CHAPTER 6

Morbidity and Mortality Associated with Disasters[1]

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Disasters disrupt the natural, built, and social environments, affecting communities and the people within them. Disasters can be triggered by climatic, geophysical, technological, or human-initiated events, or a combination of these. Their impact on the health of a community can be immediate or delayed, and changes in health status may be attributable to the original event or result from events subsequent to the disaster. Deaths, injuries, and other health outcomes of a disaster are usually caused by the destruction of the built infrastructure. In the absence of people living in built communities, disasters do not occur.

The frequency and severity of disasters triggered by natural hazards have increased over the last 15 years, part of which is attributable to cyclic changes in climate patterns. Of even greater relevance, however, is the fact that population density in cities and in geophysically vulnerable areas has increased dramatically since 1950, both in developed and developing countries. The majority of the world's largest cities (17 of 20) are in developing countries, 80% of the world's population will be concentrated in developing countries by 2025, and half of the large cities in the developing world are vulnerable to natural disasters such as floods, severe storms, and earthquakes (Noji, 2005). Disaster-related health problems in developing countries are exacerbated by lower immunization rates and poor nutritional status relative to those in the United States and other developed countries, and greater vulnerability of the facilities that provide water and handle sewage.

Health effects vary across disaster types. For example, death by drowning rarely occurs during earthquakes, but is a major cause of death during hurricanes and floods. The extent to which infectious diseases occur is determined by the health of the affected community before the disaster, and the ability of the infrastructure to recover sufficiently to prevent, or at least control, the spread of infectious diseases. In general, increases in infectious disease rates following disasters are more common in developing than in developed countries.

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It has often been stated that "vulnerable" populations, such as women, children, the elderly, nondocumented immigrants, underrepresented groups, and the poor, are differentially and negatively affected by disasters (e.g., Bolin, 1976; Bolin & Bolton, 1986; Bolin & Stanford, 1991; Drabek & Key, 1984; Kaniasty & Norris, 1994; Kilijanek & Drabek, 1979; Tierney, Lindell, & Perry, 2001). Research on physical morbidity and mortality associated with natural hazards and terrorist events generally does not support that perception, at least in the United States. In contrast, the literature on mental health morbidity shows that vulnerable persons are particularly prone to post-disaster stress, a topic addressed at the end of this chapter.

Age is the only characteristic that has been consistently reported to have a weak association with disaster-related morbidity and mortality. Following the Northridge earthquake, studies of hospital admissions and emergency room logs found that older persons were more likely to be hospitalized because of injuries suffered (Peek-Asa et al., 1998; Seligson & Shoaf, 2003) and were somewhat more likely to present at emergency rooms (Mahue-Giangreco, Mack, Seligson, & Bourque, 2001), but when residents were asked about injuries in community-based samples following three California earthquakes, women and younger persons were more likely to report being injured (Shoaf, Nguyen, Sareen, & Bourque, 1998). The elderly were also more likely to be killed in the Hanshin-Awaji earthquake in Kobe, Japan, but here the higher death rates for elderly are confounded by the fact that the elderly tended to sleep on the first floor of "bunka jutaku," two-story wooden houses with heavy tiled roofs and thin walls that were built after World War II (Kunii, Akagi, & Kita, 1995).

It is somewhat easier to conclude that *recovery* from disasters favors those with knowledge and money. In a series of analyses conducted at UCLA, we have demonstrated that persons with higher education and income are more likely to engage in preparedness and hazard mitigation activities before earthquakes, are more likely to take first aid courses, and know more about where to obtain assistance after disasters. Conversely, immigrants and persons who are linguistically isolated are less likely to have invested in preparedness and hazard mitigation, or to know where to go for assistance (e.g., Goltz, 2005; Kano, Siegel, & Bourque, 2005; Nguyen, Shen, Ershoff, Afifi, & Bourque, in press; Nguyen, Shoaf, Rottman, & Bourque, 1997; Russell, Goltz, & Bourque, 1995). Interestingly, however, during the Northridge earthquake, newer homes inhabited by middle-class whites were more likely to be damaged than older homes that were inhabited by groups more often considered vulnerable (Comerio, 1995; Shoaf & Bourque, 1999), but African-American residents more often *perceived* themselves to be victims of the earthquake than did other groups with more property damage.

