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Changes in potential wildland fire suppression costs due to restoration treatments in Northern Arizona Ponderosa pine forests☆

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ABSTRACT

Wildfire suppression costs have been increasing since the early 1970's. With growing concern over wildfire suppression costs, our analysis addresses restoration treatment effectiveness in reducing wildfire suppression costs. We examine past fires across the Northern Arizona landscape to determine fire behavior characteristics that are significant in predicting wildfire suppression costs and capable of being modeled in fire simulations prior to wildfire events. We find burn severity metrics to be significant in predicting wildfire suppression costs. Three proposed treatment alternatives for the Four Forest Restoration Initiative (4-FRI) are analyzed to determine treatment effectiveness and policy implications in reducing burn severity metrics and wildfire suppression costs. The more aggressive treatments are more effective in reducing wildfire suppression costs except in the case of sever wind and weather events.

1. Introduction

Federal agencies, including the USDA Forest Service and Department of Interior (DOI), experienced a rising trend in wildland fire management expenditures beginning in 1971. A 2015 GAO report documented the average annual expenditure on wildland fire management activities at $3.4 billion over the 2004–2014 fiscal years (GAO, 2015). The appropriation for wildland fire management activities by the Forest Service and DOI more than doubled to an annual average of $2.9 billion during the 2001–2007-time frame compared to an annual average of $1.2 billion from 1996 to 2000 (GAO, 2009). This rising trend in wildland fire management expenditures is forecasted to continue in the future with higher frequency of wildland fire occurrences, longer durations of wildland fire seasons (Westerling et al., 2006), and the expansion of residential development within the wildland-urban interface (WUI) (Radeloff et al., 2005a, 2005b).

In previous studies wildfire size has been shown to be correlated with estimating suppression costs (Calkin et al., 2005; Liang et al., 2008; Thompson et al., 2013). If fire suppression costs are to be mitigated, it seems appropriate to focus on the factors, treatments, and policy that relate to fires categorized as "large" in size or where the severe wildfire threat is greatest (Pollet and Omi, 2002; Holmes et al., 2008). Our analysis expands on previous studies by examining burn characteristics of previous wildland fires that are significant in predicting wildfire suppression costs. Examining previous wildfires near our study area allows us to determine which fire behavior characteristics are useful in predicting suppression costs. We further seek wildfire behavior characteristics that can be modeled via fire modeling programs to determine wildfire suppression costs *ex ante*. Incorporating wildfire behavior results, we develop a regression model to predict wildland fire suppression costs. However, wildfire modeling is not without error. Incorrect use of model inputs and underprediction bias from the models impact the model outputs and the conclusions drawn from model outputs (Varner and Keyes, 2009; Cruz and Alexander, 2010). Our results are complementary to the future application of Risk and Cost Analysis Tools Package (R-CAT) (USDA Forest Service, 2010). R-CAT's general purpose is to standardize the methods for estimating risk reduction and cost savings resulting from land management proposals and treatments. R-CAT is required for all fire projects funded by the USDA Forest Service Collaborative Forest Landscape Restoration Program (CFLRP) and our results are not meant to replace the required procedure (USDA Forest Service, 2010).

2. Background

There have been considerable efforts to understand the factors affecting overall costs of wildland fires (e.g. Donovan and Rideout, 2003;

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Donovan et al., 2004; Gebert et al., 2007; Liang et al., 2008; Lynch, 2004; Prestemon et al., 2008; Donovan et al., 2011). Intuitively, one important factor is the increasing trend in total hectares (ha) burned by large wildland fires. Wildland fires < 122 hectares (ha) in size accounted for approximately 98.5% of the fires managed by the Forest Service from 1980 to 2002 but these small fires accounted for 6.2% of the total wildland fire suppression expenditures (Strategic Issues Panel on Fire Suppression Costs, 2004). A comparison of the average number of ha burned by wildland fires from 1970 to 1986 and 1987–2002 shows a stark increase from approximately 115,340 ha burned to over 405,000 ha burned annually (Calkin et al., 2005). For another comparison, 1700 fire ignitions burned about 1.21 million ha of forests in the Northern Rocky Mountains in 1910, while three ignitions triggered the Rodeo-Chediski and Hayman fires, which burned > 200,000 ha in 2002. While not studied directly, Calkin et al. (2005) reported that total hectares burned track wildland fire suppression costs "very well" on an annual basis. Large wildfires (> 400 ha) constitute a small number of total wildland fires that occur across the landscape (1.1%) and these large wildland fires accounts for 97.5% of the total hectares burned (Calkin et al., 2005). The frequency of large wildfires has markedly increased since the mid-1980s as there were almost four times as many large fires burning nearly seven times more land between 1987 and 2003 than compared to 1970 through 1986. The trend in the frequency of large wildfires has gotten worse and is projected to continue with warmer temperatures and earlier spring onset via climate change (Westerling et al., 2006). Although total fire size (area burned) increases overall suppression cost, expected suppression cost per ha decreases as fire size increases due to the fixed nature of many fire suppression related expenditures.

Total wildland fire suppression cost has been positively correlated with various spatial factors in addition to fire size. However, some of these factors have produced differing results. In a study that examined 100 wildland fires > 120 ha in size between 1996 and 2005, approximately 58% of the variation in wildland fire suppression costs was attributed to fire size and percentage of private land burned (Liang et al., 2008). After examining 1550 wildland fires across the US, Gebert et al. (2007) found that total housing value within 32 kilometers (km) of the wildland fire ignition point had a positive effect on expected suppression cost. Yoder and Gebert (2012) also found that housing values within a 20 mile radius of the wildfire contributes to an increase in estimated wildfire suppression costs. Complicating the hypothesis that the proximity of houses to wildfire increases suppression costs, Donovan et al. (2004) didn't find housing density or total housing to be significant in predicting wildfire suppression costs. Rather, fire size was again found to be the most significant variable (Donovan et al., 2004).

