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ORIGINAL PAPER

Human fatalities from wind-related tree failures in the United States, 1995–2007

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Abstract There were 407 deaths from wind-related tree failures in the United States, 1995–2007. The most common cause of the deadly fallen tree was a thunderstorm (41%), followed by nonconvective high winds (35%), tropical cyclones (14%), tornadoes (7%), and snow and ice (3%). Most (62%) of the deaths were males while the median age was 44 years. The most common location of the fatality was in a vehicle struck by the tree or a vehicle that crashed into a downed tree on the road (44%), followed by persons outdoors (38%), in mobile homes (9%), and in frame houses (9%). Persons killed by wind-related tree failures during tropical cyclones and tornadoes were more commonly at home (40%) when struck than those killed at home by thunderstorm and nonconvective high winds (13%). Seasonality of the deaths varied by weather type with deaths in thunderstorms clustered during May–August, nonconvective high winds October–April, tropical cyclones August–October, tornadoes in April and November, and snow and ice December–April. Regional patterns result from frequency of the wind events, population density, and tree cover. Suggestions are made for hazard reductions.

Keywords Storm deaths · Fallen tree · Fatalities

1 Introduction

Fallen trees are a significant hazard to human health and life during severe weather (Mitchell et al. 1989). Legal liability of tree owners for damages caused by fallen trees has been rising in the United States (Mortimer and Kane 2004). Recent research on storm mortality in the United States revealed that falling trees accounted for about 10% of deaths from tropical cyclones (Rappaport 2000) and 33% of deaths from nonconvective high wind events (Ashley and Black 2008). The purpose of this research is to investigate and summarize the deaths from wind-related tree failures in the United States and report on the circumstances of the deaths. These results will place this hazard in the context of other

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severe weather hazards in the United States, form a basis for comparisons with similar hazards elsewhere, and provide guidance for improved preparedness and safety recommendations.

Tree species vary in their resistance to breakage or being uprooted (Duryea 1998; Harris 1999; Greenberg and McNab 1998) and vulnerability for failure is further affected by tree age, size, and health, and local site conditions of exposure, slope, soil type, soil moisture, and adjacent trees (Harris 1999; Kane 2008). Temperature of the tree stem affects resistance to breakage under load (Silins et al. 2000). A bibliography of trees and wind is provided by Cullen (2002). It is not the goal of this research to assess wind speeds associated with deaths from fallen trees, but some estimates are provided from the literature. The Enhanced Fujita (EF) Scale for ranking intensity of tornadoes includes estimates of the 3-s gust speeds necessary for damage to trees (http://www.spc.noaa.gov/efscale/ef-scale.html). In the EF Scale descriptions for hardwood trees (oak, maple, birch, ash), a 3-s gust of 74 mph will break large (>1″) branches, 91 mph will uproot trees, and 110 mph will snap tree trunks. For softwood trees (pine, spruce, fir, hemlock), a 3-s gust of 75 mph will break large branches, 87 mph will uproot trees, and 104 mph will snap tree trunks. These are not absolute numbers but a value near the middle of the range of minimum wind speeds expected to cause the damage according to the EF Scale. Mayer (1987) reported that no tree species can survive violent storms with mean wind speeds over 10 min of 30 m s^{-1} (67 mph) or higher. Wind speeds of these magnitudes occur with weak tropical cyclones, weak tornadoes, thunderstorm downbursts, nonconvective winds associated with extra-tropical cyclones, among other meteorological events. In addition, heavy accumulations of snow or ice may cause trees to fail even with lighter wind speeds.

2 Data

The online resource *Storm Data* (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms) was searched for events with at least one death under the event categories of tornadoes, hurricane and tropical storms, thunderstorms and high winds, and snow and ice in the 50 states. *Storm Data* contains the best national information available for these hazards and is the primary source used to examine past severe weather events, in spite of some omissions and inconsistencies in the data (as reviewed by Ashley and Black 2008). The Tornado Project web site (http://tornadoproject.com) was examined for deaths from tornadoes and the annual review of the Atlantic hurricane season as published in *Monthly Weather Review* was consulted for additional details on deaths during tropical cyclones. The National Weather Service 'Service Assessments' published after severe weather events were also consulted (National Weather Service 1997, 2000, 2001, 2004; http://www.nws.noaa.gov/om/assessments/index.shtml). Summaries of deaths associated with Hurricanes Marilyn, Opal, and Katrina were obtained from *Morbidity and Mortality Weekly Report* (MMWR 1996, 2006). Deaths from Hurricane Katrina in Mississippi and Louisiana are not included here due to uncertainty in the data, although indications are that at least 15 deaths were caused across inland Mississippi due to fallen trees.

