Wildland Fires within Municipal Jurisdictions

Douglas S. Thomas (douglas.thomas@nist.gov) is economist, and David T. Butry (david.butry@nist.gov) is economist, National Institute of Standards andTechnology, Department of Commerce, Office of Applied Economics, 100 Bureau Road MS 8603,Gaithersburg,MD20899.

The authors thank Joshua D. Kneifel, Nicos Martys, and Robert Chapman for their many ideas and suggestions for this article.

Abstract:
Each year, wildland fires threaten structures and occupants of the wildland-urban interface (WUI). Currently, wildfire ignition estimates largely exclude ignitions originating within municipal jurisdictions, whose jurisdiction encompasses the majority of the U.S. population. The objective of this paper is to provide national estimates and trends of the WUI-fire problem; in particular we analyze the U.S. Fire Administration's (USFA) National Fire Incident Reporting System (NFIRS) fire incident data from 2002 to 2006 reported by local municipal fire departments across the United States. We estimate that, on average, the burning of wildland fuels are associated with 116 971 fires annually. Each year, these fires are responsible for, on average, 15 civilian (non-fire service) fatalities, 88 civilian injuries, and $160 million in direct property losses. These damages include losses to 599 residential structures, 649 non-residential structures, and 829 vehicles (per year). Based on the value of a statistical life ($8.75 million) and statistical injury ($189 thousand), we find that the economic value of fatalities and injuries averaged $148 million annually. Thus, the losses associated with fires occurring on municipal lands total on average $308 million annually over this time period.

Introduction
In recent years, communities have increasingly developed in close proximity to forested areas making wildfires a growing threat to businesses, infrastructure, and personal safety. Needed are risk-based methods to prioritize and distribute wildland fire mitigation resources (International Code Council 2008). Currently, standardized science-based risk assessment tools do not exist, partly because the exposure conditions impacting structure vulnerability during wildland fire incidents are not well-characterized (Mell et al. 2010). National wildfire statistics, which are often used to define the U.S. wildfire problem (and motivate research in the area), are based on federal and state fire incident data, and do not account for wildland fires originating within municipal jurisdictions (i.e., towns and communities). Municipal fire departments are responsible for protecting the majority of the U.S. population. In doing so, they respond to a significant number of fires involving wildland fuels (e.g., forests) on non-federal and non-state lands, which threaten structures and lives. In properly defining the size and the scope of the U.S. wildfire problem these fire incidents must be taken into account. Optimal forest management—on either public or private lands—will not occur without, at least first, measuring the threats facing forested communities. In addition, a better understanding of the factors that contribute to structure loss will lead to a better characterization of the exposure conditions. Thus, there is much to be gained—in terms of structure protection and forest management—from analyzing all wildland fire incidents that encroach upon the Nation's communities.

Wildfires damage structures and timber while affecting the health and safety of people who live nearby. They also account for 9 of the 25 largest fire loss incidents in U.S. history, with 4 in the top 10 (NFPA 2009). Of these fires, damages ranged from $0.5 billion to $2.4 billion in direct losses per incident (in 2008 constant dollars; NFPA 2009). Wildfires have the potential of creating large amounts of damage because a single wildfire can threaten many homes at a time (Cohen 2000). For instance, in 2002, the Hayman Fire burned more than 600 structures in 20 days, an immense amount of land and property in a short period of time (Graham 2003). Another example was the Rodeo-Chediski fire, which burned more than 470 structures later that same year (USDA Forest Service 2002).

As people move toward rural areas and closer to forest lands, the risk to people and infrastructure from wildfires increases making it vital to understand the wildfire problem. Every state has some amount of land classified as wildland urban interface (WUI)–areas where people and their developments "meet or intermix with wildland fuel" (Office of the Federal Register 2001). It is estimated that between 13 % to 38 % of conterminous U.S. housing units reside within the WUI (Theobald and Romme 2007; Radeloff et al. 2005). This area is estimated to grow 10 % by the year 2030. Rapid WUI growth is already occurring in the western states with moderate growth in mid-west states (Theobald and Romme 2007). The northern lower part of Michigan, for example, had a significant amount of wildland area that has increased from a population of 400 000 to 750 000 between 1970 and 2000 (Haight et al. 2004). This growth has resulted in approximately 24 % of the houses and 19 % of the people being in high risk WUI areas (Haight et al. 2004).

Minimizing the total of costs and losses of wildfire, an economic objective of wildfire management, necessitates obtaining accurate information regarding both the costs of fire management and the resulting fire-related losses (direct and indirect). However, excluding the most devastating wildfires, well-characterized information about the damages *from all* wildfires remains minimal, if it exists at all, making it difficult to ascertain the true size and scope of the problem. This limits the ability of wildfire managers to evaluate the cost-effectiveness of suppression, fuels management, and prevention programs. Additionally, current national wildfire damage estimates measured in dollars is not available. Current damage estimates for the nation are often reported in terms of acres burned. For example, over 9 million acres burned in 2007 (National Interagency Coordination Center 2008), but these estimates provide no indication of the damage caused to structures and property. Damage estimates, however, are sometimes calculated for individual, usually extreme, fires such as the Southern California Firestorm of 2007, which caused $ 1.9 billion in damage (in 2008 constant dollars; NFPA 2009). Because of their extreme nature, these estimates do not provide an overall accounting of wildfire ignitions and damages.

