LIGHTNING-CAUSED DEATHS AND INJURIES IN THE VICINITY OF TREES

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1. INTRODUCTION

The goal of this study is to examine the types of lightning-caused human casualties in and near trees. The present report focuses on trees, and uses some of the same approaches used in previous studies of lightning casualties related to dwellings and other buildings (Holle 2009a,b, 2010); vehicles (Holle, 2007, 2008); motorcycles (Cooper and Holle 2007); water (Holle 2007); soccer, baseball, golf, and camping (Holle 2005a); hiking and mountain climbing (2005b), and running (Holle et al. 2007).

The category of "Trees" has been found to be one of the most important immediate environments of lightning casualties in several previous studies. In the U.S. in the 1990s, 15% of lightning deaths and 6% of lightning injuries were under or near a tree (Holle et al. 2005). In the 1890s, the same study found 7% of deaths and 2% of lightning injuries under or near a tree. Several other studies have specifically identified trees as a persistent source of danger from lightning. The lightning fatality percentages under and around trees have been directly identified in publications in recent years as 24% in Australia (Coates et al. 1993), 12% in Brazil (Cardoso et al. 2011), 9% in Singapore (Pakiam et al. 1981), and 5% in Greece (Agoris et al. 2002). An analysis of lightning safety in an open field compared with a forest found minor differences between these two situations (Roeder 2012).

It is hoped that the results of this study based on a large number of cases will provide a better understanding of the dangers of lightning related to trees. The results may also be helpful in developing lightning safety messages.

2. DATA

The cases were randomly collected through web reports, newspapers, broadcast media, published papers, and other publications and sources. The U.S. cases were separated from others throughout this study in order to compare the situations in more developed regions with other areas of the world. Some U.S. events were from NOAA's *Storm Data* compiled by local National Weather Service offices. The reports are mainly from the last two decades. Additional cases were included from several prior papers describing two or more events (Barannyk et al. 2010; Kitigawa 2000; Kitagawa et al. 2002).

Events are obtained as described by the news source. It must be noted that the reports may be affected by preconceived ideas of reporters, casualties, and witnesses about lightning and its effects (Cooper 2012). The nature of data collection precludes conversion to an absolute rate for each scenario. Nevertheless, relative values generally indicate which types of events are more common.

First to be described are the number of events, then the number of victims per event, the gender and age of casualties, then time of day. The paper will attempt to describe the behavior of people in the vicinity of trees in terms of activity and location. When possible, the path will be described from the lightning, to the tree, to people affected by the lightning. The distance of casualties from trees will be described for a few cases, and the mechanism of injury if possible.

3. NUMBER OF EVENTS

A total of 444 events related to trees are considered in this study (Table 1); more than half came from the U.S. These cases accounted for 362 deaths and 1101 injuries. There is a much higher fatality rate per event in the non-U.S. cases (1.8) than in the U.S. (0.5). It is possible that cases with multiple fatalities are reported more often outside the U.S., but it fewer multiple-fatality events may occur in the U.S.

Some events in Table 1 involve both one or more fatalities, and one or more injuries. For the U.S., there were 51 events with at least one fatality and one injury (16% of events). For the non-U.S. cases, 31% of the events had at least one fatality and one injury.

There is a ratio of more than four injuries for each death in the U.S., while the ratio is about two injuries per fatality in non-U.S. locations. Both are quite low compared with the ratio of 10 injuries per death requiring medical treatment that was found from a review of all available medical records in Colorado (Cherington et al. 1999).

TABLE 1. Number of lightning-related events, deaths, and injuries involving trees within and not in the U.S.

Location	Events	Deaths	Injuries
United States	328	156	662
Non-U.S.	116	206	439
Total	444	362	1101

4. NUMBER OF VICTIMS PER EVENT

In the U.S., it was found that 91% of lightning fatalities involved one person per *Storm Data* incident from 1959 to 1994 (Curran et al. 2000). Another 8% of the deaths involved two people per event, and 1% involved more than two fatalities. The corresponding injury distribution was 68% single, 17% to two people, and 14% to more than two people per event.

