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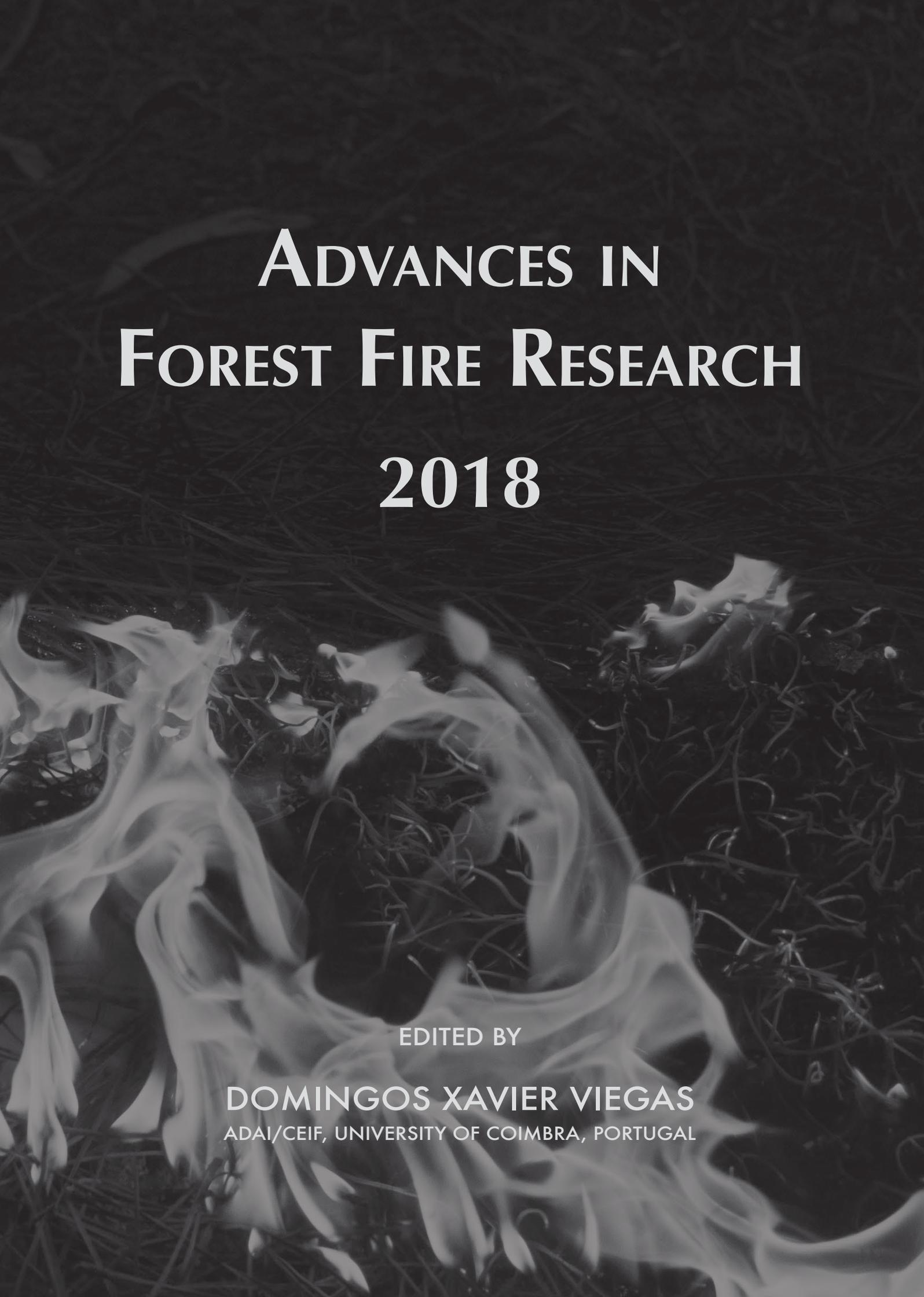
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**ADVANCES IN  
FOREST FIRE RESEARCH  
2018**

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## Effects of law enforcement efforts on intentional wildfires