Understanding the extent and location of wildfire is important for mitigation and prevention. Currently, national wildfire estimates largely exclude fires within municipal jurisdictions, whose jurisdiction encompasses the majority of the U.S. population. In 2004, U.S. fire departments responded to 1.6 million fire incidents, with 35 % being outside fires (USFA 2007). Approximately 84 % of those did not involve mutual aid, meaning they only involved the local jurisdiction (USFA 2007). Without understanding the municipal wildfire problem, it will be difficult to allocate fire management resources in the most efficient manner (i.e., to minimize the cost plus loss of wildfire).

The objective of this paper is to provide trackable national estimates of the WUI-fire problem responded to by local municipal fire departments. In particular, we analyze the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS) fire incident data from 2002 to 2006, as reported by local municipal fire departments across the United States. NFIRS provides detailed fire incident reporting, including information regarding ignition, suppression, damages, fatalities, and injuries. An advantage of analyzing the NFIRS reported fire records is that it provides detailed incident information about structure fires, including residential and non-residential, and vehicle fires involving wildland fuels. Because NFIRS is a voluntary system it does not include all fires;[1] however, a procedure exists to scale reported fire incidents into national estimates (Hall and Harwood 1989). This procedure is used extensively in documents published by USFA and the National Fire Protection Association (NFPA), and is used in this analysis.

This research makes the following contribution to the literature: (1) it provides national estimates of the wildfires responded to by municipal fire departments, which as we demonstrate, far outnumber current published estimates; and (2) it provides a method to track trends in fire statistics over time. Combined, this information can be used by wildland managers and researchers to properly define the U.S. wildfire problem, track the impact of forest management on wildfire behavior, and to evaluate the economic returns of investments into wildfire mitigation (including suppression and education).

Methodology

The data in this paper is drawn from the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association (NFPA) annual nationwide survey of municipal fire departments. NFIRS is a voluntary data collection system, and approximately 20 000 fire departments reported to NFIRS in 2006.[2] NFIRS was developed in response to the National Fire Prevention and Control Act (Public Law 93-498), which required the collection of national fire incident data for use in analyzing the U.S. fire problem (NFIRS 2006). The NFPA data is from an annual survey where 3000 fire departments are randomly selected from 30 300 municipal fire departments (Karter 2009) to produce nationwide estimates of residential and non-residential structure fires, vehicle fires, and outside and other fires. In addition to numbers of fires, the NFPA survey collects data on damages and civilian (non fire service) injuries and fatalities. While the NFPA survey provides a rigorous method for estimating high-level statistics related to fires that local municipal fire departments responded to, it does not provide detailed insight into the specifics of the incidents. The NFIRS data, on the other hand, provides in depth reporting of fire incidents and includes information regarding, for example, ignition, suppression, fire spread, structure characteristics, and property use. In a methodology described in Hall and Harwood (1989), details from the analysis of the NFIRS data can be scaled into national estimates using data from the NFPA survey.

Reported Fires
NFIRS data is completed by local fire departments. This data is sent to a state agency where the data is aggregated and transmitted to the National Fire Data Center to develop a national database. The current version of NFIRS (Version 5.0) consists of 11 modules, each specific to different circumstances of the incident.[3] Not every module is relevant to all incidents (e.g., the *Structure Fire* module might not be relevant to an outside fire incident). Some are mandatory (e.g., the *Basic Module*), while others are not (e.g., the *Arson Module*). Even within the mandatory modules, only some of the field elements are mandatory (e.g., Incident Type within the *Basic Module*). In this analysis, we focus on data derived from the *Basic*, *Fire*, *Structure Fire*, *Wildland Fire*, *Civilian Fire Casualty*, and *Arson Modules*. These modules contain mandatory and non-mandatory information about fire incidents involving wildland fuels.

The *Basic Module* is completed for every emergency call to which the department responds. It request information about the location of the incident, incident type, aid given (i.e., mutual aid), alarm time and response time, actions taken (e.g., extinguishment), property losses, casualties, and property use. For non-contained fires, the fire department is required to fill out either the *Fire Module* or the *Wildland Fire Module*, which requests information about the ignition (e.g., area of origin, heat source, item first ignited), cause, and factors contributing to ignition.[4] The *Structure Fire Module* is required for all structure fires. Structures can include "buildings, open platforms, bridges, roof assemblies, over open storage or process areas, tents, air-supported structures, and grandstands" (pg. 5-3, NFIRS 2006). This module requests information about the structure type, fire origin, fire spread, and the presence and operation of smoke detectors and automatic fire sprinklers.