The inability to demonstrate a relationship between traditional indicators of vulnerability and morbidity and mortality does not automatically mean that it does not exist. Rather it may reflect the generally weak methodology of most studies. Very few studies allow prevalence estimates and rates to be calculated for the morbidity and mortality associated with disasters (Bourque, Shoaf, & Nguyen, 1997; Dominici, Levy, & Louis, 2005; Ibrahim, 2005). Most studies describe those cases in a coroner or medical examiner's office, or at a hospital or emergency room, with no effort to describe the denominator population from which the cases are drawn. A study focused only on the dead, injured, and sick who present at a particular location provides no insight into how deaths and injuries are distributed across the population at risk, and whether certain groups are more vulnerable to death and injury. Increased use of cluster samples in rapid needs assessments after floods and hurricanes provides some ability to generalize to a larger population. Unfortunately, rapid assessment techniques do not work well following earthquakes where structural damage is less predictably distributed (Noji, 2005).

Other useful, but underutilized, methodologies include case-control designs, geographic information systems (GIS), comparative cohorts, and probability proportionate to size (PPS) surveys. All have the potential to provide information about whether morbidity and mortality are differentially distributed across populations. A case control design considering persons who died or were hospitalized as a result of the Northridge earthquake and sets of age-matched and geographically matched controls selected from a post-quake survey of Los Angeles County residents revealed that persons at elevated risk of death or hospitalization were females, elderly, close to the epicenter, in areas of high peak ground acceleration or high Modified Mercalli Intensity, or in buildings that were damaged or constructed after 1970 (Peek-Asa, Ramirez, Seligson, & Shoaf, 2003). Comparative cohorts were used by Semenza, McCullough, Flanders, McGeehin, and Lumpkin (1999) to examine excess hospital admissions during the July 1995 Chicago heat wave, and by Leor, Poole, and Kloner (1996) and Kloner, R. A., Leor, J. U., Poole, W. K., and Perritt, R. (1997) to examine deaths on the day of the Northridge earthquake. GIS could, for example, be used to "map" the addresses where the injured and dead lived or were at the time of impact (Peek-Asa, Ramirez, Shoaf, Seligson, & Kraus, 2000). This information could then be compared with census data about the populations who live in those areas, similar to what Klinenberg (2001) did after the 1995 Chicago heat wave. But these methodologies require substantial resources, which are not readily available to researchers. Similarly, ongoing surveillance systems in hospitals and emergency rooms would increase our ability to determine whether the number and pattern of presenting cases change in the aftermath of a disaster. Surveillance has long been advocated by the public health community, but has yet to be instituted widely in the United States.

Further complicating research is the lack of agreement on what constitutes a disaster-related death, injury, or disease. Twenty years ago, the Centers for Disease Control and Prevention (CDC) took the lead in attempting to develop a standardized definition of disaster-related deaths and injuries; more recently, Seligson, Shoaf, and colleagues have attempted to develop standardized procedures for identifying earthquake-related deaths and injuries (Seligson & Shoaf, 2003). In spite of these attempts, the majority of researchers continue to develop their own definitions of which injuries and deaths are counted, often with little regard for or even knowledge of past research and discussions. Disaster-related mortality is more accurately described than are injuries, where official numbers are often guesses compiled by a public health employee who contacts the Red Cross and hospitals within an affected area for estimates of the injured and sick seen in emergency rooms. The majority of injured do not utilize emergency rooms and the person representing the hospital usually does not know which patients are injured or sick because of the index disaster and which are not. Thus, the numbers reported simultaneously exaggerate and minimize actual counts. Careful review of emergency logs and admissions records is necessary to determine whether a condition is related to the event and, even with careful review, not all cases can be resolved.

The health effects of disasters can be categorized in many ways, but for purposes of this chapter we adopt the typology defined by Combs, Quenemoen, Parrish, and Davis (1999) and used by the CDC: ". . . disaster-attributed deaths [are] those caused by either the direct or indirect exposure to the disaster. Directly related deaths are those caused by the physical forces of the disaster. Indirectly related deaths are those caused by unsafe or unhealthy conditions that occur because of the anticipation, or actual occurrence, of the disaster" (p. 1125).