The sex and age of the victims were recorded, along with the state, county, and weather event type. If a fallen tree or limb was given as the cause of death, it was considered a death from a wind-related tree failure. It was noted, when given, where the person was struck by the fallen tree, such as outdoors, in a vehicle, in a mobile home, or in a frame house. Deaths in campers, tents, on motorcycles, or on all-terrain vehicles were considered 'outdoors.' Deaths in vehicles struck by a fallen tree and in vehicles that struck a fallen tree on the road were considered to have been caused by the fallen tree, but deaths from vehicles veering off the road and into a tree were not included. Deaths from falling trees or limbs a few hours after the trees were damaged by wind were counted as fallen tree deaths. Deaths from trees being cut or trimmed before the storm or during tree removal after the storm were not counted. Although not always associated with high winds, deaths caused by trees or limbs that fell under the weight of snow or ice were included in this database as trees felled by severe weather.

3 Results

There were 407 deaths caused by wind-related tree failures in the United States during 1995–2007, an average of 31/year. These occurred in 41 states and the District of Columbia (Fig. 1). Of the 407 known deaths caused by wind-related tree failures during 1995–2007, the location of the victim (such as in vehicle, outdoors, in house) was known for all 407 deaths, age was known for 392 (96%), and sex was known for 391 (96%). Most (62%) of the victims were male, the median age was 44 years (range 1–91 years), 44% were struck by a fallen tree or limb while in a vehicle, 38% were struck outdoors, and 18% were struck while in their home, half in a mobile home and half in a frame house (Table 1). The regional distributions of deaths are shown in Figs. 1, 2, 4, 6, 8, and 10 and the monthly distributions in Figs. 3, 5, 7, 9, and 11. Two fallen trees caused four deaths each. A school bus carrying 10 children was struck by a fallen tree during a nonconvective high wind event in Queens, New York City, on March 6, 1997, killing four and injuring six. A tree fell on a vehicle in Yakima County, Washington, on August 26, 1997, killing all four occupants. This event is listed as a "high wind" in *Storm Data*, although other damaging events that day are listed as "thunderstorms." The discussion continues below by the type of severe weather that caused the fallen trees.

3.1 Thunderstorm winds

There were 165 deaths from fallen trees caused by thunderstorm winds. This was 53% of all deaths due to thunderstorms. About 40% of these thunderstorms are expected to have been associated with derechos (Ashley and Mote 2005). Most (58%) of the deaths were male, the median age was 39 years (range 1–89 years), and deaths occurred primarily to persons in vehicles (47%) and outdoors (40%) (Table 1). Deaths from fallen trees in thunderstorms occurred almost entirely (96%) east of 100° W longitude, perhaps due to lower population density and fewer trees to the west on the Great Plains, and fewer severe thunderstorms farther west (Fig. 2). This spatial distribution follows the patterns found by Ashley and Mote (2005) for all fatalities caused by derecho winds. A concentration of deaths occurred in the Megalopolis region from southern New England to northern Virginia where population density is greatest. Most (78%) deaths occurred during May through August, when thunderstorms are most frequent in the eastern United States (Fig. 3).

3.2 Nonconvective high winds

These winds include nonconvective winds associated with extratropical cyclones, other gradient winds, downslope winds, and gap winds. There were 143 deaths from fallen trees caused by nonconvective high wind events. This was 46% of all deaths due to nonconvective high winds. Most (61%) of the deaths were males, the median age was 45 years