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### Abstract

Wildland managers and law enforcement organizations devote significant resources attending to the consequences of illegal firesetting across many parts of the world. Intentional wildfires may be set for reasons of malice, as acts of protest, or as pure vandalism. Incendiary wildfires result in deaths, property, and resource damages that exceed rates found for fires of accidental or natural origin. In fact, there is a great concern with how such fires tend to occur nearer populations and values at risk. Extensive evidence suggests that arsonists were behind many of the deadly wildfires that have occurred in many countries, particularly in 2017 in the United States (California), Chile, Portugal, and Spain (Galicia). Apart from firefighting resources, prevention measures may reduce wildfire occurrence. Prevention measures may include fuel reductions (thinnings, fuel breaks, prescribed fire). Research has also shown that education programs and information campaigns, fire investigations, surveillance efforts, as well as law enforcement efforts could reduce unwanted ignitions. Studies of the effects of law enforcement or other wildfire prevention measures have shown that these interventions can reduce wildland arson occurrence overall. Based on Becker's economic theory of crime, law enforcement affects crime in a direct way, through fines and incarceration, and in an indirect way, through deterrence. Criminologists have also recognized the possibility that efforts by law enforcement intended to reduce crime in one time or place or of one type could lead to displacement of crime in a variety of ways (temporal, spatial, target, tactical, and offense), but some research has shown that the opposite could happen—diffusion. In the spatial sense, one kind of diffusion is where law enforcement efforts in one defined location lead to reduced crime across many neighboring locations. The objective of this paper is to describe our efforts to analyze the effect of law enforcement measures—namely, arrests for intentional firesetting—on intentionally-set illegal wildfires. We have conducted two studies (Prestemon et al. 2012, forthcoming) showing evidence for Galicia (NW of Spain). Firstly, we investigated, the effect of an arrest for intentional firesetting on future intentional wildfires in the same location and in neighboring locations. Secondly, we evaluated whether arrests have displacement or diffusion effects, as they may increase or decrease intentional wildfires in nearby locations or later periods, due to both a risk-perception adjusting effect and an incapacitation effect. Therefore, by relating intentional wildfire occurrence to arrest of suspected firesetters, we identify a likely principal mechanism for achieving law-enforcement success. Additionally, we separately quantify the effects of an arrest on agriculturally-based versus non-agriculturally-based intentional firesetting, leaving open the prospect that these two subcategories have different behavioral responses to law enforcement actions and other variables. Such differences could be key to the design of effective policing strategies in response to firesetting in the region.

**Keywords:** arson, arrest, crime, Galicia, incendiary, Spain,

### 1. Introduction

Wildland managers and law enforcement organizations devote significant resources attending to the consequences of illegal firesetting across many parts of the world. Intentional wildfires may be set out of malice, as acts of protest, or as pure vandalism, among other reasons. Incendiary wildfires result in deaths, property, and resource damages that exceed rates found for fires of accidental or

natural origin. In fact, there is great concern with how such fires tend to occur nearer populations and values at risk. Extensive evidence suggests that arsonists were behind many of the deadly wildfires that have occurred in many countries, particularly in 2017 in the United States (California), Chile, Portugal, and Spain (Galicia). Apart from firefighting resources, prevention measures, such as fuel reductions (thinnings, fuel breaks, prescribed fire), may reduce wildfire occurrence. Research has also shown that education programs and information campaigns, fire investigations, surveillance efforts, as well as law enforcement efforts could reduce unwanted ignitions (e.g., Donoghue and Main 1985, Prestemon and Butry 2005, Butry and Prestemon 2005, Prestemon and Butry 2010, Abt et al. 2015). Based on Becker's (1968) economic theory of crime, law enforcement affects crime directly, through fines and incarceration, and indirectly, through deterrence. Criminologists have also recognized the possibility that efforts by law enforcement intended to reduce crime in one time or place or of one type could lead to displacement of crime in a variety of dimensions (temporal, spatial, target, tactical, and offense), but some research has shown that the opposite could happen—diffusion. In the spatial sense, one kind of diffusion is where law enforcement efforts in one defined location lead to reduced crime across many neighboring locations.