We concentrate on how natural hazards worldwide and terrorist events that occurred in the United States have affected the health of populations. These events are neither more important nor more lethal than events not described, but they are the centerpiece of this chapter because a greater quantity of methodologically rigorous research has focused on these disasters. This work provides insights into the types of morbidity and mortality that would be expected to occur when natural hazards and terrorism result in a "disastrous event." As highlighted in this chapter, definitions of what constitutes a death or injury *caused* by a disaster vary within a type of disaster, as well as across disasters. The CDC has attempted to develop a system that differentiates the time (relative to the disaster) when the death or injury occurs, and whether the event is directly or indirectly related to the disaster, but the protocol is difficult to apply. The most accurate estimates of morbidity and mortality are probably those reported in studies conducted after the Northridge earthquake in California (1994) and the Murrah Federal Building in Oklahoma (1995). Even there, as discussed in the section on earthquakes, the range of reported morbidity and mortality is wide. Estimates from events outside the United States, especially in areas that lack mechanisms for centralized data gathering, are expected to be even lower in accuracy. This chapter concludes with a note about the mental health effects of disasters.

HURRICANES

According to current estimates, hurricanes caused about 75,000 deaths during the 20th century (Nicholls, Mimura, & Topping, 1995; Rappaport & Fernandez-Partagas, 1997; Shultz, Russell, & Espinel, 2005). Most deaths occurred in developing nations, with 42% in Bangladesh and 27% in India.

Prior to the development of effective warning, evacuation, and shelter systems, most deaths were caused by drowning in storm surges (Shultz et al., 2005). Japan and the United States, two developed countries at high risk of hurricanes, cyclones, and typhoons, have experienced no storms that resulted in more than 1,000 deaths since 1959, while 50 high-fatality storms (with more than 1,000 deaths) occurred in developing nations of the Asia-Pacific region and 16 in the Caribbean and Central American area. At the time of this writing, the full consequences of Hurricane Katrina (November, 2005) are unknown.

Data available on deaths and injuries from Hurricanes Elena (1985), Gloria (1985), Hugo (1989), Andrew (1992), Marilyn (1995), Opal (1995), Georges (1998), Floyd (1999), and Isabel (2003) provide information about how and when deaths and injuries occur (Centers for Disease Control and Prevention [CDC], 1986b, 1989b, 1989d, 1989e, 1992a, 1992b, 1992c, 1993a, 1993c, 1996a, 1996c, 1998b, 1999, 2004d, 2005). A total of 208 deaths were attributed to these hurricanes. Of the 103 for which CDC assigned a time of death, 9 occurred before, 57 during, and 37 after the hurricane. Of the 142 individuals for whom a cause of death was clearly indicated, 62 drowned with 26 in motor vehicles and 20 in or when beaching boats. Others died when hit by falling trees, in fires, from carbon monoxide poisoning, by being crushed or asphyxiated in collapsing structures, by electrocution, by blunt or penetrating trauma, while using a chain saw, by falling in the absence of electricity, in motor vehicle crashes, and in cardiovascular events. Some information is available on injuries that occurred during these hurricanes. Although the numbers of pre- ($N = 198$) and post-hurricane ($N = 184$) injuries from Hurricane Opal were about equal, most of the injuries from Hurricane Andrew ($N = 321$) took place after the hurricane, with only 15 before and 70 during the hurricane. In all hurricanes, the majority of injuries, regardless of when they occur, are cuts, lacerations, sprains, and strains and fractures, generally in the upper or lower extremities. Both corneal abrasions and insect bites and stings have been found elevated after hurricanes. As many as 75% of the injured are male, a substantial number of whom had been injured while using chain saws during cleanup activities.

The 2004 hurricane season was one of the most destructive to the state of Florida in recent history, and hurricanes in 2005 exceeded those in 2004. Four hurricanes hit Florida, with Hurricane Charley resulting in 35 deaths, Hurricane Frances in 40, Hurricane Ivan in 29, and Hurricane Jeanne in 19 (Dahlburg, 2005). In Hurricane Charley, 17 of the 35 deaths, 10 on the day of impact, were due to trauma caused by falling trees, flying debris, and destroyed physical structures. Only one death was caused by drowning. Other causes of death, all after impact, included carbon monoxide poisoning, electrocution, suicide, exacerbation of a medical condition, and lack of necessary respiratory equipment (CDC, 2004c).