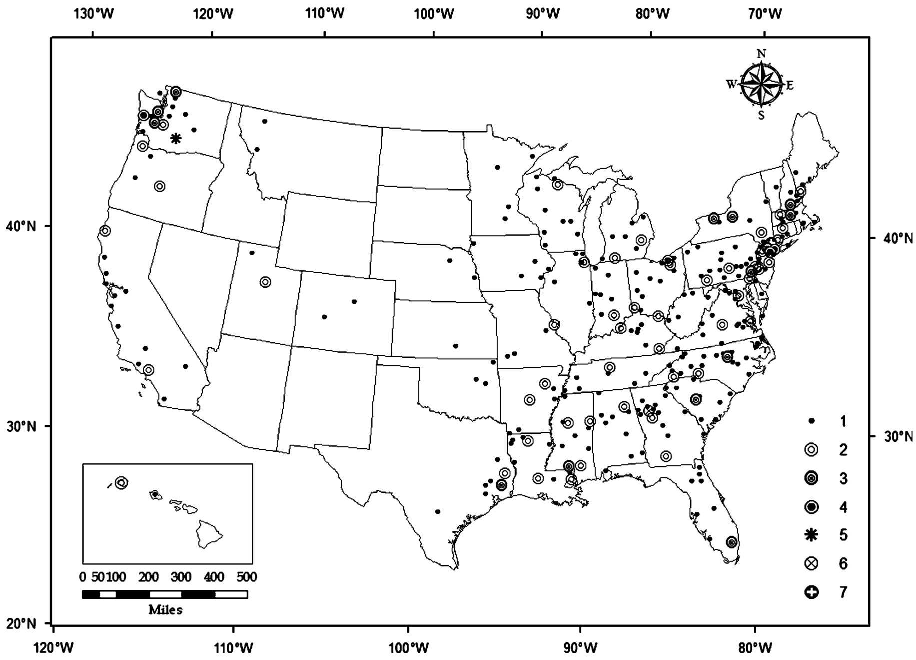

Fig. 1 Distribution of deaths due to wind-related tree failures, 1995–2007

Table 1 Demographic information on deaths due to wind-related tree failures

				Percentage of deaths by location			
	N	Male (%)	Median age	Vehicle	Outdoor	Mobile home	House
Overall	407	62	44	44	38	9	9
Thunderstorms	165	58	39	47	40	6	7
Nonconvective	143	61	45	50	38	7	4
Tropical cyclones	57	68	45	34	29	18	21
Tornadoes	28	69	52	32	25	21	21
Snow and ice	14	79	69	21	71	0	7

(range 1–90 years), and deaths occurred most commonly to persons in vehicles (50%) and outdoors (38%) (Table 1). Deaths from fallen trees during nonconvective wind events occurred most frequently in the Pacific Northwest and the mid-Atlantic coastal region with secondary maxima in California and the southern Appalachians (Fig. 4), similar to the pattern found by Ashley and Black (2008). Although it occurred prior to the period studied here, one of the deadliest nonconvective wind storms in history killed over 40 people in the Pacific Northwest in October 1962 (Potter 2007), many due to fallen trees. There were three deaths in Hawaii. Most (88%) deaths occurred during October through April, when extratropical cyclones are strongest (Fig. 5).

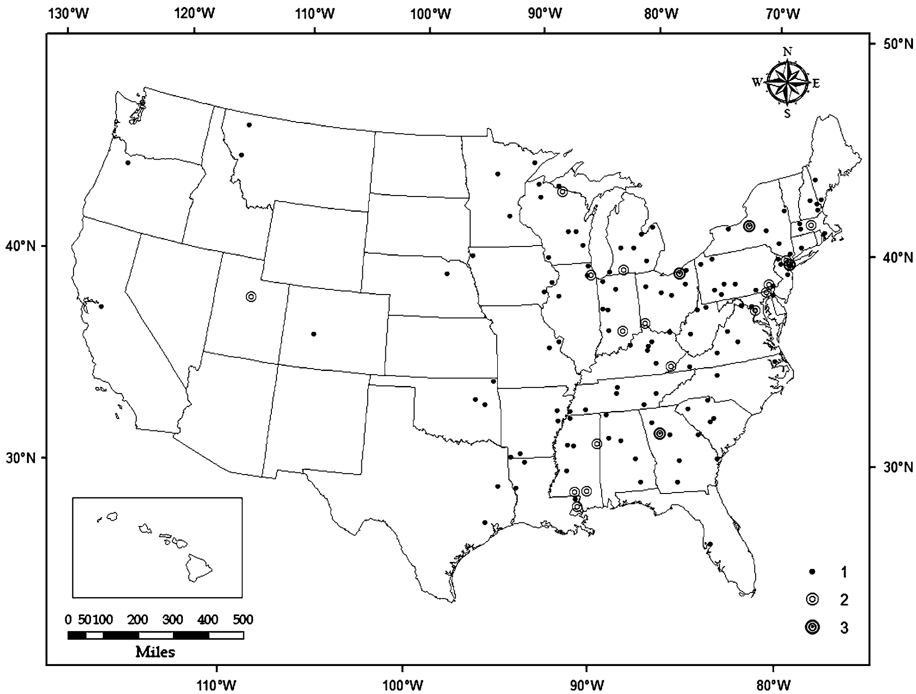

Fig. 2 Distribution of deaths due to wind-related tree failures caused by thunderstorms, 1995–2007

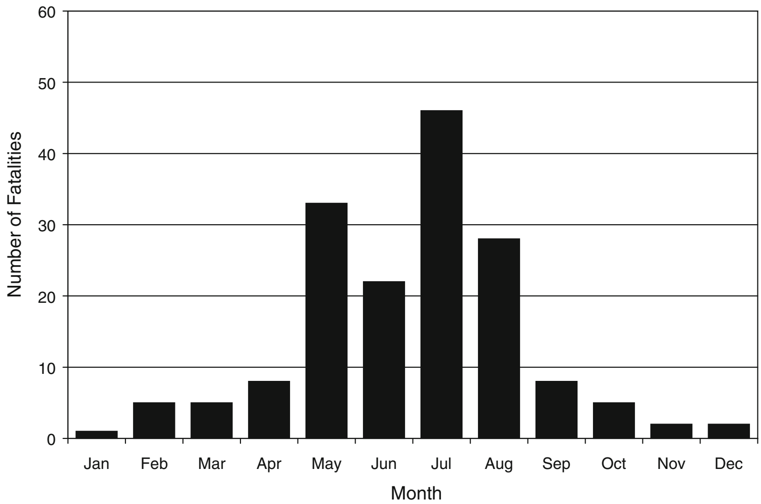

Fig. 3 Monthly distributions of deaths due to wind-related tree failures caused by thunderstorms, 1995–2007