For this analysis, we were interested in identifying all those fires that involved wildland fuel. The data can be found within the NFIRS (mandatory) *Basic Module* and *Fire Module* and is based on information related to the incident type, suppression factors, area of origin, and actions taken, which are described below. Multiple variables were used to identify wildland fires, rather than just relying on the incident type recorded, because the numerous methods of coding in NFIRS combined with the nature of fire make it difficult to define one type of fire from another. A fire that burned structures and wildland may be coded as a structure fire in the incident type or coded as originating in wildland. Examining multiple fields ensures that wildland fires that burn structures or originate at non-wildland locations are identified as wildland. We have precisely outlined the variables that we used to identify wildland fires in Table 1. If the *Wildland Fire Module* was completed, and it was not deemed a prescribed fire under the fire incident variable, then it was considered a wildfire. (The *Wildland Fire Module* is not required by fire departments, so it is rarely completed.)

Table 1. NFIRS modules and fields used to identify fire incidents involving wildland fuels.

Module	Field	NFIRS Definition	Wildland Fuel Identifier	Notes
Basic	Incident Type	*This is the actual situation that emergency personnel found on the scene when they arrived* (pg. 3-19, NFIRS 2006)	▪ *Forest, woods, or wildland*	There are a total of 50 incident types to select from, however only one type can be selected.
Basic	Actions Taken	*The duties performed at the incident scene by the responding fire department personnel* (pg. 3-36, NFIRS 2006)	▪ *Establish fire lines around wildfire perimeter* ▪ *Contain fire [wildland]* ▪ *Confine fire [wildland]* ▪ *Control fire [wildland]*	Three categories can be entered in NFIRS along with subcategories for a fire incident; there are a total of 76 to select from.
Fire	Area of Origin	*The primary use of the area where the fire started within the property* (pg. 4-13, NFIRS 2006)	▪ W*ildland, woods*	A number of categories can be entered along with subcategories for a fire incident; there are a total of 96 to select from.
Fire	Suppression Factors	*Factors that contributed to the growth, spread, or suppression of the fire* (pg. 4-38, NFIRS 2006)	▪ U*rban-wildland interface area*	Any three categories can be entered in NFIRS along with subcategories for a fire incident; there are a total of 132 to select from.

Entries recorded in NFIRS are listed based on incident and exposure numbers. One incident can have hundreds of exposures. For example, a wildland fire that spread throughout a neighborhood might have a unique exposure number for each house that caught fire, but all of them would have the same incident number. For the purpose of this paper, only unique incidents are identified as being a fire. If an exposure has any of the characteristics of a wildland fire, then the fire incident was labeled as such, damages/injuries were summed with the incident. If the required variables were left blank, then the incident was deleted from our data set (incident type, area of origin, and actions taken are required fields). To avoid double counting, incidents were deleted if they were recorded as being "aid given" to another fire department under the aid variable. Thus, we are estimating the number of fire incidents that were responded to by municipal fire departments exclusively.

The incidents discussed in the rest of this analysis were defined by incident type and property use; these include residential structure fires, non-residential structure fires, vehicle fires, and outside and other fires. To be classified as a residential fire, an incident had to be coded as a 'structure fire' under the incident type variable in NFIRS and be coded as 'residential' under the property use variable. To be classified as a nonresidential fire, an incident had to be coded as a 'structure fire' under the incident type variable in NFIRS and not be coded as 'residential' under the property use variable. To be classified as a vehicle fire, an incident had to be coded as a 'mobile property (vehicle) fire' under the incident type variable in NFIRS. Outside and other fires included the following labels for the incident type variable: natural vegetation fire, outside rubbish fire, special outside fire, cultivated vegetation/crop fire, and other.

Scaling

Based on the Hall and Harwood (1989) methodology, our national estimates of fire involving wildland fuels were calculated by multiplying the number of reported fires involving wildland fuels (from NFIRS) by a scaling ratio for four different types of fires. The procedure can be defined by the following equation:

$$E_{i,j} = R^{w}_{i,j} * \frac{S_{i,j}}{R_{i,j}}$$

where E is the national estimate of j (j is either the number of fires, losses, fatalities, or injuries) for incident type i (i is either residential structure fires, non-residential structure fire, vehicle fire, or outdoor and other fire). Variable R^w is the total reported value (from NFIRS) of j for incident type i that is associated with burning of a wildland fuel (e.g., the total number of residential structure fires originating from a wildland fuel). Variable S is the NFPA (surveyed) estimate of j for incident type i. Variable R is total reported value (from NFIRS) of j of incident type i. For example, to calculate the national estimate (E) for the number of residential structures involving wildland fuels (j), take the number of residential structure fires associated with wildlands in NFIRS and multiply it by the number of residential structure fires estimated by the NFPA divided by the number of residential structure fires recorded in NFIRS.[5]

