Forest Service Large Fire Area Burned and Suppression Expenditure Trends, 1970–2002

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ABSTRACT

Extreme fire seasons in recent years and associated high suppression expenditures have brought about a chorus of calls for reform of federal firefighting structure and policy. Given the political nature of the topic, a critical review of past trends in area burned, size of fires, and suppression expenditures is warranted. We examined data relating to emergency wildland fire suppression expenditures, number of fires, and acres burned and developed statistical models to estimate area burned using drought indices for the USDA Forest Service from 1970–2002.

Keywords: wildland fire, Forest Service suppression expenditure trends, Palmer Drought Severity Index (PDSI)

Unprecedented expenditures on wildland firefighting over the past several years have brought federal wildland fire management to the forefront of political debate. Extreme fire seasons have occurred in 3 of the last 4 years (2000, 2002, and 2003), with federal expenditures on emergency fire suppression exceeding $1 billion in each of those 3 years. The fire season of 2002 was the most expensive on record. Federal firefighting expenditures totaled $1.6 billion, with the USDA Forest Service alone spending over $1.1 billion (National Interagency Fire Center 2003). In 2002, three western states experienced their largest single wildfire seasons on record: the Hayman fire in Colorado, the Rodeo-Chediski in Arizona, and the Biscuit in Oregon; an estimated 6.9 million acres burned nationwide. Our focus is on USDA Forest Service fire suppression expenditures, which account for nearly three-fourths of all federal suppression expenditures.

A variety of explanations have been offered for the high levels of emergency fire suppression expenditures, including excessive fuel loading caused by decades of successful fire suppression, increased development in the wildland-urban interface (WUI), lack of financial accountability of fire managers, and severe and prolonged drought (National Academy of Public Administration 2002). In fire-adapted ecosystems common throughout much of the West, there is strong evidence that past fire suppression has resulted in fuel loads well outside historic regimes and is largely responsible for the increased size and severity of some wildland fires (Arno and Brown 1991, Arno et al. 2000). Residential development in the WUI and the emphasis of federal firefighting organizations on protecting residential structures has also been mentioned as a potential factor increasing suppression expenditures (Snyder 1999). Additionally, there is much discussion about the lack of financial accountability of fire managers and an incentive system that makes fire managers more risk averse than socially optimal (USDA, USDI, NASF 2003). Risk aversion can cause both excessive use of firefighting resources and substitution of expensive (but less risky) capital resources for less expensive (but more risky) labor resources.

The influence of weather on fire season severity is well established. A number of recent studies have explored the relationship between drought and fire season severity (Westerling et al. 2003, Swetnam and Betancourt 1998, Balling et al. 1992). In a much-cited study of subalpine pine forest types, Bessie and Johnson (1995) state "forest fire behavior is determined primarily by weather variation among years rather than fuel variation associated with stand age." However, Agee (1997) and Betancourt et al. (2003) argue that, while weather is the dominant factor in determining fire severity and size in forest types that typically burn infrequently and at high intensity, fuel buildup cannot be discounted in the drier forest types that typically burn frequently but at low intensity.

Given the extreme fire seasons and associated suppression expenditures that have recently been experienced, it is important to examine the data to identify real trends and dispel any incorrect assumptions regarding USDA Forest Service emergency fire suppression expenditures. The following analysis is a first step in understanding emergency firefighting expenditures by critically exam-

ining macro-level data for the USDA Forest Service.

Methods

We examined data relating to emergency wildland fire suppression expenditures, number of fires, and acres burned for the USDA Forest Service from 1970 to 2002 for individual USDA Forest Service regions and aggregated for the continental United States. These data have been compiled from the USDA Forest Service's accounting system (Central Accounting Data Inquiry (CADI) for data prior to fiscal year 2000 and Foundation Financial Information System (FFIS) for fiscal year 2000 and beyond) and the National Interagency Fire Management Integrated Database (NIFMID), the USDA Forest Service's fire occurrence database. Financial data for the continental United States are from fiscal year 1971 to 2002, while regional acreage burned data are from calendar year 1970 to 2002. We compiled data on the total number of fires and all fires greater than or equal to 300 ac (class E, F, and G), which we call large fires, the cost per acre of suppressing the large fires, and total area burned by all fires and by large fires. Expenditure data are for emergency wildland fire suppression; initial attack funding is not included in this analysis. This focus was necessary due to changes in accounting structures within the initial attack budget. Historical data at the regional and national level were graphed, and, where appropriate, econometric models were developed to identify relevant trends.