3.3 Tropical cyclones

There were 57 deaths from fallen trees caused by 15 tropical cyclones during 1995–2007, not including deaths from Hurricane Katrina in Louisiana and Mississippi (Table 2). This

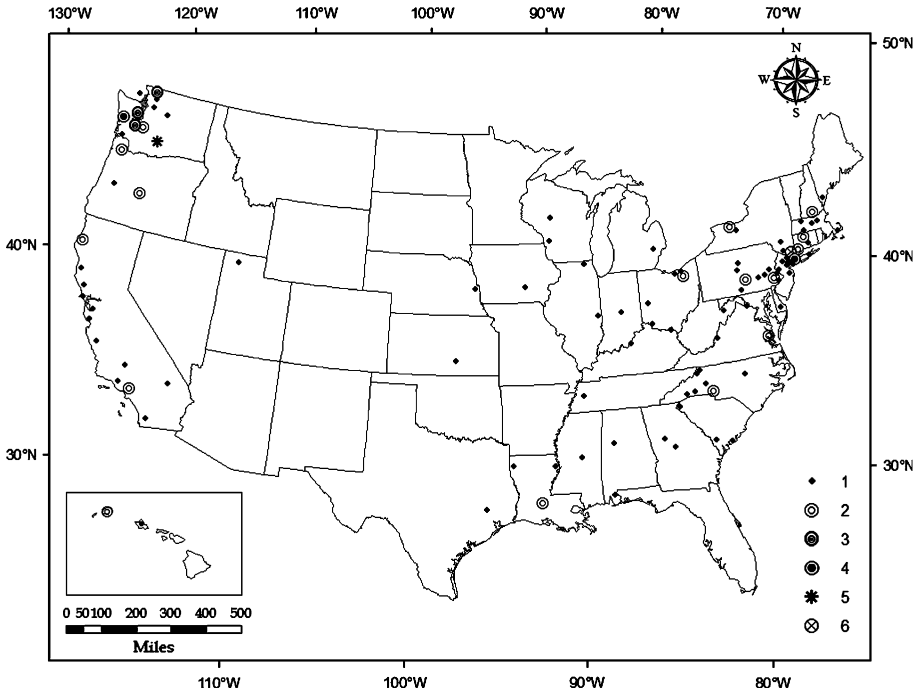

Fig. 4 Distribution of deaths due to wind-related tree failures caused by nonconvective high winds, 1995–2007

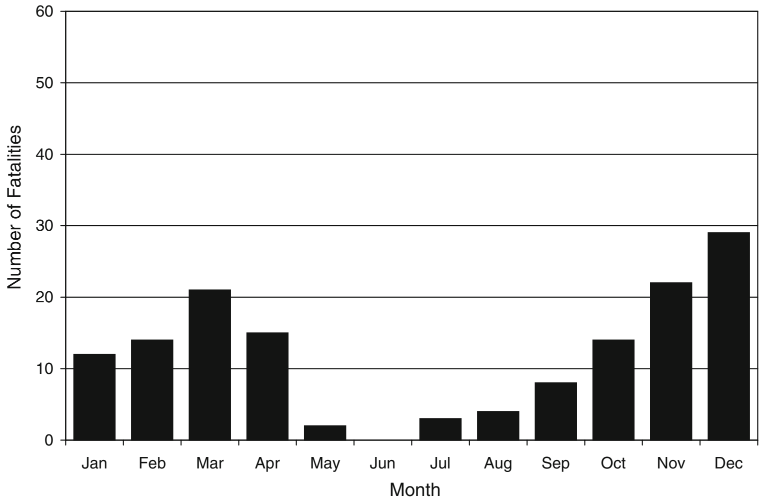

Fig. 5 Monthly distributions of deaths due to wind-related tree failures caused by nonconvective high winds, 1995–2007

was 31% of all tropical cyclone deaths. Two-thirds (68%) of the deaths were male, the median age was 45 years (range 3–87 years), and deaths occurred in nearly equal numbers to people in homes (frame houses and mobile homes), in vehicles, or outdoors (Table 1).