Surveys after the hurricanes found that the most prevalent risk factor for indirect morbidity and mortality was improper use of portable gas-powered generators. "A total of 167 persons had nonfatal CO poisoning diagnosed during the study period, representing a total of 51 exposure incidents. The number of cases and incidents peaked within three days after landfall of each hurricane" (CDC, 2005, p. 699). Environmental concerns considered most important by respondents included water quality (50.9%), sewage disposal (13.2%), and food protection (11.8%). Only 51.3% of respondents reported having an evacuation plan before the hurricanes.

TORNADOES

Although tornadoes occur in other parts of the world, information about morbidity and mortality associated with tornadoes comes exclusively from North America, primarily the United States. Reports generally provide information on Fujita scores or wind speed.[2] Data on deaths and injuries are available for the following tornadoes: Topeka, 1966; Omaha, 1975; Wichita Falls, Texas, F4, 1979; the Carolinas, 1984; Pennsylvania, 1985; Southern Ontario, 1985; Saragosa, Texas, F4, 1987; Illinois, F5, 1990; Kansas, F5, 1991; Alabama, F4, 1994; Arkansas, F4, 1997; Texas, three tornadoes at F3, F4 and F5, 1997; and Oklahoma, F5, 1999 (Bell, Kara, & Batterson, 1978; Carter, Millson, & Allen, 1989; CDC, 1984c, 1986c, 1988, 1991, 1992d, 1994c, 1997b, 1997c; Daley et al., 2005; Erickson, Drabek, Key, & Crowe, 1976; Glass et al., 1980; Pereau, 1991). Four hundred and sixty-one deaths and 5,882 injuries were attributed to these tornadoes.

Deaths were overwhelmingly instantaneous, occurring at the time of tornado impact, and resulting from head, chest, and body traumas: 89% (43/48) in Wichita Falls, 100% (12/12) in Ontario, 82% (23/28) in Illinois, 84.5% (22/26) in Arkansas, and 89.7% (26/29) in Texas in 1997. Victims died as a result of becoming airborne and being slammed into structures and objects, or from being crushed by structures. Some reports attributed deaths to brief, nonexistent, or insufficient warnings.

Although the majority of deaths occurred in buildings, persons in mobile homes, motor vehicles, and outdoors were at high risk of death. In Wichita Falls in 1979, 60% (26/43) of the deaths from multiple traumas occurred in motor vehicles, and 77% (20/26) had entered their vehicles expressly to outrun the tornado. Studies of Oklahoma victims, however, found that risk of death in motor vehicles was not elevated but that persons in mobile homes and persons outdoors were at high risk (Daley et al., 2005). The authors attributed this difference in findings to improved warnings about the expected path of tornadoes, which led residents to evacuate the predicted impact areas.

The most common injuries from tornadoes are contusions, lacerations, abrasions, strains/sprains/muscle spasms, fractures, penetrating wounds, and closed head injuries (CDC, 1984c, 1997b). What differentiates those hospitalized from those treated and released is the

[2] Tornadoes are graded on the Fujita Scale, which ranges from F-0 to F-12. Anything above F-5, or 319 mph, rarely occurs (Fujita, 1987).

severity and combination of injuries suffered, not the type of injury. Carter, Millson, and Allen (1989) report that most nonfatal injuries are caused by being struck by moving objects. There is no evidence that rates of disease or malnutrition increase as a result of tornadoes.

FLOODS

Floods are the most common disasters in the world, but the origin of a given flood is not always clearly delineated (Pielke & Klein, 2005). Floods may be caused by tropical cyclones and hurricanes, excess rain, tsunamis, dam breaks, and so forth. Deaths usually are caused by drowning or from trauma that results from blows by objects in fast-flowing water (Ahern, Kovats, Wilkinson, Few, & Matthies, 2005). Flash flooding is the leading cause of weather-related mortality in the United States (accounting for approximately 200 deaths per year) (CDC, 1993e, p. 656; French & Holt, 1989), but floods also affect the geology of an area, with landslides being one source of death and injury. During floods in Puerto Rico, 48% of 95 deaths occurred in landslides and 50% (23/40) were due to traumatic asphyxia (Dietz, Rigau-Perez, Sanderson, Diaz, & Gunn, 1990).