Figure 1 shows that the U.S. has a dominance of one fatality or one injury per event, while the non-U.S. distribution is spread almost equally between two and three casualties per event. Note that Figure 1 only extends to 17 people per event in order to make the figure more legible. It does not illustrate one U.S. event with 22 injuries and one with 30. Outside the U.S., there are two events with 30 injuries per event, one with 40, and one with 60 injuries in an event, accompanied by fatalities in two cases (Table 2). The conclusion is that more people tend to be killed or injured by lightning per event in the vicinity of trees outside the U.S. than within the U.S.

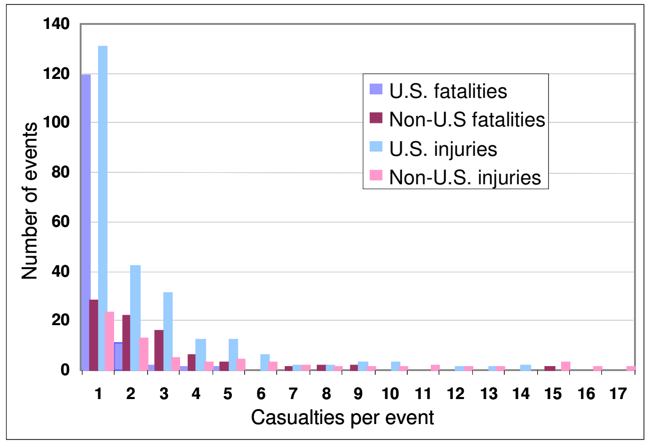

FIGURE 1. Number of fatalities and injuries per event related to trees within and outside the U.S.

TABLE 2. Description of six events with 22 or more people injured by lightning in the vicinity of trees.

Date of event or report	Location	Casualties	Description
14 January 2004	Swaziland	60 injuries	Participants in annual sacred Swazi ceremony sought shelter under trees.
17 August 1978	Gozaishyotake, Japan	40 injuries	Along a mountain path in a forest near a mountain top; tree directly struck; 40 people affected, 2 hospitalized (Kitigawa et al. 2002).
28 April 2011	Mondulkiri province, Cambodia	3 fatalities, 30 injuries	Victims working for pine tree company planting trees during heavy rain.
23 June 2010	Uluberia, India	1 fatality, 30 injuries	Lightning struck a casuarina tree within a school compound at the end of morning classes; students were sitting in, or by open windows and received hearing and shock effects.
17 July 2005	Pennsylvania, United States	30 injuries	Family reunion with numerous trees on farm.
13 August 1994	Massachusetts, United States	22 injuries	Lightning struck a tree at a campground, then travelled through the ground beneath people standing in water or holding onto aluminum tent poles.

5. GENDER, AGE, AND TIME OF VICTIMS

Many previous publications have shown the male ratio (Cooper and Holle 2007; Cooper et al. 2007; Curran et al. 2000; Holle 2005a,b, 2007, 2008; Holle et al. 2007). Table 3 summarizes results with respect to gender for the present study involving trees. Outside and within the U.S., 65 to 74% of the casualties related to trees are male. Most prior references to large samples of lightning casualties have found a male ratio over 70%, throughout the world, both now and in the past. The dominance of male lightning casualties has been attributed to many factors, including the tendency for greater risks to be taken by males with regard to lightning and other hazards. Inspection of the non-U.S. cases indicates that the larger percentage of females than in the U.S. may be related to more females involved in labor-intensive agriculture who seek shelter under trees near the fields.

TABLE 3. Gender of lightning casualties in the vicinity of trees within U.S. and outside the U.S.

Gender	U.S.	Non-U.S.
Male		
Fatalities	115	92
Injuries	255	69
Total male %	**74%**	**65%**
Female		
Fatalities	31	54
Injuries	100	31
Total female %	**26%**	**35%**

In terms of age, Table 4 shows the distribution by 10-year age groups when age was mentioned in the source report. People between 11 and 20 are the most frequent casualties around trees in both areas, and ages 31-40 are the second largest in both. There is a much higher likelihood of the age being reported for a U.S. fatality (69%) than a non-U.S. injury (12%).