Table 2 Tropical cyclones that caused deaths from wind-related tree failures, 1995–2007

Cyclone	Date	Deaths	States (deaths)
Opal	October 4, 1995	14	AL (2), GA (8), NC (2), SC (2)
Fran	September 5, 1996	10	NC (8), SC (2)
Bonnie	August 26, 1998	1	NC (1)
Floyd	September 16–17, 1999	5	PA (2), VT (1), VA (2)
Isadore	September 25, 2002	1	MS (1)
Bill	July 1, 2003	1	GA (1)
Claudette	July 15–16, 2003	2	TX (2)
Isabel	September 18–19, 2003	8	NJ (1), NC (2), VA (5)
Charley	August 13, 2004	2	FL (2)
Frances	September 4, 2004	1	FL (1)
Ivan	September 16, 2004	2	MS (1), NC (1)
Jeanne	September 25, 2004	1	FL (1)
Dennis	July 10, 2005	1	GA (1)
Katrina	August 25, 2005	3[a]	FL (3)
Rita	September 23–24, 2005	5	TX (5)

[a] Deaths from Hurricane Katrina in Mississippi and Louisiana are not included here, although indications are that 15 deaths were caused by wind-related tree failures in Mississippi

The deaths occurred in 11 states from Texas to Vermont and all occurred within 200 miles of the coast (Fig. 6). North Carolina had the most deaths with 14. Deaths occurred only in the months July through October, with a peak (58%) in September, corresponding with the tropical cyclone season in the North Atlantic (Fig. 7). Rappaport (2000) found that males comprised 71% of all deaths associated with tropical cyclones in the United States 1970–1999. A small tornado associated with outer rain bands of Tropical Storm Allison caused a tree to fall on a vehicle, killing one man. Although related to a tropical storm, this is considered a tornado-related death. Trees may be especially vulnerable to uprooting or breakage during the winds of tropical cyclones due to the heavy rains that may weaken the soil strength and the fact that deciduous trees are in full leaf during the tropical cyclone season.

3.4 Tornadoes

There were 28 deaths that were directly the result of fallen trees during tornadoes. This was 4% of all deaths due to tornadoes. Of the 28 fatalities from tornado-fallen trees, 69% were males (Table 1). The median age was 52 years (range 13–91 years). The most common location of a person killed by a fallen tree during a tornado was in a home (42%), followed by in a vehicle (32%) and outdoors (25%). Fatalities from fallen trees during a tornado occurred in 14 states, all in the eastern half of the United States, with Arkansas having the most (4) of any state (Fig. 8). Deaths from fallen trees did not show a strong seasonality associated with tornado occurrences. Deaths occurred in all months except July, and 32% of the total occurred in 2 months, April or November (Fig. 9). Multiple fatalities occurred in two cases. Two men died when their truck was crushed by a tree and two men seeking shelter in a ditch were killed by a tree. The descriptions in *Storm Data* for the tornadoes that caused one or more deaths from wind-related tree failures showed a median path length of 5 miles and median path width of 200 yards. More than one-third (38%) of the

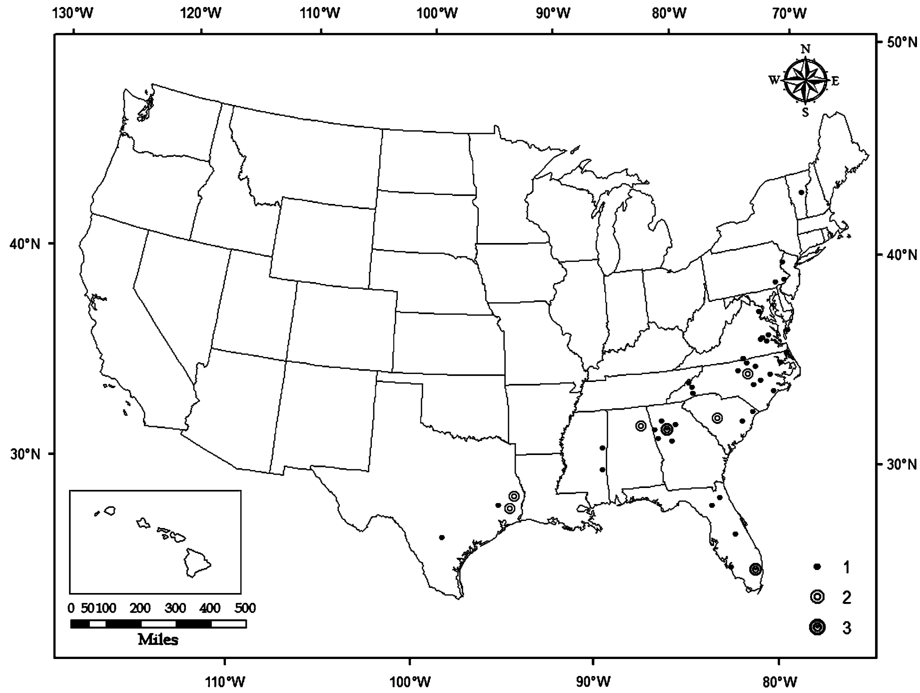

Fig. 6 Distribution of deaths due to wind-related tree failures caused by tropical cyclones, 1995–2007