In the United States, most deaths in floods occur in motor vehicles that are driven into high water. The Midwest floods of 1993 resulted in 43 deaths, the majority of which were due to drowning in flash floods and riverine floods, with many occurring in motor vehicles (CDC, 1993b). Reported morbidity included 250 injuries, 233 illnesses, and 32 hospitalizations (CDC, 1993d). Injuries were primarily sprains/strains (34%), lacerations (24%), and abrasions/contusions (11%). Of the 28 deaths that occurred in Georgia floods of July 1994, 27 were drownings and 20 were motor vehicle related (CDC, 1994a). Similarly, 24 of 29 deaths that occurred in Central Texas in October 1998 were drownings and 22 occurred because a vehicle was driven into high water (CDC, 2000b).

Ahern et al. (2005) note that there is a potential for increased fecal–oral transmission of disease, vector-borne disease (e.g., malaria), and rodent-borne disease (e.g., Hantavirus), especially in areas with poor sanitation and endemic levels of diarrheal disease. Generally, such outbreaks do not occur in the United States, suggesting that mass immunization for diseases such as typhoid is not needed (CDC, 1983).

EARTHQUAKES

Compared to other types of natural hazards, it is easy to determine when earthquakes start and end. Casualties that occur while the ground shakes, or immediately afterwards, are impact-phase events; those that occur after the shaking has stopped are post-impact events. There are no pre-impact events. Distinguishing between direct and indirect earthquake casualties is more difficult. Injuries that occur during the earthquake, such as falls, are direct effects of the physical force of the earthquake. But an injury that occurs because of structural collapse can be either direct or indirect. If it happens during an earthquake, it is direct; if it happens 24 hours later, it usually is considered indirect. Thus, the cause of injury and the outcome may be the same; the timing relative to when the earthquake occurred often determines the difference. In the 1989 Loma Prieta earthquake, 57 of the 60 deaths were considered direct and resulted from injuries sustained within 2 minutes of the earthquake (CDC, 1989c); three deaths considered indirect resulted from injuries sustained up to 24 hours after the earthquake.

The casualty reports for U.S. earthquakes (i.e., 1987 Whittier Narrows, 1989 Loma Prieta, 1994 Northridge, 2001 Seattle/Nisqually, 2003 San Simeon) note that the major causes of deaths include structural collapse of buildings and infrastructure (i.e., freeways) and debris falling from damaged buildings (Durkin, 1995; Earthquake Engineering Research Institute, 2005b; Eberhart-Phillips, Saunders, Robinson, Hatch, & Parrish, 1994; Peek-Asa et al., 1998; Weber, 1987). Injuries that result in death are mainly crush and other traumatic injuries.

The overwhelming majority of earthquake-related health problems are injuries, with soft tissue and orthopedic injuries caused by falls and being struck by nonstructural elements (e.g., furniture, ornaments, light fixtures) accounting for most (Kano, 2005; Mahue-Giangreco et al., 2001; Peek-Asa et al., 2000; Shoaf et al., 1998). The majority of these injuries are minor and do not require hospital admission. Earthquakes can also cause environmental pollution that affects health. Following the 1994 Northridge earthquake, active surveillance in Ventura County documented increased cases of coccidioidomycosis, an infectious disease known as "valley fever."

Studies conducted after the 1994 Northridge earthquake (Bourque, Peek-Asa et al., 1997; Seligson & Shoaf, 2003) allow us to examine the extent to which estimates of disaster-related deaths and injuries differ between sources, and the extent to which injuries are incorrectly reported. Where Durkin (1995) reported 72 earthquake deaths and the official count by the State of California was 57 (EQE International, Inc., 1997), Peek-Asa et al. (2000), after a careful review of coroners' records, reported 33 deaths caused by the earthquake. The discrepancies are explained by a tendency to include in the "official mortality count" any case in the coroner's office during or immediately after an earthquake or, in the case of state estimates, all deaths for which burial expenses were approved.

Most troubling is the inclusion of deaths that occur from cardiac events. Normally, people who die from heart attacks do not become "coroner's cases;" rather, death certificates are signed by attending physicians and bodies are released to next of kin. Following the Northridge earthquake, Leor et al. (1996) and Kloner et al. (1997) reviewed all death certificate data to identify deaths from ischemic heart disease (IHD) and atherosclerotic cardiovascular (ACD) disease for January 1994 and compared them with similar data collected in January 1992 and January 1993. The numbers of deaths attributed to IHD and ACD on January 17 were higher ($N = 125$) than the daily average for the preceding 16 days ($N = 73$), but average rates dropped to 57 deaths for the rest of the month. Overall rates of death for January 1994 did not differ from those of January 1992 and 1993. We refer to this as a harvest effect. Deaths that are imminent occur a few days early. These results are consistent with research conducted in Athens and in the Hanshin-Awaji earthquake (Kario & Ohashi, 1997; Suzuki, Sakamoto, Miki, & Matsuo, 1995; Trichopoulos, Katsouyanni, Zavilsanos, Tzonou, & Dalla-Vorgia, 1981).