The oldest victim, aged 101, was killed in Louisiana when lightning hit a tree, ran down the tree trunk, hit a nearby mobile home next to where his bedroom was located, then the man was unable to escape due to smoke. The second oldest fatality was a 91-year-old woman walking beneath a tree in Pennsylvania when lightning hit the tree and severed a large branch that fell on her.

TABLE 4. Ages of known lightning-related deaths and injuries involving trees within and not in the U.S.

Age range	U.S.			Non-U.S.		
	Deaths-injuries-total			Deaths-injuries-total		
0-10	5	21	26	10	9	19
11-20	24	71	95	27	16	43
21-30	14	26	40	16	5	21
31-40	24	19	43	23	12	35
41-50	12	22	34	9	5	14
51-60	17	16	33	8	4	12
61-70	7	8	15	2	1	3
71-80	2	4	6	2	1	3
81-90	0	1	1	0	1	1
91-100	1	0	1	0	0	0
101+	1	0	1	0	0	0
Total	107	188	295	97	53	150

In terms of time of day, Table 5 indicates that most events (68%) occurred between noon and 1800 local time in both areas. Note in Table 5 that the six-hour period from noon to 1800 is divided into two three-hour periods. Not many reports from outside the U.S. provided time, but more than half of the U.S. events identified times. Not included here are general descriptions such as afternoon or night. The afternoon concentration is consistent with the lightning maximum over most of the U.S. (Holle 2012, 2013).

TABLE 5. Local time of day of lightning casualties in the vicinity of trees within and not in the U.S.

Time	U.S.	Non-U.S.
0000 to 0600	1	1
0600 to noon	19	5
Noon to 1500	**56**	**8**
1500 to 1800	**66**	**9**
1800 to 0000	36	2

6. ACTIVITY

The activities of people killed or injured by lightning while in the vicinity of trees are summarized in Tables 6 and 7. Table 6 describes situations when people are described in the narrative reports to have actively taken and reached shelter from rain or a storm.

Outside the U.S., the most frequent activity immediately before taking shelter in the vicinity of trees is agriculture. This is a particularly vulnerable group in labor-intensive agricultural societies. It represents the farm-related situations that were common in the earlier years in the U.S. (Holle et al. 2005).

In the U.S., the most frequent situation where people stopped their activity to take shelter in the vicinity of trees is on a golf course and during team sports. Other relatively frequent activities where casualties stopped in the vicinity of trees in Table 6 include fishing, at a public park or pool, and soccer, among many others.

TABLE 6. Activities of lightning casualties before actively taking shelter in the vicinity of trees from rain, heavy rain, a downpour, storms, and/or thunderstorms.

Activity	Events	
	U.S.	Non-U.S.
Agriculture	0	10
Golf course	9	0
Team sports except soccer	6	2
Fishing	4	2
Park/pool	4	2
Soccer	2	4
Bicycle/motorcycle/4-wheeler	4	0
Bus stop/inside car/exiting car	4	0
Other activities	20	11
Unspecified prior activity	29	26

The other activity group is when people were in the vicinity of trees but had not stopped what they were doing (Table 7). By far the most common activities without taking action to reach shelter were standing and walking in the vicinity of trees. Most of these events were in the U.S. The most frequent non-U.S. activity is agriculture, as also shown in Table 6.

TABLE 7. Activities of lightning casualties who had <u>not</u> actively taken shelter in the vicinity of trees from rain or storms.

Activity	Events	
	U.S.	Non-U.S.
Standing	56	5
Walking	25	2
Agriculture	13	8
Sitting	13	6
Picnic/party	12	0
Golfing/working on course	7	4
Camping	8	1
Waiting	3	4
Hiking	5	2
Sleeping	3	3
Working/mowing in yard	6	0
Children playing	5	0
Caring for animals in yard	5	0
To or from vehicles	5	0

7. LOCATION

The locations of people killed or injured by lightning while in the vicinity of trees are summarized in Table 8 and Figure 2. The description is directly taken from the report, where the distinction between being under or near a tree is likely imprecise. The dominant location is under a tree. Next most often is near trees, then other less frequent locations. The same data are in Figure 2.

TABLE 8. Locations of lightning casualties relative to trees at the time of occurrence of the lightning strike.