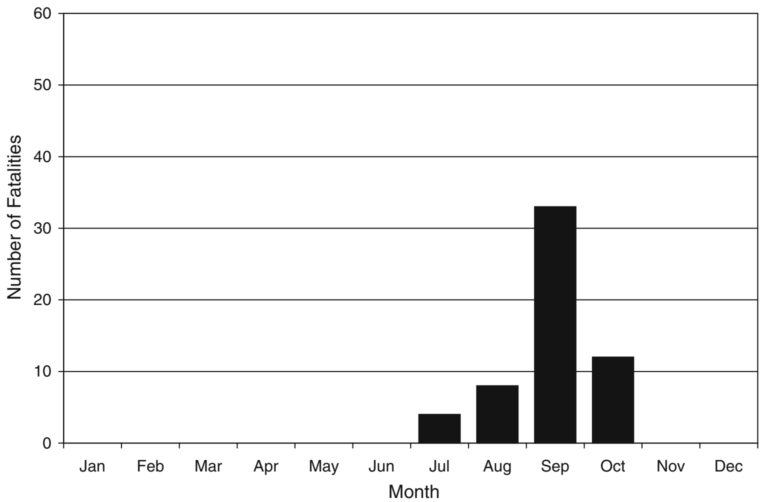

Fig. 7 Monthly distributions of deaths due to wind-related tree failures caused by tropical cyclones, 1995–2007

deaths from wind-related tree failures in tornadoes were associated with tornadoes rated F0 or F1 on the Fujita Scale, yet only 7% of all deaths caused by tornadoes during 1995–2007 were from tornadoes rated F0 or F1. This emphasizes that risk for death from wind-related

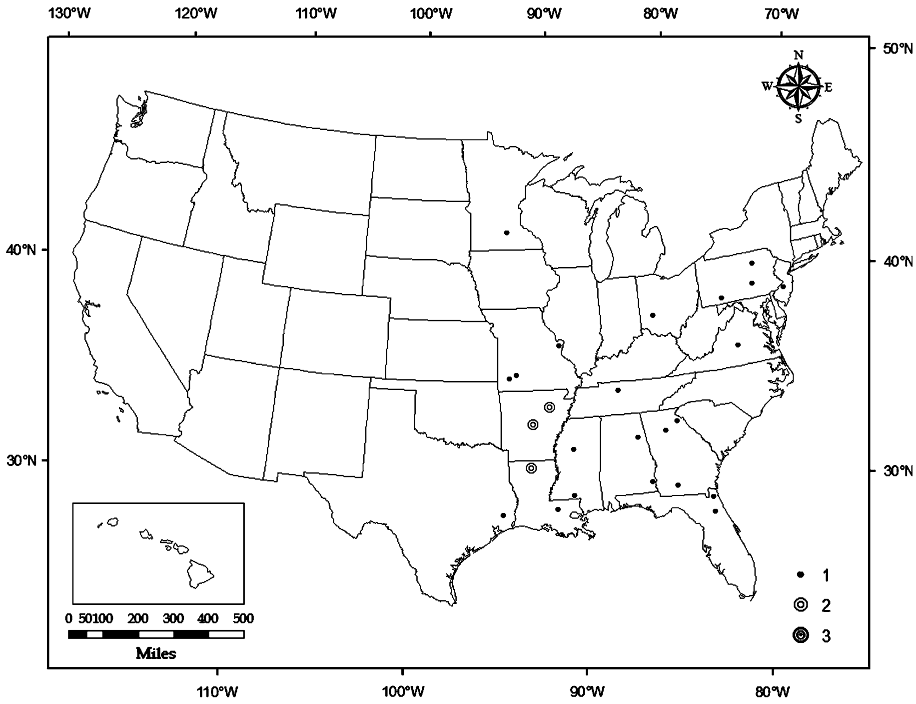

Fig. 8 Distribution of deaths due to wind-related tree failures caused by tornadoes, 1995–2007

tree failures increases at wind speeds of 70–90 mph, a lower threshold than associated with risk for death from high winds due to destruction of houses or vehicles (Schmidlin et al. 2002).