Results

Table 2 shows the number of reported fires in NFIRS that involved wildland fuels. Over the five-year study period, 61 894 reported outside fires were classified as beginning in the wildlands (*area of origin*). Of these, 120 spread to residential structures, 383 spread to non-residential structures, and 324 spread to vehicles. Wildland suppression activity (*actions taken*) occurred in connection with 640 residential structure fires, 645 non-residential structure fires, 1119 vehicle fires, and 41 606 outside and other fires. Finally, factors that affected WUI fire growth and suppression effort (*suppression factors*) were found in connection with 47 residential structure fires, 45 non-residential structure fires, 116 vehicle fires, and 1220 outside and other fires. Comparing the *area of origin* and *actions taken* data, the results demonstrate more wildland fires occurred because of structure fires rather than the converse. This suggests a role of building materials in limiting wildland exposure to structure fires—i.e., fire resistant building materials could reduce the number of wildland fires, which present risks to adjacent structures. It is also clear that vehicle fires began a significant number of WUI fires.

In addition, the information in Table 2 demonstrates that the reported number of annual fire occurrences increased over the study period—nearly threefold. If we only considered those fires labeled as wildland fires, based on the reported NFIRS incident type, we would be ignoring a significant number of wildland fires that burned structures and vehicles.

Table 2. Reported fires in NFIRS associated with the burning of wildland fuels identified by NFIRS Definition (area of origin, actions taken, suppression factors, and incident type).

	Area of Origin[a]	**Actions Taken**[b]	**Suppression Factors**[c]	**Incident Type**[d]
Fire Incident Type				
Residential Structure	120	640	47	0
Non-Residential Structure	383	645	45	0
Vehicle	324	1,119	116	0
Outside and Other	61,894	41,606	1,220	51,453
Year				
2002	7,792	4,968	166	6,185
2003	8,870	6,603	242	6,657
2004	10,497	7,670	204	8,452
2005	15,909	11,097	351	12,691
2006	19,653	13,672	465	17,468

[a] The primary use of the area where the fire started within the property
[b] The duties performed at the incident scene by the responding fire department personnel
[c] Factors that contributed to the growth, spread, or suppression of the fire
[d] The actual situation that emergency personnel found on the scene when they arrived
NOTE: This table shows the number of fires identified as wildland by the NFIRS definition; therefore, a single fire may be identified by multiple definitions.

Estimated Fire Statistics

Because NFIRS only documents reported fires, the NFPA annual survey data can be used to scale the reported fire statistics into representative national estimates. Table 3 presents the total number of structure, vehicle, and outside and other fires reported by NFIRS, the scaling factors used to produce the national estimates, and the estimated total number of fires associated with wildland fuels. For each year and category (residential, nonresidential, vehicle, and outside and other), the total number of fires is the number reported in NFIRS multiplied by the scaling ratio. Not surprisingly, fires with the incident type of 'outside and other' comprised the largest number of wildland-based fires. We estimate, on average, 114 985 outside and other fires involved wildland fuels annually. These fires were reported to have no impacted structures or vehicles.

We estimate, on average, 599 residential structure fires and 649 non-residential structure fires either began in the wildland, or burned in connection with a wildland fire event. Vehicles accounted for another 829 fires annually, on average. The results suggest that for every 94 outside and other fires, one structure is involved, on average. Vehicles are involved in one out of every 141 outside and other fires.

Estimated Property Damage and Causalities

Table 4 presents estimates of direct property damage and civilian fatalities and injuries. Property damage averaged $160.2 million annually, but the magnitude of these damages fluctuated from year to year. The largest damages occurred in 2003, at $526.8 million, followed by damages in 2006, at $122.5 million. The damage in other years varied between $38.1 million and $70.3 million. While the largest number of damaged structures also occurred in 2003 and 2006, the relative difference between the number of fires in these years and the others do not seem to explain the overall differences in damage. That is, it is more likely that the fires in 2003 and 2006 were more damaging, per incident, than those in the other years. The increased damage could be caused by the location of the fires or by differences in fire spread.

Over the five-year study period, civilian injuries averaged 88 injuries and 15 fatalities per year. The economic value of fatalities and injuries in Table 5 were calculated by multiplying the numbers by the value of a statistical life and statistical injury. In this analysis, we used a value of a statistical life of $8.75 million, based on the median value reported in Viscusi and Aldy (Viscusi and Aldy 2003), inflated into 2008 dollars. Also, we used a value of a statistical injury of $189 198, based on the median value reported by the U.S. Consumer Product Safety Commission (Zamula 2004, 2005; Ray et al. 1993), inflated to 2008 dollars. Thus, we estimate the average annual economic loss due to fire-related fatalities was $131.3 million and due to fire-related injuries was $16.6 million.

Table 3. Reported NFIRS fires, calculated scaling ratios, and estimated total number of fires involving wildland fuels.