Activity	Events		
	U.S.	Non-U.S.	Total
Under tree(s)	123	77	200
Near tree(s)	95	15	110
Forest/woods/grove	10	2	12
Between trees	8	1	9
Fallen branch/tree	7	1	8
In tree	3	3	6
Exploded tree	2	2	4
Orchard/tree farm	1	3	4

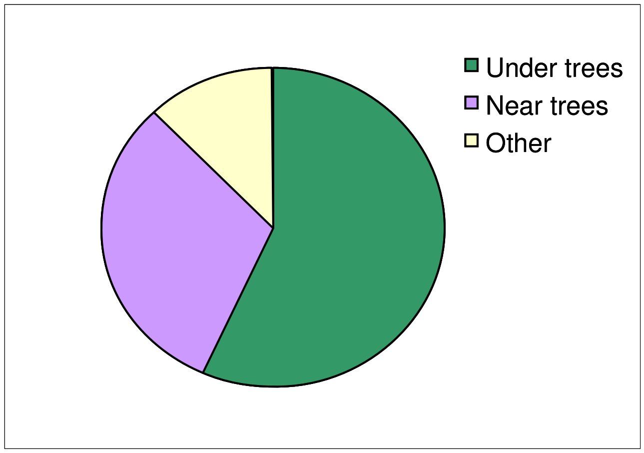

FIGURE 2. Locations of lightning casualties relative to trees.

8. INTERMEDIATE PATHS

Many events involve lightning striking a tree, then another man-made object, finally reaching the casualty. Figures 3 to 5 indicate the variety of paths that are described reasonably well in the reports. Figure 3 shows 31 events with a single intermediary object along the path, while Figure 4 has 21 events with two intermediary paths. Figure 5 describes three cases where lightning struck another object before reaching the tree, then the casualty. Both U.S. and other cases are included here, although there is a tendency for the U.S. reports to identify the path more often.

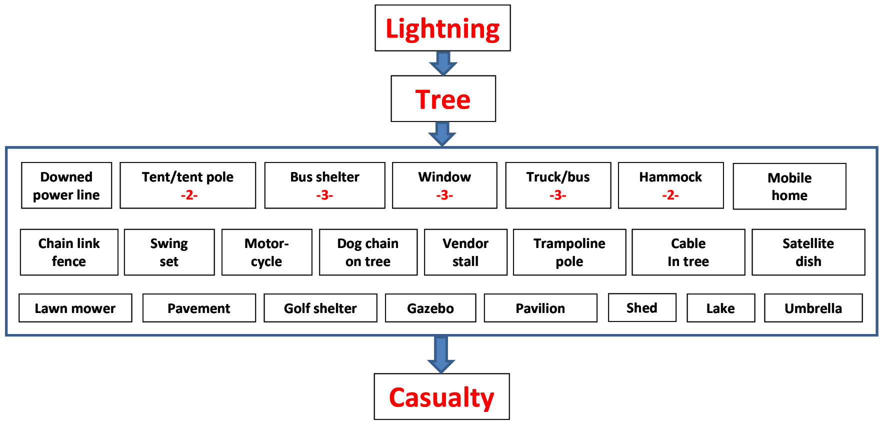

FIGURE 3. Single intermediary path from tree to casualty.