A number of recent studies have used a common measure of drought, the Palmer Drought Severity Index (PDSI, Palmer 1965), to predict fire season severity including Balling et al. (1992), Swetnam and Betancourt (1998), and Westerling et al. (2003). The PDSI is a measure of the scope, severity, and frequency of prolonged periods of abnormally dry or wet weather and is useful as an indicator of general conditions and not local variations (National Oceanic and Atmospheric Administration, National Weather Service 2003). Swetnam and Betancourt (1998) identified a strong correlation between tree-ring-reconstructed regional fire-scar chronology and June-Aug. PDSI time series for the Southwest. Westerling et al. (2003) investigated associations between the PDSI and seasonal acres burned in western wildfires and identified positive correlations with PDSI 12–15 months prior to Aug. The authors conclude that this result

appears to reflect a trade-off between fuel accumulation and flammability, with wet conditions in the previous year contributing to fuel accumulation and wet conditions in the current year suppressing fire activity by moistening the fuels, and, conversely, dry conditions in the previous year inhibiting fuel accumulation and dry conditions in the current year enhancing fire activity by drying the fuels.

There are indications of significant shifts in long-term weather regimes, influenced by interdecadal oceanic oscillations, over the period of analysis (Swetnam and Betancourt 1998). Weather in North America is affected by interdecadal oceanic circulation regimes in all three oceans that ring the continent, the Pacific, Arctic, and Atlantic Oceans (Hurrel 1995, Thompson and Wallace 1998, Mantua and Hare 2002). Among the most prominent were ocean-climate regime shifts in the early 1940s, mid-1970s, around 1987–89, and most recently around 1997 (Hare and Mantua 2000). The regime shifts in the 1940s and 1970s are associated with a three-decade cooling trend in the middle of an otherwise continuous warming trend over the 20th century (Folland et al. 2001). With the regime shift in the mid-1970s, the western United States has undergone two extreme wet-dry cycles unlike anything since the onset of the 20th century. The extreme El Niños in 1983 and 1998 punctuate the wet episodes, while the 1987–89 regime shift and the most recent years (ca. 2000–2002) were among the driest in historic times. The 1987–89 regime shift produced prominent signals in all three oceans, but persisted in the Arctic and North Atlantic to the present. These wet and dry periods may have increased the severity of fire seasons, especially since 1987. Vegetation fuels increased during the extended wet

periods, while fires were more limited, and then the fuels were dried and easily combusted during the extended dry periods.

We developed statistical models to predict area burned for individual Geographic Area Coordination Center (GACC) regions using Palmer drought indices as explanatory variables. We used the following base model:

$$\text{area burned}_t = \text{fn} (\text{PDSI(fire)}_t, \text{PDSI}_{t-1}, \text{annual dummy})$$

Area burned is total area burned by all USDA Forest Service fires in the specified region. PDSI(fire)_t is the average PDSI over the fire season, and PDSI_{t-1} is the previous year's average annual PDSI for that region. Palmer drought indices used in this analysis were provided by Neilson and aggregated at the GACC regions. PDSI(fire) was averaged for the individual regions based on the primary fire season months shown in Table 1. For the Southern California region, we examined two alternative fire season definitions. The first, including only July and Aug., was identified by Tom Wordell of the National Interagency Coordination Center (NICC). The second included the months of July and Aug. as well as Sept., Oct., and Nov. to represent the potential effects of Santa Ana winds on fire season severity. The annual dummy variable was included to test for variation in area burned related to weather regime shifts over the study period.