Similar problems exist in counts of injuries. As of September 2005, the National Information Service for Earthquake Engineering continues to list 5,000 injuries from the Northridge earthquake on its Web site while the Red Cross lists "1,500 serious injuries," and the Federal Emergency Management Agency (FEMA) lists "more than 5,000" (American Red Cross, 2005; Federal Emergency Management Agency, National Earthquake Hazards Reduction Program, 2005; National Information Service for Earthquake Engineering, n.d.). Both the state and Durkin (1995) reported 11,846 injuries. According to Durkin, this figure was based on data collected by the Red Cross, which suffer from lack of uniformity in both data collection methods and in the definition of "earthquake relatedness." None of the numbers are in accord with what was found through actual review of hospital and coroner's records or population-based surveys.

After review of hospital records, Peek-Asa et al. (1998) found that only 138 injuries were serious enough to require hospitalization; five people had injuries such that they died after hospitalization. Mahue-Giangreco et al. (2001), in a review of emergency room logs in four hospitals, found that 423 injured persons were treated and released, and Shoaf et al. (1998), in a survey of a population-based sample of households, found that 8.1% of households reported an injury to at least one member of the household. Ten percent of those injured, or 0.81% of the total sample, sought treatment from some source, with a third of them (0.27% of the total sample) seeking treatment from a hospital. Thus, extrapolating to Los Angeles County from these studies, the death rate was 0.38/100,000 population; the hospitalization rate was 1.5/100,000 population; there were approximately 240,000 minor injuries, of which 6.6% sought out-of-hospital treatment; and 3.3% went to emergency departments (Seligson & Shoaf, 2003). These numbers are quite different from those that continue to appear on official Web sites.

Earthquakes in other areas of the world have resulted in many more casualties and other devastating health effects. The 2001 Gujarat, India earthquake resulted in 20,000 or more deaths, and the 2003 Bam, Iran earthquake resulted in 30,000 or more deaths (Earthquake Engineering Research Institute, 2005a). As in the United States, the primary cause of death and serious injury was structural collapse (De Brucycker, Greco, & Lechat, 1985; Glass et al., 1977; Noji et al., 1990), which occurs more often in areas with weak or nonexistent building codes (Ramirez & Peek-Asa, 2005).

VOLCANOES

Three active volcanoes have erupted in the United States in the last 25 years—Mount Saint Helens in Washington in 1980, Mauna Loa in Hawaii in 1984, and Kilauea, which has been continuously active in Hawaii since 1982. Thirty-one bodies were recovered from the Mt. St. Helens eruption and 32 persons were missing and presumed dead. Deaths were from asphyxiation by dense ash exposure (19/31), burns (7/31), falls (1/31), flying rocks (1/31), and falling trees (3/31) (Merchant et al., 1982). Hospital visits and admissions for respiratory illnesses, especially asthma, increased following the eruption. Repeated exposure to volcanic ash increases risk of pneumoconiosis, especially if particles are inhaled (CDC, 1986a), putting persons involved in post-disaster cleanup and those who work outdoors at elevated risk. The presence of free silicon increases future lung damage, but results of a longitudinal study of loggers exposed to Mt. St. Helens indicated that risks of chronic bronchitis or pneumoconiosis were negligible.

More insidious is the air pollution caused by sulfur dioxide gas when it combines with other gases emitted by volcanoes and interacts chemically in the atmosphere with oxygen, moisture, dust, and sunlight to create vog. This has been a constant problem since 1986 on the island of Hawaii, where the Kilauea volcano produces a nearly constant outflow of lava and gas. Vog, in turn, produces acid rain which damages crops and is thought to increase health problems, particularly asthma among children (Elias, Sutton, Stokes, & Casadevall, 1998; Sutton, Elias, Hendley, & Stauffer, 2000; United States Geological Survey, 2001).

