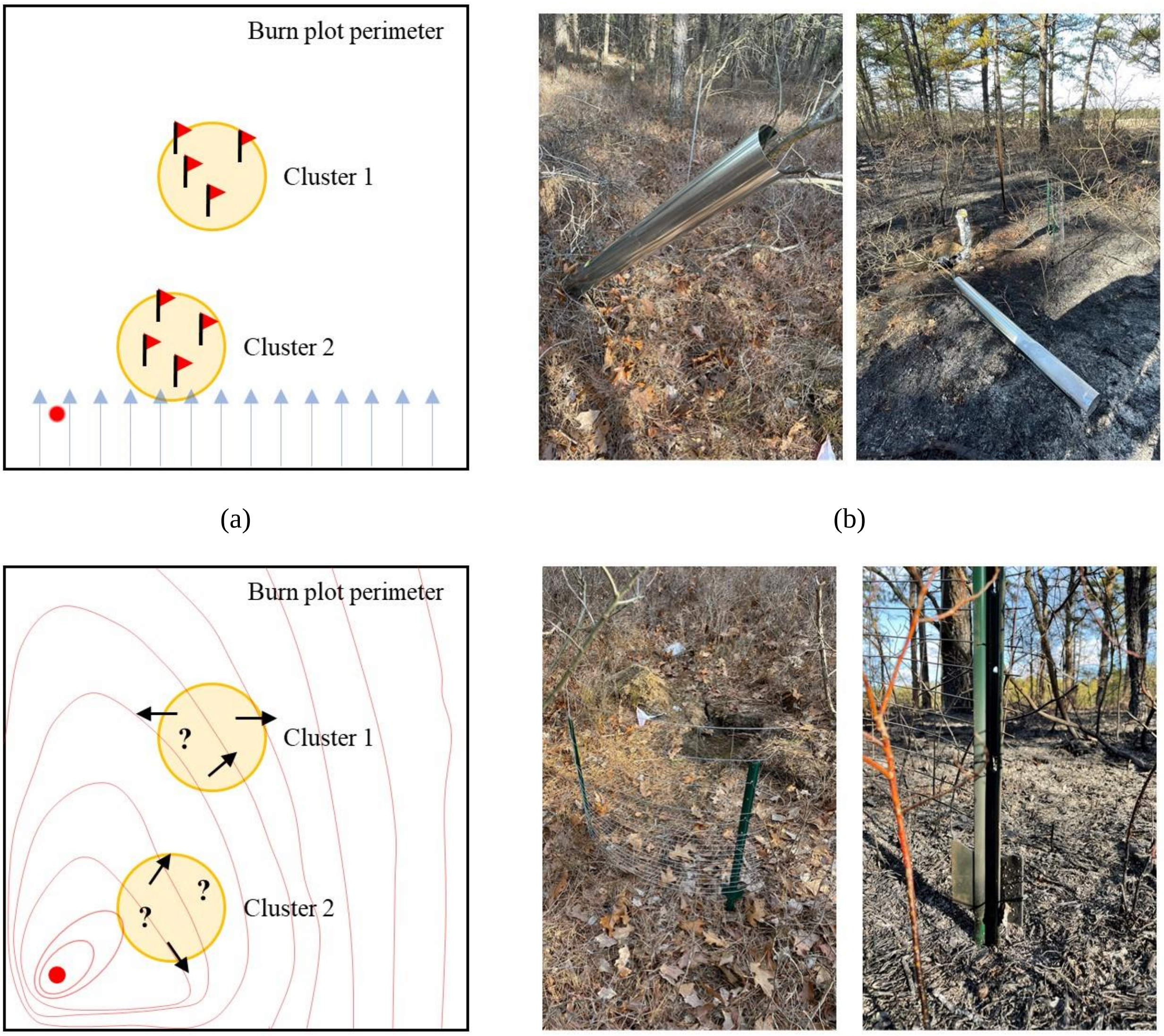
The current work presents and demonstrates an approach for systematic studies of fire pattern indicator reliability in wildland fire investigations. The results of this demonstration support the existing idea that fire pattern indicators are a valuable and valid tool for the determination of the area of origin of a fire, but only when they are used holistically. Further results and analysis to be presented in the full version of this work include fire spread and the characterization of the heat exposure that generates the fire pattern indicators observed in the complete experimental campaign.



(a)

(b)

Figure 3: Example of the LiDAR scans conducted close to a cluster of planted elements (in red circles) in Experiment 6, (a) pre-burn scan, (b) post-burn scan.



(a) (b)

(d) (c)

Figure 4: Generation of FPIs, (a) Placements of the clusters within the burn plot, wind direction, and point of ignition, (b) Damage generated by the fire in a supporting element of cluster 1, (c) fire damage over a supporting element of cluster 2, (d) fire spread derived from visual observation, and propagation direction indicated by the individual FPIs.

5. References

Clark, K. L., Skowronski, N., & Gallagher, M. (2015). Fire Management and Carbon Sequestration in Pine Barren Forests. Journal of Sustainable Forestry, 34(1–2), 125–146. https://doi.org/10.1080/10549811.2014.973607

Hammer, R. B., Radeloff, V. C., Fried, J. S., & Stewart, S. I. (2007). Wildland-urban interface housing growth during the 1990s in California, Oregon, and Washington. International Journal of Wildland Fire, 16(3), 255–265. https://doi.org/10.1071/WF05077

Maranghides, A., & Mell, W. (2013). Framework for Addressing the National Wildland Urban Interface Fire Problem- Determining Fire and Ember Exposure Zones using a WUI Hazard Scale. NIST Technical Note 1748.

Mueller, E. V., Skowronski, N., Clark, K., Gallagher, M., Kremens, R., Thomas, J. C., … Simeoni, A. (2017). Utilization of remote sensing techniques for the quantification of fire behavior in two pine stands. Fire Safety Journal, 91(February), 845–854. https://doi.org/10.1016/j.firesaf.2017.03.076

NFPA. NFPA 921: Guide for Fire and Explosion Investigations. , (2016).

NIFC. (2022). Statistics. Retrieved May 5, 2022, from https://www.nifc.gov/fire-information/statistics

NWCG. (2016). Guide to wildland fire origin and cause determination, PMS 412. National Wildlife Coordinating Group.

Sample, M., Thode, A. E., Peterson, C., Gallagher, M. R., Flatley, W., Friggens, M., … Swanston, C. (2022). Adaptation Strategies and Approaches for Managing Fire in a Changing Climate. Climate, 10(4), 58. https://doi.org/10.3390/cli10040058

Simeoni, A., Owens, Z. C., Christiansen, E. W., Kemal, A., Gallagher, M., Clark, K. L., … Hadden, R. M. (2017). A preliminary study of wildland fire pattern indicator reliability following an experimental fire. Journal of Fire Sciences, 35(5), 359–378. https://doi.org/10.1177/0734904117720674

Skowronski, N., Clark, K., Nelson, R., Hom, J., & Patterson, M. (2007). Remotely sensed measurements of forest structure and fuel loads in the Pinelands of New Jersey. Remote Sensing of Environment, 108(2), 123–129. https://doi.org/10.1016/j.rse.2006.09.032