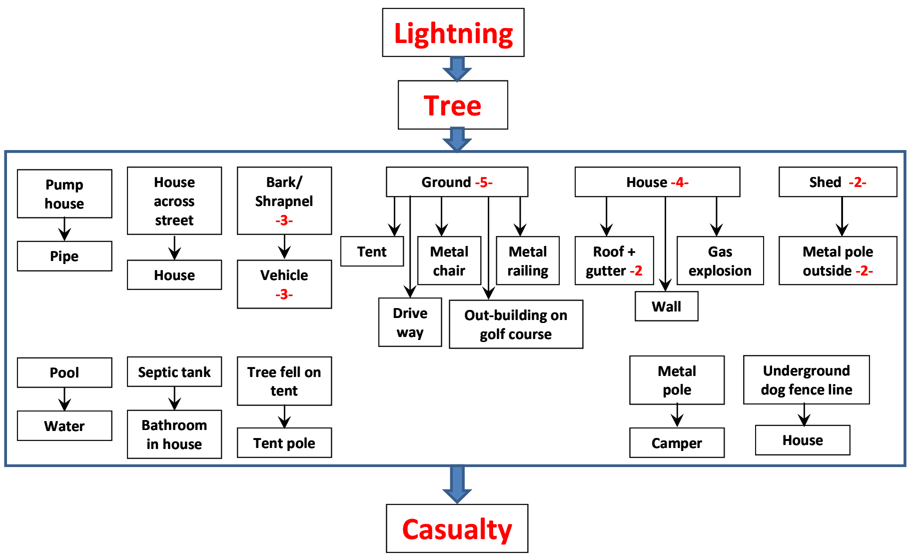

FIGURE 4. Two intermediary paths from tree to casualty.

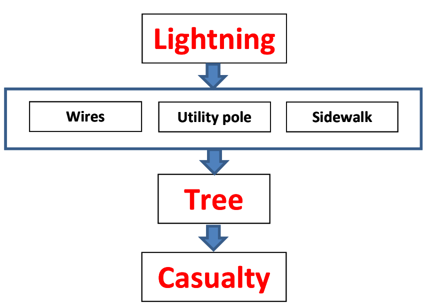

FIGURE 5. Tree is secondary portion of path from lightning to casualty.

9. DISTANCE FROM TREES

In a small number of events, the source report identifies distances from the tree that affected the casualty. Table 9 indicates the distances as reported in the narratives, while Figure 6 divides them into fewer and increasingly large distance ranges.

All three fatalities with known distances are within 7 m of the nearest tree. Most injuries occur within a range of 1.5 to 10 m away, but the tree is up to 100 m away in one event. There is usually uncertainty as to whether specific events involved ground current only, or also involved shrapnel from the tree such as bark, branches, or splinters. In the well-documented 100-m case in Table 9, chunks of wood were thrown that far when a car window was penetrated and the wood seriously injured the driver.

TABLE 9. Distance of casualties relative to trees at the time of the lightning strike.

Distance	Events
Fatalities	
1 m	1
5 m	1
7 m	1
Injuries	
0.3 m	1
0.6 m	1
1.5 m	1
2 m	2
3 m	7
5 m	7
6 m	3
10 m	3
12 m	1
15 m	1
30 m	1
100 m	1

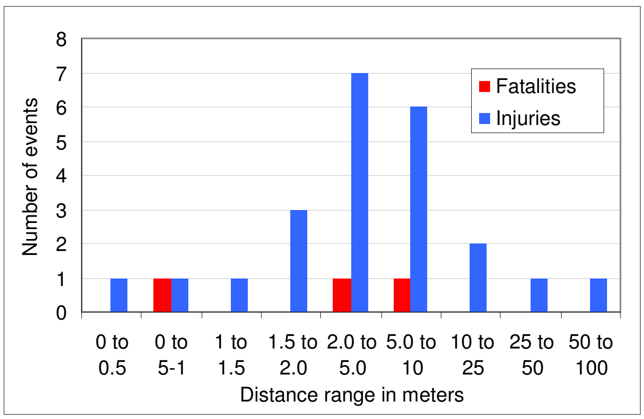

FIGURE 6. Distance of lightning casualties from trees.

10. MECHANISMS OF LIGHTNING INJURY

This was among the most difficult categorizations to make, since the lightning path to the person is mentioned in only a small number of events. Lightning injury is typically categorized into five distinct mechanisms. In descending order of frequency, they are ground current, side flash, contact, upward leader, and direct strike. Blunt trauma sometimes accompanies one of more of these mechanisms (Cooper and Holle 2010; Cooper et al. 2008, 2010).

While it is difficult to isolate these mechanisms for trees, some events make specific mention of how the person was affected by the strike (Table 10). The following explanations apply to Table 10 entries:

- Ground events are specifically indicated in the reports. If there was an intermediate path, it is included in chapter 8.
- Side flash includes cases where lightning is reported to bounce, jump, or ricochet from tree to person. In several events, casualties were struck on the side of the body, such as the head, nearest the tree.
- Blunt trauma includes reports of trees or branches falling on people or vehicles with people inside, the explosion of tree parts or gas lines, concussive effects such as being thrown, and a motorcycle running into a lightning-felled tree.
- Contact events are when a person is reported to be physically in contact with the tree, such as by leaning, playing, or working in or on the tree.