The objective of this paper is to describe our efforts to analyze the effects of law enforcement measures—namely, arrests for intentional firesetting—on intentionally-set illegal wildfires. We have conducted two studies (Prestemon et al. 2012, forthcoming) where we describe intentional wildfire in a mixed Routine Activity and Rational Choice (in the Becker [1968] context) theoretical framework, showing evidence for Galicia (NW of Spain). The choice of our study area is relevant because the region of Galicia has the highest wildfire incidences of Spain, and nearly all the fires are human-caused (88%), which have traditionally been associated with illegal behaviour through intentional ignitions (82%). In addition, Galicia is among the most heavily forested regions of Spain, with nearly 70% of the territory classified as forestland, 2 million hectares (ha), which produce 59% of Spain's timber. The primary objective of Prestemon et al. (2012) was to develop and test the forecast performance of forward-looking intentional fire hotspotting models that could be used by managers and law enforcement. A secondary objective was to evaluate whether spatio-temporal lags of intentional wildfire occurrence could be used to aid in these forecasts. Thus, we investigate the effect of an arrest for intentional firesetting on future intentional wildfires in the same location and in neighboring locations. The primary innovation of this work is that we compare competing alternative forward-looking models and identify a superior forecasting empirical model. Our testing framework is rigorous, in the sense that the fit of a forecast is compared against the fit of plausible alternatives, with parameters estimated over a training dataset which pre-dates the long forecast sample. A secondary innovation is that we successfully identify the form of spatio-temporal relationships of intentional wildfire occurrence. Third, we confirm the validity of existing crime theories in the context of intentional fires, particularly in Galicia, Spain, where such tests have not been made. Fourth, and unlike previous research, our models relate intentional wildfire occurrence to a more proximate measure of law enforcement effort: previous arrests of suspected firesetters. The implication of the joint findings of significant spatio-temporal relationships in fire occurrence and of arrests is that law enforcement has broad-scale, long-run impacts that reach far beyond the immediate landscape or short time horizons following arrest. Prestemon et al. (forthcoming) evaluate whether arrests have displacement or diffusion effects, as they may increase or decrease intentional wildfires in nearby locations or later periods, due to both a risk-perception adjusting effect and an incapacitation effect. Therefore, by relating intentional wildfire occurrence to arrest of suspected firesetters, we identify a likely principal mechanism for achieving law-enforcement success. Additionally, accurate quantification of the spatio-temporal displacement of arrests on intentional firesetting might depend on the motivations of firesetters. Thus, we separately quantify the effects of an arrest on agriculturally-based versus non-agriculturally-based intentional firesetting, leaving open the prospect that these two subcategories have different behavioral responses to law enforcement actions and other variables. Such differences could be key to the design of effective policing strategies in response to firesetting in the region. The

remainder of this work describes data, methods and main results of these two papers, and, finally, the main conclusions obtained.

## **2. Forecasting intentional wildfires using temporal and spatiotemporal autocorrelation (Prestemon et al. 2012)**

### **2.1. Data**

We relate reported daily ignitions of intentional wildfires in Galicia, covering January 1, 1999, to December 31, 2006, to intentional wildfire arrests in the forest districts and spatial lags of these arrests at different distances. Variables hypothesized to relate to intentional wildfire occurrences (counts) include: day dummies indicating leisure (Friday, Saturday, Sunday, and non-weekend Holiday), which index potentially lower opportunity costs of crime commission through foregone wages; month dummy variables, which may index the direct costs of successful crime commission, related to fuel conditions and average weather; the Modified Fire Weather Index (MFWI) (Goodrick 2002), which also measures fuel conditions and direct costs; daily minimum relative humidity and maximum one-hour wind speed, capturing direct costs; aggregate income in the spatial unit of inference, and income per capita in the spatial unit of inference, both of which index opportunity costs of crime commission and being caught; and the number of arrests of individuals for intentionally and illegally igniting wildfires in the previous year in the region of Galicia.

### **2.2. Methods**

We develop daily spatio-temporal ignition count models for intentional wildfires as a function of arrests, weather and climate, and socio-economic factors. We specify statistical intentional wildfire forecast models that could be used by managers and law enforcement as tactical and strategic tools. We estimated Poisson autoregressive models of order  $p$ --PAR( $p$ ) models--and three competing alternative models (a static Poisson, a constant rate, and a random walk) at the daily time step. Models are estimated independently for each of the 19 forest districts in Galicia, Spain, over a 1999-2003 training dataset and then evaluated out-of-sample with a 2004-2006 dataset. PAR( $p$ ) and static Poisson models included covariates deriving from crime theory and an understanding of the drivers of wildfire occurrence. Among the covariates were dummy variables indicating the occurrence of intentional wildfires in nearby and distant forest districts in days  $t-1$  and  $t-2$ .

### **2.3. Results**

Models show highly significant autoregressive components, lasting up to four days, in intentional firesetting across all of Galicia's forest districts. This autoregressivity was the primary source of superior forecast performance of the PAR( $p$ ) models over all competing models, reducing out-of-sample forecast root mean squared error of forecast counts for most forest districts by an average of 15 percent compared to the static Poisson and larger amounts for the constant rate and random walk alternatives. Most additional covariates were statistically significantly different from zero and signed consistent with theory. Arrests of individuals for illegal firesetting in Galicia and spatio-temporal lagged occurrences of wildfires in other districts were found to be predictive of wildfire occurrences. This suggests the existence of serial and copycat behavior, and the potential spatial and temporal broad scale impact of law enforcement. We find that the combined temporal and spatio-temporal long-run marginal effect of an additional arrest, summed across forest districts in Galicia, is -139.6 intentional wildfires, equivalent to a long-run elasticity of -0.94.