	Reported in NFIRS[a]	**Scaling Ratio**[b]	**Estimated Total**[c]
Residential Structures			
2002	64	5.98	383
2003	180	4.10	737
2004	149	3.64	542
2005	213	2.93	625
2006	234	3.02	707
Average	168	3.93	599
Non-Residential Structures			
2002	141	4.94	696
2003	176	3.53	621
2004	174	3.05	530
2005	262	2.48	650
2006	310	2.41	748
Average	213	3.28	649
Vehicles			
2002	193	4.15	801
2003	270	2.77	748
2004	335	2.34	784
2005	454	1.91	867
2006	497	1.90	944
Average	350	2.61	829
Outside and Other			
2002	13,581	8.92	121,183
2003	16,297	6.36	103,688
2004	19,427	5.21	101,149
2005	28,586	3.98	113,867
2006	36,476	3.69	134,587
Average	22,873	5.63	114,895

[a] The total number of fires reported in NFIRS per year per category (residential, non-residential, vehicle, and outside and other) involving wildland fuels

[b] The calculated scaling ratio per year per category

[c] The total estimated number of wildfires

Table 4: Total fires, damage, injuries, and deaths associated with wildland fuels

	Fires	Direct Damage ($2008 Million)	Injuries	Deaths	Structures Damaged	Non-Residential Structures Damaged	Residential Structures Damaged	Vehicles Damaged
2002	123 062	$43.1	53	17	1079	696	383	801
2003	105 794	$526.8	101	9	1358	621	737	748
2004	103 005	$38.1	91	9	1072	530	542	784
2005	116 009	$70.3	104	18	1275	650	625	867
2006	136 986	$122.5	92	20	1455	748	707	944
Average	116 971	$160.2	88	15	1248	649	599	829

Table 5. Estimates of the value of fatalities and injuries associated with wildland fuels (damages in millions of 2008 constant dollars).

Year	Economic Value of Fatalities	Economic Value of Injuries
2002	$148.8	$10.0
2003	$78.8	$19.1
2004	$78.8	$17.2
2005	$157.5	$19.7
2006	$175.0	$17.4
Average	$131.3	$16.6

Seasonal Trends

Figure 1 plots the percent of reported fires by month for each incident type. The seasonal pattern of numbers of wildland fires affecting residential and non-residential structures follows the number of outside and other fires (i.e., those purely wildland fire events). These fires peaked in March and April with a little resurgence in the late summer months of July and August. The peak corresponds with previous findings showing the peak number of fire department fire runs occurred in March (10.1 %) and April (10.2 %)(USFA 2007). Vehicle fires involving wildland fuels demonstrated a very different seasonal pattern and tended to peak in the late summer months. This peak corresponds with a second, but smaller peak in the number of fire department fire runs shown in July (9.0 %)(USFA 2007). The number of structure fires from all causes does not display this pattern. It appears to be relatively flat, from month to month (USFA 2004). Overall, wildland fires impacted the monthly workload of the municipal fire service (i.e., affected the yearly distribution of fire runs). However, it appeared as to be a seasonal process, as well as regional, meaning planning using forecasting methods, might be used in the future to alleviate potential resource constraints related to fire service response and effectiveness. It also suggests a mechanism that can be used by fire education specialists in timing their message to at-risk WUI communities.

The percent of reported losses did not appear to demonstrate any appreciable pattern (results not shown). Losses related to residential structures spiked in May and September; losses related to non-residential structures spiked in February, July, and November; losses related to strictly outside and other fires spiked in May and July; and losses related to vehicle fires spiked in July. But taken as a whole, wildland fire damages tended to fluctuate and occurred throughout the year (on average). This is likely a function of regional differences in fuel conditions throughout the year across the United States.

Dangerous wildland-related fires tended to occur in late-winter and early-spring, and again in late summer months, but no appreciable patterns were observed (results not shown). The number of injuries and fatalities were the highest in March for those wildland fires affecting residential structure fires. Dangerous fires occurred during winter months (December and January) for those wildland fires affecting non-residential structures. Injuries and fatalities related to outdoor and other fires peaked in April, while again, the peak for vehicle fires were in July and August. Fatalities related to wildland fires appear to have less seasonality than for all fires. A report by USFA (USFA 2005) demonstrated that fire-related fatalities peak in January and steadily fall to June, at which point they steadily increase to December. Fatalities from wildland fires remain relatively small. Trends in injuries from all fires display similar patterns (USFA 2008).