3.5 Snow and ice

Fourteen people were killed by falling trees or limbs due to heavy accumulations of snow or ice. Most were males who were outdoors (Table 1). Ice accumulations were the cause in 10 of the 14 deaths. The median age was 69 years (range 29–78 years). These deaths were concentrated in the northeastern portion of the United States and in Washington (Fig. 10), a pattern that aligns with the regions experiencing the maximum number of hours with freezing rain (Houston and Changnon 2007). Somewhat surprisingly, there were two deaths in Louisiana following an ice storm. Deaths from fallen trees due to snow or ice occurred from October to April with 50% in December (Fig. 11). Broder et al. (2005) studied injuries from an ice storm in North Carolina and found that nearly all life-threatening injuries resulted from the falls of heavy limbs during storm assessment or cleanup.

4 Conclusions

Deaths from wind-related tree failures occurred in 41 states and the District of Columbia (Fig. 1). New York had the most (30), followed by Washington (28), Pennsylvania (27),

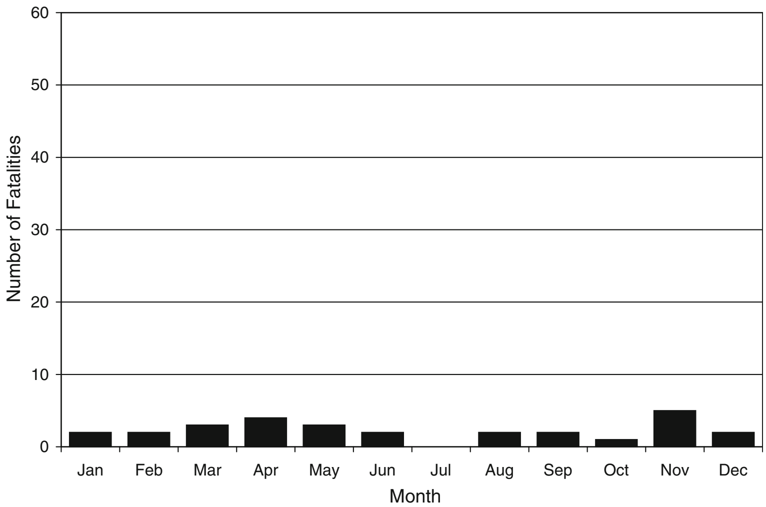

Fig. 9 Monthly distributions of deaths due to wind-related tree failures caused by tornadoes, 1995–2007

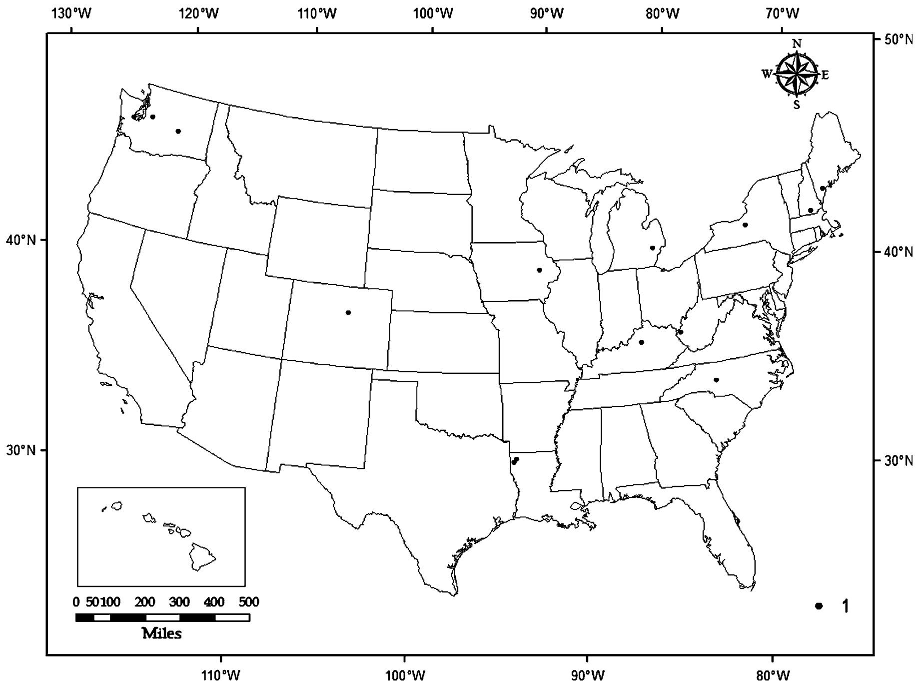

Fig. 10 Distribution of deaths due to tree failures caused by snow and ice, 1995–2007

Georgia (24), and North Carolina (24). A death rate was calculated for each state by dividing the total deaths from wind-related tree failures during 1995–2007 in each state by the 2000 state population in millions. Table 3 shows the states with the 15 highest death rates and the weather type primarily responsible for the deaths. (The addition of 15 deaths