The information in Table 10 indicates that ground current is more frequent than side flash and blunt trauma, and only a few cases involve contact with a tree. The mechanisms that apply in the other 362 events are not identified sufficiently to categorize.

TABLE 10. Mechanisms of lightning injury in the vicinity of trees within and outside the U.S.

Mechanism	Events
Ground	30
Side flash	23
Blunt trauma	22
Contact	7

11. DISCUSSION

Several anecdotes included comments that were given by participants or rescue personnel related to the perception of safety in the vicinity of trees, as follows:

- A 2000 event with one injury on a remote island in Canada involving campers had the following quote from the police "…It seemed the group did everything they could to protect themselves against a lightning strike…the group split up and each of the members sat by themselves, on their life jackets, in a forest, away from large trees."
- A 2000 event in Massachusetts where four people were injured at a YMCA camp noted that the struck tree "…was not isolated or the tallest in the area…"
- A Minnesota wilderness trip leader in 2006 "…told his 12 teenage campers to spread out, stay away from trees and crouch into catcher's position….The tree near us evaporated" and severely injured one camper.
- A 2006 event in North Carolina injured three soldiers in training where "The soldiers also followed other standard precautions such as moving weapons away and staying away from trees and water…however the training area is full of pine trees."

- A 2006 event injuring two motorcyclists said "If it had been the only tree, I wouldn't have gone under it…but there were hundreds of trees."
- A 2011 U.S. event related that the Missouri Water Patrol searching for missing boaters stated that "If you stay in your canoe, you're in the water. If you get out, you're under trees."
- A 2012 event in Malaysia emphasized that sending students under a tree beside a soccer field was not in the safety protocols that school officials who organized the game were to follow.
- It has been emphasized that bus shelters should not be located very near trees, after documenting two events in Ukraine in this situation (Barannyk et al. 2010). A similar event occurred in the U.S.

11. SUMMARY

A number of case studies have described the impacts of lightning on trees. Among them is a thorough examination of the types of tree damage that occur from lightning (Makela et al. 2003); the relationship to people was not included. It should also be noted that damage to trees has been used to calibrate the location accuracy of a lightning location system (Makela et al. 2010).

The present study appears to be the first to summarize the impacts of lightning on people in the vicinity of trees for a large sample. Among the 444 events, single-person events were most common, while some events had up to 60 injuries; multiple injuries were more common outside the U.S.

Most of the victims were male, and the most frequent age range was between 11 and 20. There was a dominance of afternoon events between noon and 1800 local time.

The activity of people who became lightning casualties in the vicinity of trees was divided into two groups:

- The first group occurred when people actively stopped their activity and sought shelter in the vicinity of trees. In this group, non-U.S. casualties were most often engaged in agriculture, while the U.S. group was dominated by people on a golf course and in team sports.
- The second group occurred when people had <u>not</u> stopped their activity while in the vicinity of trees. People standing or walking comprised most of these events.

The location of people was determined to be dominated by being under and near trees. A few other locations included forests and fallen trees. Quite a few reports included a description of the probable path by which lightning reached the person. The most common situation was for one object to be in the path from a tree to a person, such as a tent, hammock, or shed. Nearly as many events involved two objects in the path, such as a pump house being hit, then the lightning effects went through pipes to the person. In a few cases, lightning first hit an object such as a utility pole, then hit a tree, then reached the casualty.

The distance from trees was found from the reports when they were explicitly provided. The three fatalities involved trees between one and seven meters from the person. The injuries ranged up to 100 meters, but most were between 1.5 and 10 meters away. The mechanism of injury was often difficult to identify, but ground current was evident most often, followed by side flash and blunt trauma, and occasionally from direct contact with a tree.

Several narratives described precautions taken by people which were thought to provide safety in a forest. A common theme was that any configuration of trees may result in a path from lightning to a tree to a person, such as under or near a single tree, or a forest or woods.

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