Increased wildland fire suppression expenditure has led to a growing interest in modeling effectiveness of fuel treatments; namely, changes in wildland fire burn probabilities and fire behavior due to fuel treatments (e.g. Ager et al., 2011; Calkin et al., 2005; Cochrane et al., 2012; Finney, 2005; Finney et al., 2005; Pollet and Omi, 2002; Stratton, 2004). The results of the fire modeling can be used to strategically locate fuel treatments in the landscape (Finney, 2005) and to estimate changes in expected suppression costs due to fuel treatments (Wildland Fire Management Risk and Cost Analysis Tools Package: R-CAT) (USDA Forest Service, 2010).

Fire modeling used to predict fire size, characteristics, and behaviors has limitations. Because wildland fire behavior is modeled over a given area of the landscape, the potential extent of a wildland fire cannot be modeled via fire behavior modeling programs (e.g. FlamMap) alone. ArcFuels, combined with fire behavior models was used to strategically implement optimal fuels treatments in Region 6 (Oregon and Washington, USA) by the US Forest Service (Vaillant et al., 2012). With the FlamMap fire model, pixels are assessed independently of each other regarding fire behavior.

Large wildland fires usually occur under the most extreme weather conditions (Finney, 2005). The creation of the landscape files that are used as inputs for modeling fire behavior are at the discretion of the modeler. These inputs determine fire behavior, thus consultation with an experienced fire ecologist should be considered to develop appropriate inputs for more accurate results. In addition, inputs such as fuel moistures; wind speed and direction; and weather conditions are needed in determining fire behavior. Varner and Keyes (2009) caution and elaborate on the need for accuracy clear statements of assumptions regarding parameter value inputs (e.g. fuel moisture and wind speed) (Varner and Keyes, 2009).

For modeling fire size, the FARSITE simulation system could be implemented which simulates wildland fire growth (Finney, 1998; Finney, 2004). FARSITE incorporates the above-mentioned inputs that FlamMap (Finney, 2006) uses but goes further to include a fire spread model, crown fire initiation model, crown fire spread model, and dead fuel moisture model.

Cruz and Alexander (2010) point out three main areas of bias that occur in fire modeling (Cruz and Alexander, 2010). Of first concern is the linkage of fire models that were created independently of one another but are used in conjunction with modeling fire behavior. Secondly, Rothermel's rate of fire spread models and Van Wagner's crown fire transition and propagation models have an underprediction bias in assessing modeled crown fire behavior. The final point of contention is the "crown fraction burned functions" (CFB functions) which are unsubstantiated by comparison to actual wildfire activity. We acknowledge the shortcomings and complexities of current fire behavior modeling tools and incorporate recommendations presented by Varner and Keyes (2009); Cruz and Alexander (2010).

There are social and political factors that affect fire managers' decisions and the expenditures committed for fire suppression efforts (Donovan et al., 2011). In addition to fire managers' decisions, land managers must also allocate resources to achieve goals of different treatments types (e.g. restoration treatments vs fuel load treatments) (Reinhardt et al., 2008; Stratton, 2004). Ecological restoration treatments can differ from fuel reduction treatments; they are not analogous. Ecological restoration is designed to return a current ecosystem to conditions representing a range of variation from multiple references. In the case of frequent-fire ecosystems like ponderosa pine (*Pinus ponderosa*) in the southwest USA, conditions from pre-fire exclusion (pre-European settlement) are used to describe a restored system (Covington and Moore, 1994). These restoration treatments include reintroducing pre-settlement fire regimes, species composition, species spatial patterns, and stand structures. Given today's overly dense ponderosa pine stands with larger fuel loads, ecological restoration treatments attempt to change fire behavior from high severity crown fires to low severity surface fires in modeling studies (Stephens, 1998; Stephens and Moghaddas, 2005; Fulé et al., 2001; Fulé et al., 2002; Roccaforte et al., 2009; Stephens et al., 2009). Ecological restoration in ponderosa pine meets Reinhardt et al.'s (2008) strict fuel treatment's objective as lessening fuel loads thereby reducing fire severity. Fuel treatments can achieve this objective. However, in those fire regimes where infrequent, stand-replacing fires are natural, fuel treatments could also create forest structures that are divergent from their historical structure.

Budgeting practices have been implemented as a method to help reduce expenditures on wildfire suppression costs. Efforts for better fire budgeting and planning started with the 1995 Federal Wildland Fire Policy and the National Fire Management Analysis System (NFMAS), a tool developed by the Forest Service (DOI Office of Policy Analysis, 2012). The efforts continue with the 2009 Federal Land Assistance, Management and Enhancement (FLAME) Act, which requires development of a National Cohesive Wildland Fire Management Strategy. The NFMAS seeks to optimize the Forest Service's fire budget for a given geographical area by minimizing wildland fire related costs, utilizing the known monetary costs associated with the "Cost plus Net Value Change" (C + NVC). However, after reviewing over 300 recommendations in the previous five years, the Strategic Issues Panel on Fire Suppression Costs (2004) characterized the federal agencies