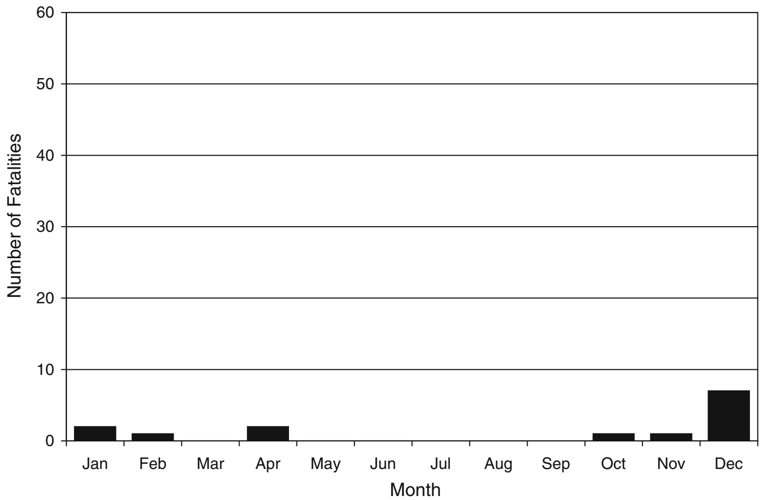

Fig. 11 Monthly distributions of deaths due to tree failures caused by snow and ice, 1995–2007

Table 3 States with the highest death rates from wind-related tree failures, 1995–2007

State	Total deaths	Death rate (deaths/million population)	Primary weather type causing fallen tree
Mississippi	15	5.27	Thunderstorm (10)
New Hampshire	6	4.86	Thunderstorm (3)
Washington	28	4.75	Nonconvective high wind (25)
District of Columbia	2	3.50	Thunderstorm (2)
West Virginia	6	3.32	Thunderstorm (4)
Maine	4	3.14	Thunderstorm (2)
Louisiana	14	3.13	Thunderstorm (5)
Arkansas	8	2.99	Thunderstorm (4), Tornado (4)
North Carolina	24	2.98	Tropical cyclone (14)
Georgia	24	2.93	Tropical cyclone (10)
Kentucky	11	2.72	Thunderstorm (7)
Delaware	2	2.55	Thunderstorm (1), nonconvective (1)
Hawaii	3	2.48	Nonconvective high wind (3)
Alabama	11	2.47	Thunderstorm (5)
Virginia	16	2.26	Tropical cyclone (7)
United States	407	1.45	

across inland Mississippi due to Hurricane Katrina, a late addition to *Storm Data*, would double the death rate for Mississippi.) These results are not very robust, given the short time period and event-driven nature of these data. Wind-related tree failures accounted for about one-half of all deaths due to thunderstorms and nonconvective high winds, about one-third of all deaths due to tropical cyclones (not including deaths from Katrina in Mississippi and Louisiana), but only 4% of all tornado deaths.

Persons killed by wind-related tree failures during tropical cyclones and tornadoes were more commonly at home (~40%) when struck than those killed by thunderstorm and nonconvective high winds (~12% at home). This pattern was also reported by Ashley (2007) for all tornado fatalities, although he found that 71% of all tornado fatalities occurred at home. A tornado warning or hurricane warning causes people to seek shelter indoors. In contrast, driving and other ordinary daily activities continue during thunderstorms and nonconvective high winds, placing people who are in vehicles or outdoors at risk from fallen trees.

In addition to deaths caused directly by fallen trees, as summarized here, wind-related tree failures cause many nonfatal, but life-changing injuries. Indirect deaths and additional suffering are caused by trees that have fallen on roads and blocked rescue to injured persons. Additional indirect deaths and injuries occur when trees or limbs broken in a storm, known as 'widow-makers,' fall later. Weak or dead trees or large limbs also fall and cause deaths without the presence of severe weather, and are not included here.

People will always live and spend leisure time around trees and trees provide many benefits to our environment. The risks from fallen trees described here emphasize the need to maintain trees in a healthy and structurally sound state so the risk from unhealthy or structurally unsound trees is minimized. A tree risk assessment and tree risk management program should be in place, especially in public areas such as along roads and in parks. Even healthy and sound trees may be broken or felled by strong winds or ice accumulations, so severe weather safety recommendations should continue to emphasize seeking shelter in sturdy buildings when any type of high winds are expected. Trees planted along roads provide shade but pose some risk to motorists during high winds. If trees are planted near a house for shade and other benefits, then they should be inspected regularly for structural defects. Large dead branches should be pruned and the entire tree removed if structural defects are significant. Risks to people outdoors in tents or campers may be reduced if they are directed to seek shelter in a sturdy building or, if none is available, enter their vehicle and park in an open area away from trees for the duration of the high winds.

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