## **3. Displacement of Wildland Arson by Law Enforcement Efforts (Prestemon et al. forthcoming)**

### **3.1. Data**

Using daily wildfire count data, from January 1, 1999, to December 31, 2014, we develop daily spatio-temporal ignition count models for municipalities. These intentional wildfires are further subdivided into those related to the (illegal) firesetting associated with agricultural activities (fires started by farmers to eliminate shrubs and agricultural debris) and those that are not. Separate model estimates were generated for agricultural intentional, non-agricultural intentional, and their sum. As covariates, we use arrests, the election cycle, day of week, weather and climate, and socio-economic factors.

### **3.2. Methods**

Estimation of the autoregressive count models was done using various assumptions about the spatio-temporal firesetting process. We estimated fixed effects negative binomial models (FENB), random effects negative binomial (RENB) models, and zero-inflated negative binomial (ZINB) models with intercept-shifting municipality dummy variables. The ZINB modeling approach was done because over 100 municipalities had very low counts (fewer than ten per year, from 1999 through 2014) of intentionally ignited wildfires and because for these and many other municipalities, at least half of the year, there were virtually zero intentionally ignited wildfires. This inflated count of zero fires therefore was captured by the first-stage logit equation relating the zero count for a day to municipality dummy variable shifters and other factors. In all models, we attempted to specify multiple autoregressive parameters, but it was clear upon estimation that this was preventing many specifications from converging in maximum likelihood. In the end, we opted for a single autoregressive term to control for the autocorrelation in firesetting that is common in intentional fires.

Effects of arrests on wildfire occurrences in the municipality and in neighboring radii were computed using arrests in two temporal running time blocks: the previous 366 to 545 days, and the previous 1 to 365 days. Buffer radii were 10, 15, and 25 kilometers, justified by the fact that the most firesetters arrested in Spain set a fire close to their place of residence (Sotoca 2016). Effects are reported for the short-run, which ignores the autoregressive effect of wildfires within a municipality, and the long-run, which incorporates the autoregressive effect. When estimating separate agricultural and non-agricultural intentional fire models, we included the lagged count and lagged zero count indicators of both categories. When calculating the long-run effects of elections and arrests, we used only the lagged count of the own type (i.e., the coefficient on agricultural intentional lagged fires was used to make the long-run adjustment, and the same for the non-agricultural category of intentional fires).

### **3.3. Results**

Across all specifications and model versions, arrests reduced the counts of intentional wildfires. This suppressive effect was also identified for progressively farther “donuts” around municipalities, with each spatio-temporal lag negatively related to the count of intentional fires. For agricultural models, the effects of arrests were substantially larger. Non-agricultural intentional fires were more inelastically related to arrests but still demonstrated more elastic responses to arrests compared to total intentional fires. The overall more elastic responses for each of agricultural and non-agricultural wildfires reveal an aggregation bias, attenuating the size of the coefficients on arrests, existing in the total intentional fire model estimates.

An examination of the temporally and spatio-temporally lagged effects of arrests in the different models nearly universally reveal a statistically significant effect of own municipality and neighborhood municipality arrests on the count of intentional fires of both agricultural and non-agricultural fires and their sum. We can conclude that arrests do not tend to displace future firesetting to nearby locations in Galicia; instead, arrests tend to dampen firesetting for at least 1.5 years within and across nearby municipalities. In other words, our models support a diffusion effect of arrests.

#### 4. Conclusions

Our work revealed that an arrest for intentional firesetting could reduce future intentional wildfires for at least one year. These effects of arrests are both direct, stemming from successes within forest districts, and indirect, stemming from successes in other forest districts. This spatio-temporal impact, whose effects until now have never before been quantified in the refereed literature on intentional wildfires, are important and consistent with expectations of a process that contains copycat or even moving serial elements in the firesetting population. Arrests, we find, have wide-ranging and large impacts because of this spatio-temporal element of intentional wildfire patterns in Galicia. Moreover, we also detect that arrests may decrease intentional wildfires in nearby locations or later periods, consistent with a pattern associated with diffusion effects. Thus, we find evidence that arrests diffuse (reduce) future intentional fires across space but do not displace them. This research offers a tool that is needed by policy makers and forest managers to assess the overall impacts of enhanced efforts to reduce the occurrence of intentional wildfires,

#### 5. Acknowledgements

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