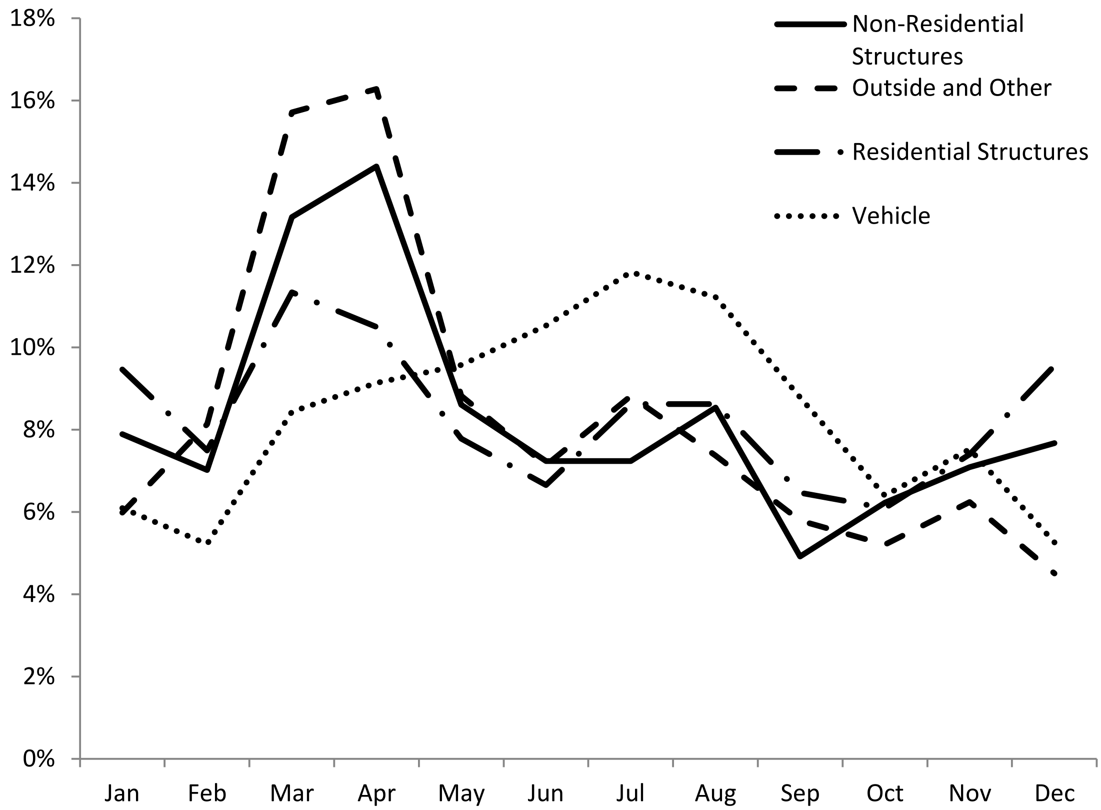

Figure 1. Percent of reported fires in NFIRS by month for each incident type.

Time of Day Trends

Figure 2 plots the percent of reported fires by hour of the day. All fires demonstrate a very pronounced pattern peaking around 3PM or 4PM, with very low activity during late night and morning hours. The trends are much less pronounced for fire losses, but the majority of losses occurred during afternoon hours. Vehicle and non-residential structure fires showed a peak also during the noon, or lunch, hour and also nearing the end of the typical work day. No significant patterns emerge for injuries and fatalities, although they tended to be highest in afternoon hours (results not shown). The exception being residential and non-residential casualties which spike at about 1AM and 1PM, respectively (results not shown). The reason for this spike is not entirely clear. It may be that residential populations are higher during the night and non-residential populations are higher during the day; however, there are very few casualties in the hours that precede or follow these spikes. It may be that these peaks are a reporting issue (particularly for the residential fires).