Results

Emergency firefighting expenditures are spent to suppress escaped fires, wildland fires 300 ac or larger (classes E, F, and G). Most fire starts are contained before the fire meets the definition of escaped wildfire. Over the period of analysis, between 97.2 and 99.7% of all fires were contained in the smaller fire classes A through D. However, a
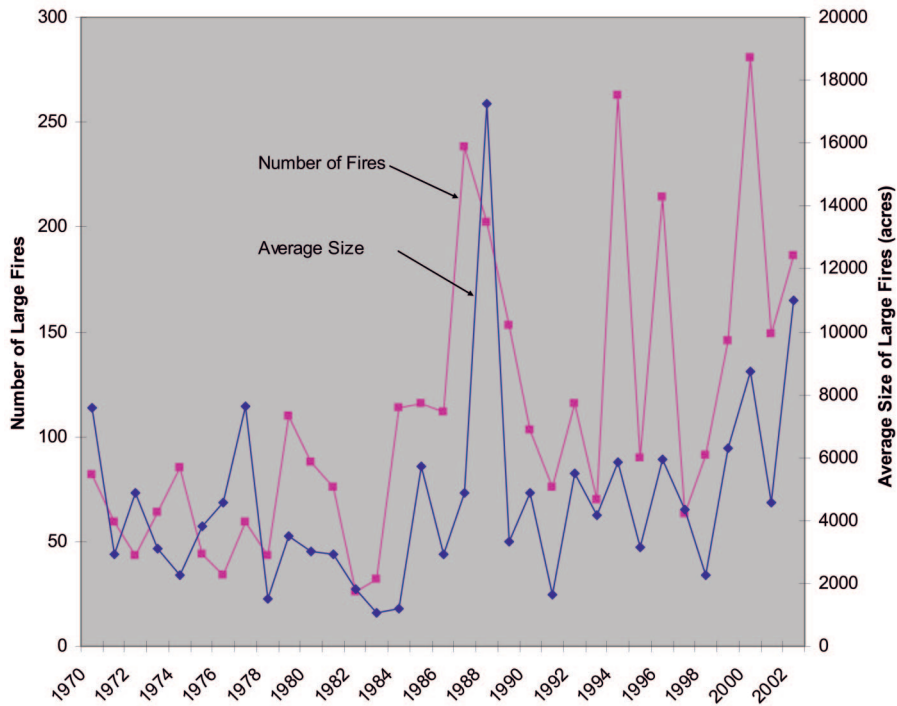
Table 1. Fire season months by region (provided by Tom Wordell, Wildland Fire Analyst, National Interagency Coordination Center).

Region	Fire season months
Pacific Northwest	June, July, Aug.
Northern California	July, Aug., Sept., Oct.
Southern California[a]	July, Aug.
Western Great Basin	June, July, Aug., Sept.
Eastern Great Basin	June, July, Aug., Sept.
Northern Rockies	June, July, Aug.
Rocky Mountain	June, July, Aug., Sept.
Southwest	May, June, July
South	Mar., Apr., May, June
East	Mar., Apr., May

[a] Additionally, we evaluated a fire season for Southern California including July, Aug., Sept., Oct., and Nov. to represent the effects of Santa Ana winds in the fall months. Results for both models are presented in Table 2.

Figure 1. Number and average size of USDA Forest Service large fires (class E, F, and G).
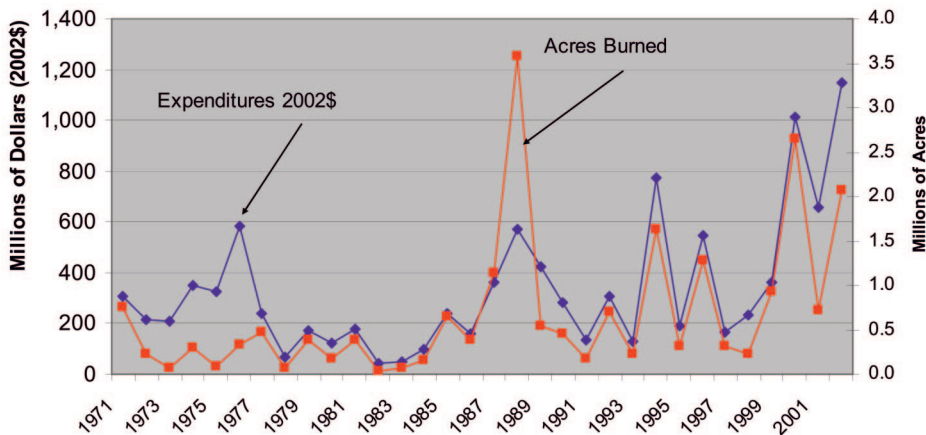

Figure 2. USDA Forest Service suppression expenditures (2002$) and area burned.
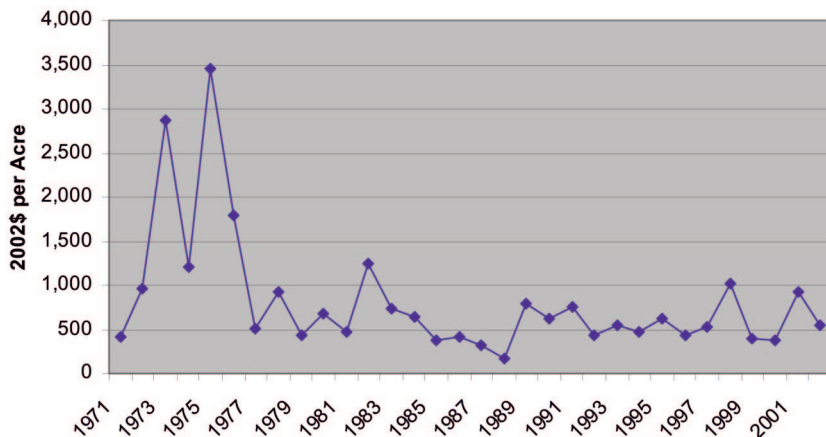

Figure 3. USDA Forest Service suppression expenditures per acre (2002$).

majority of all acres burned occurred in the larger fire classes. Averaged over the length of the study period, large fires accounted for only 1.1% of all fires but accounted for 97.5% of the area burned. Furthermore, there appears to be a trend of an increasing number of large fires and average size of these large fires over time (Figure 1).