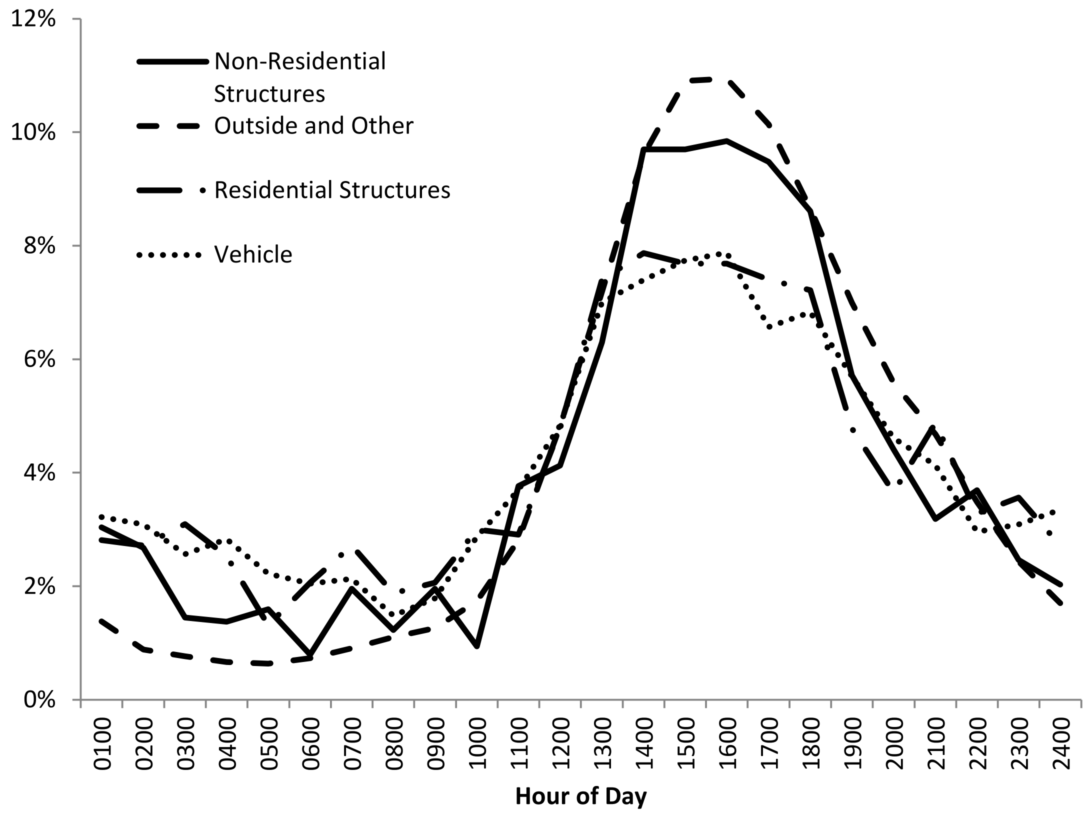

Figure 2. Percent of reported fires in NFIRS by time of day for each incident type.

These patterns are typical for other fire types (i.e., non-wildland). Fires in one- and two-family residential dwellings tend to peak around 5PM to 7PM, although the difference between the percent of building fires between the peak and the trough are much smaller (i.e., 5.0 %) (USFA 2010) than shown in Figure 2. Outside fires are more likely influenced by time-of-day weather patterns related to temperature, relative humidity, and thunderstorm activity.

Discussion

Between 2002 and 2006, municipal fire departments responded to 584 855 reported wildland fires (116 971 on average per year). These fires caused $ 801 million in property damage along with 75 fatalities and 440 injuries, creating a total social economic loss of $1.5 billion. There existed significant variation in damages across years.

Wildland fires and WUI fires involving structures tended to peak in the spring time while those involving vehicles peaked in the summer. All fires peaked in the evening, similar to non-wildland fires. Coupled with NIFC wildfire estimates, these estimates and trends provide a more thorough understanding of the damage and extent of wildland fires in the U.S. than has been previously available.

We compare the NFIRS-scaled estimates of municipal fire involving wildland fuels with national estimates produced by the National Interagency Fire Center (NIFC). NIFC generates wildfire counts based primarily on information from Situation Reports, which are submitted by wildland fire dispatch centers, and includes data reported on state and federal lands. Since these figures are based on reports from wildland fire dispatch centers, they largely exclude wildland fires in municipal jurisdictions. For instance, in 2006, 'State and Other' accounted for 76 % of all wildfires reported by NIFC (National Interagency Coordination Center 2008) and there is only limited data for private lands. Between 2003 and 2006, only 3732 wildfires were reported on private and other lands in the NIFC data, with 2354 being reported in 2006.

We find that over the 2002 to 2006 study period, there were 42 % more municipal fires involving wildland fuels than total fires reported to NIFC (see Figure 3). The number of municipal fires are consistently higher than the NIFC reported fires over the study period. This suggests that the wildfire problem is much larger than previous thought, at least in terms of ignitions.

We do note some time trend similarities between the NIFC and NFIRS-scaled estimates, which suggests that some phenomena (e.g., climate and weather; see Westerling et al. 2006) influencing ignition patterns in publically-owned lands are also affecting fire conditions in WUI communities. This suggests predictive models forecasting fire weather conditions for federal lands (e.g., see Westerling et al. 2003; Preisler and Westerling 2007) may be relevant to forecast fire risk conditions in the WUI.