Total annual emergency firefighting expenditures are extremely volatile, but an increasing trend is obvious in the data with nine of the 10 most expensive fire seasons (adjusted to 2002 dollars) occurring since 1987 (see Figure 2). Moreover annual suppression expenditures exceeded $1 billion in both 2000 and 2002.

Total expenditures can be broken down into two parts, total acres burned on large fires and the cost per acre of fighting these fires. Figure 3 displays that emergency suppression expenditures per acre burned have, in fact, exhibited a downward trend that starts to flatten out in the late 1980s. However, total area burned shows a different trend, increasing and becoming far more volatile around 1987 (Figure 2). If you simply take the average of area burned from 1970–1986 and 1987–2002, you see that the average has increased from approximately 285,000 to over 1,000,000 ac per year. Simply put, suppression expenditures increased and became erratic when acres burned increased and became erratic. Graphing emergency fire expenditures against total area burned (Figure 2) shows the close correlation between total expenditures and area burned (Pearson's correlation coefficient equaled 0.76 while the correlation between expenditures and cost per acre was an insignificant -0.019).

Results of modeling area burned as a function of PDSI were regional specific, but common patterns were evident. From the generic model described in Equation 1, the following model was developed:

$$Ln\ (area\ burned_t) = B_0 + B_1 * PDSI(fire)_t + B_2 * PDSI_{t-1} + B_3 * D1987_t$$

Coefficient values, levels of significance, and model fit for the individual regional models are presented in Table 2. We transformed area burned using the natural logarithm to improve model fit based on results from Box-Cox tests (Green 1993). Not surprisingly, PDSI fire season was negative and significant in all regions; area burned increases when the fire season is drier. The previous year's PDSI was positive and significant (at

Table 2. Econometric model results for individual GACC regions (all results significant at the 0.05 level unless italicized with significance level in parenthesis).

Region	Constant	PDSI(fire)$_t$	PDSI$_{t-1}$	D1987$_t$	R^2
Pacific Northwest	9.453	−0.578	*0.185 (0.202)*	1.357	0.56
Northern California	9.717	−0.405	*0.204 (0.101)*	0.885	0.38
Southern California (July, Aug.)	10.776	−0.175	0.466	*0.503 (0.124)*	0.43
Southern California (July—Nov.)[a]	10.802	−0.193	0.454	*0.447 (0.176)*	0.43
Western Great Basin	7.652	−0.351	0.505	1.908	0.56
Eastern Great Basin	9.934	−0.600	0.699	1.847	0.67
Northern Rockies	9.211	−1.086	0.509	1.462	0.74
Rocky Mountain	8.894	−0.817	0.690	1.183	0.58
Southwest	10.212	−0.220	*0.268 (0.073)*	0.942	0.37
South	10.135	−0.361	0.271	0.627	0.56
East	9.028	−0.429	0.375	*0.087 (0.691)*	0.29

[a] Two fire season definitions were examined for Southern California. The first includes only July and Aug., while the second includes July and Aug. as well as Sept., Oct., and Nov. to represent the effects of Santa Ana winds on fire season severity.

the 0.05 level) in all regions except the Pacific Northwest and Northern California (significant at the 0.202 and 0.101 levels, respectively). These results are consistent with Westerling et al. (2003); moist growing seasons in the previous year increase fuel loading and thus area burned in the following fire season. Residual analysis of a model using only the two PDSI variables, as well as recursive residuals and Chow tests (Green 1993), confirmed that a structural shift in the model occurred around 1987 consistent with a significant shift in weather regimes. The annual dummy variable (D1987) was defined as 0 for years 1970–1986 and 1 for 1987 forward. The coefficient for D1987 was positive and significant in eight of the 10 models, indicating that after accounting for variations in PDSI, total area burned increased significantly starting in 1987. The coefficient for the dummy was positive but insignificant for the Southern California and Eastern regions (significant at the 0.124 and 0.691 level, respectively). The two alternative fire season definitions for Southern California performed equally well in predicting area burned with only modest changes in model parameters.

We calculated estimated area burned using a "smearing" estimate (Duan 1983) from the individual regional models and aggregated these results to determine estimated total area burned in the continental United States. Figure 4 presents the results of graphing estimated area burned against actual area burned for the United States over the length of the data series. The estimated acres burned tracks the actual acres burned very closely ($R^2 = 0.90$).

Discussion

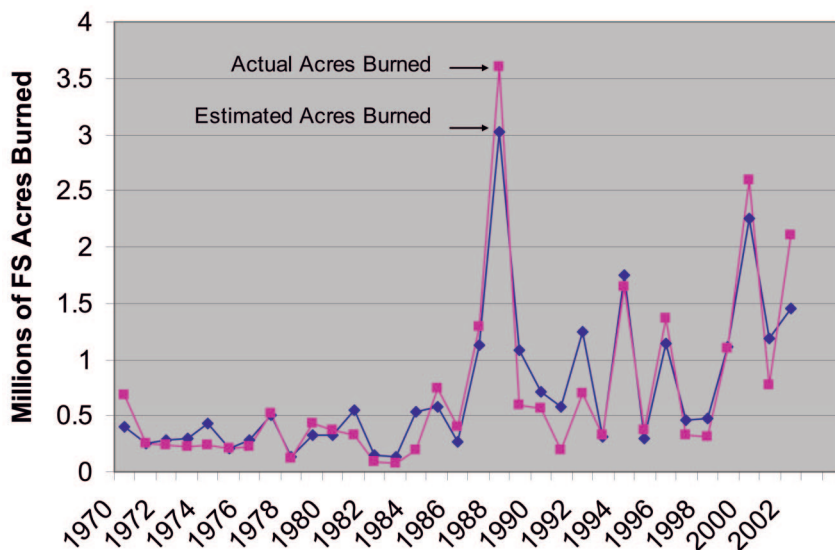Total USDA Forest Service emergency fire suppression expenditures have been in-

Figure 4. Estimated versus actual USDA Forest Service area burned.

creasing over time with expenditures exceeding $1 billion in 3 of the last 4 years (including FY 2003). This increase in suppression expenditures appears to be related to the increase in acres burned (which also increased substantially over the same period) and not a per acre increase in suppression expenditures (trend for average per acre expenditures did not increase). Large fires represent a small number of the total fires, but constitute the bulk of total area burned; 1.1% of all fires burned 97.5% of total area. Both the number of large fires and average size of large fires appear to have increased over time.

Total area burned tracks suppression expenditures very well. Area burned can be modeled successfully using current and past regional drought indices, yet a significant dummy variable improves model fit, implying that total area burned significantly increased after 1987. The common rationales for increasing fire expenditures do not ac-

count for this structural shift. Increasing development within the wildland-urban interface has been increasing over the study period, but does not account for any distinct shifts. Firefighting agencies are likely focusing more resources on structural protection, reflecting the development trends in the WUI, but those shifts are also continuous and do not explain a major change occurring in 1987. Excessive fuel loading has certainly been responsible for the increased size and severity of some wildland fires, but fuel loading has been building for decades. The key factor that we believe is driving the system and interacting with the excessive fuel loads is the weather. Over the past 15 years, a long-term weather regime shift, caused by oceanic interdecadal oscillations, has increased the length and intensity of the wet and dry periods. During wet periods, fine fuel growth increases fuel loading where fuel loads are often already well above historic

conditions due to past fire exclusion. During prolonged, intense dry periods, these fuels dry out, and then if a fire starts, it is more likely to be large and of high intensity.

Currently, cost containment strategies are being put forward as the means to control the unprecedented suppression expenditures seen in the last several years. In the fall of 2003, a blue ribbon panel is being convened by the USDI and USDA to address cost containment. The Large Fire Cost Reduction Action Plan (USDA, USDI, NASF 2003) highlighted this issue, stating that "we must elevate cost containment commensurate with other objectives." Along these lines, there have been recommendations to reduce utilization of high cost resources such as aircraft. We do not deny that inefficiencies in fire suppression efforts likely exist and that these actions should be identified and addressed. However, making assumptions that reducing the use of high-cost resources will improve cost containment is premature. The production functions for fire suppression resources are largely unknown, as is the effect in certain instances of not applying suppression resources. Without this additional information, high cost, highly effective resources may be replaced with lower cost, but less effective resources. The results of our analysis suggest that the current level of suppression expenditures is largely a function of acres burned, and acres burned are largely a function of weather-related variables. Current weather patterns are exacerbating a difficult firefighting environment due to fuels accumulation and WUI development. Strategies to contain costs based on anecdotal information without carefully thought out analysis may in fact increase fire damages and overall costs.

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