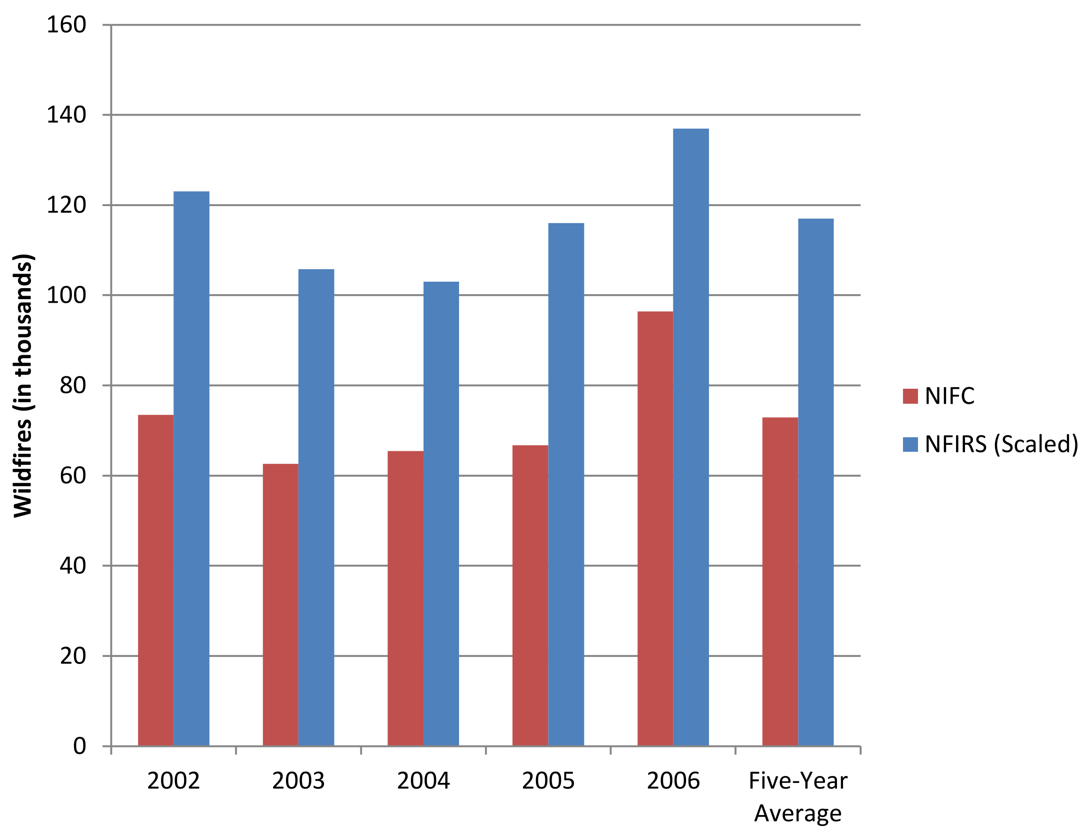

Figure 3. Yearly NIFC and NFIRS (scaled) estimates of wildfires from 2002 to 2006.

In addition to providing wildfire ignition estimates, our analysis provides evidence that wildfires do not occur uniformly over time. Understanding the temporal occurrence of wildfire is important in allocating fire management resources effectively. Since wildfire ignitions are not temporally uniform, the most effective distribution of fire prevention and mitigation efforts will not be temporally uniform. We showed that there was a high concentration of fires during the spring season; however, there are likely to be regional patterns as well. Fire prevention efforts, such as public service announcements and ignition surveillance, might be targeted to specific times of the year, providing a more efficient distribution of fire management resources. Additionally, we showed that wildfire ignitions do not occur uniformly throughout the day. Surveillance for wildfire ignitions and other prevention efforts, such as patrolling, can be targeted during peak times of ignition for increased effectiveness. Efficient temporal distribution of fire management resources is likely to prevent more wildfire ignitions than allocating resources uniformly.

In addition to understanding the location and temporal occurrence of wildfire, it is also important to have a valid metric to measure the extent of damage. Wildfire damage is often measured in acres burned; however, this type of measure does not accurately reflect the effect on people and communities. For instance, a wildfire that burns only a few acres and numerous homes is likely to be more damaging to society than a wildfire that burns uninhabited forest land. Acres burned also does not provide a metric that can be used to determine the optimal expenditure on wildfire prevention efforts. We estimate that each year, those wildfires responded to by municipal fire departments were responsible for, on average $160 million in property damages and $308 million in total losses. Annual dollar estimates of losses, such as the estimates developed in this paper, can be utilized in assessing the optimal expenditure on wildfire prevention efforts and be used to measure the effectiveness of prevention and mitigation efforts over time.

A complete and accurate description of the wildland fire problem needs to include not only state and federal fire incident data, but also municipal incident data. This research provides national estimates of the wildfires responded to by municipal fire departments, which as we demonstrate, far outnumber current published estimates; and it provides a method to track trends in these fire statistics over time, which is consistent with techniques used by USFA and NFPA. Combined, this information can be used by wildland managers and researchers to analyze the economic returns to wildfire suppression, fuels management, and prevention activities (e.g., track progress over time). Furthermore, the results of this analysis implicate that there is a need for forest management beyond state and federal lands. Specifically, there is a need for forest management within municipal jurisdictions.

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[1] Currently, over 22 000 fire departments report to NFIRS from all 50 states and the District of Columbia (USFA 2010). It is estimated that 65 % of all reported fires are reported to NIFRS (USFA 2010). http://www.usfa.dhs.gov/fireservice/nfirs/about.shtm

[2] The number of reporting fire departments is calculated as the number of unique fire departments listed that reported at least one fire in NFIRS.

[3] The modules include: Basic, Fire, Structure Fire, Civilian Fire Casualty, Fire Service Casualty, EMS, Hazardous Materials, Wildland Fire, Apparatus or Resource, Personnel, and Arson.

[4] These modules are optional for confined fires, which include fires confined to a cooking container, chimney or flue, incinerator, burner, compactor, or trash area.

[5] The NFIRS data is scaled using NFPA survey data obtained from municipalities, therefore, any data in NFIRS reported by the National Park Service, U.S. Forest Service, Bureau of Indian Affairs, Bureau of Land Management, U.S. Fish and Wildlife Service, and state department data was deleted (this comprised only a handful of incidents). There were 2 724 405 total fire observations remaining for 2002 through 2006 after those with missing data and non-municipal data were deleted. Deleting data with missing values assumes that the unlabeled variables are distributed similar to the labeled variables, an assumption used by the NFPA.