TSUNAMIS

The tsunami in Papua, New Guinea, and the tsunami caused by the Sumatra-Andaman Islands earthquake are the first for which attempts were made to ascertain population-based rates of deaths and injuries. Deaths resulting from fifteen tsunamis occurring since 1946 have been estimated at 291,058,[3] with the vast majority (283,100) caused by the December 26, 2004,

[3] Number of dead were: 173, Hawaii (1946); 61, Hawaii after the Chilean earthquake (1960); 11, Crescent City, CA after the Alaska Earthquake (1964); 920, Mindenaio, Philippines (1976); 1,000, Flores Island, Indonesia (1992); 170,

tsunami associated with the Sumatra-Andaman Islands earthquake, and 4,966 caused by the 1998 Papua, New Guinea, tsunami. In Papua, New Guinea, although no pre-tsunami census data existed for the area, fatality rates were estimated at 18.8% (Dengler & Preuss, n.d.), 23.1% (International Tsunami Survey Team, 1998), and 28.9% (Office for the Coordination of Humanitarian Affairs, 1998). Death rates ranged from 2.3% in Sissano to 49.1% in Warupu.

Injury estimates were reported first for the 1964 tsunami in Crescent City, California, by Lander and colleagues, with 35 injuries, and the 1996 Chimbote, Peru tsunami, with 55, including one serious injury (Humboldt State University, Geology Department, n.d.; Petroff, Bourgeois, & Yeh, 1996). In Papua, New Guinea, 1,000 injuries were reported by the International Tsunami Information Center (2005, March 23), 668 major injuries were reported by the Office for the Coordination of Humanitarian Affairs (OCHA) (Office for the Coordination of Humanitarian Affairs, 1998), and 369 injuries in Warupu were reported by the International Tsunami Survey Team (1998). The most common injuries were fractures, abrasions, deep cuts, and broken limbs (Dengler & Preuss, n.d.). In some cases, delayed care (beyond 12 hours) led to the development of gangrene and amputations.

The tsunami caused by the Sumatra-Andaman Islands earthquake[4] destroyed miles of coastline in 12 countries with devastation, death, and injuries correlated with the number and height of waves, the amount of runup, and the extent of development. Adger, Hughes, Folke, Carpenter, and Rockström (2005) noted that coastline in Sri Lanka that remained covered with indigenous mangrove forests and that had not been degraded by mining of coral reefs fared better than areas that had undergone development. Preliminary data reported by the many affected areas on mortality, morbidity both from physical injury and other disease sequelae, and the impact on the health structure have been considerably more extensive than those from the more contained Papua, New Guinea tsunami. The most comprehensive data are available from Thailand, owing to the well-developed national health care system that was in place before the tsunami. Estimates of dead and missing presumed dead as posted on various Web sites in June 2005 averaged 283,100, with 125,000 reported injured. The latter figure is presumed to be a substantial underestimate, given the unreliability of most injury reports following natural disasters. In Sumatra, Indonesia, reported mortality rates ranged from 13.9% in Meulaboh to 22.2% in Banda Aceh (Doocy, Rofi, Robinson, Burnham, & Shanker, 2005, May); in Sri Lanka, from 4.2% in the Northern Province to 20.0% in the Southern Province (Pomonis, 2005); in Thailand, death rates were 25% for residents and 50% for tourists in Phang Nha, and 3% to 5% in Phuket (Pomonis, 2005; Wilkinson, 2005, April); and in India, 3.3% were dead and 13.7% were missing in the Nicobar Islands (Jain et al., 2006).

HEAT

Deaths directly caused by heat occur from hyperthermia, which is defined as a core body temperature of 105° Fahrenheit or 40.6° centigrade. When bodies are found in a hot, unventilated environment, with unknown core body temperature at the time of death, heat is frequently

Nicaragua (1992); 320, Okushiri Island, Japan Sea (1993); 250, East Java, Indonesia (1994); 62, Mindoro Island, Philippines (1994); 11, Kuril Islands, Russia (1994); 1, Alaska (1994); 1, Indonesia (1994); 12, Chimbote, Peru (1996); 4,966, Papua, New Guinea (1998); 283,100, Sumatra-Andaman Islands Earthquake (12/26/04).

[4] Nineteen countries were affected by the tsunami: Indonesia, Sri Lanka, India, Thailand, Somalia, Maldives, Malaysia, Myanmar, Tanzania, Seychelles, Bangladesh, Kenya, Singapore, Madagascar, Mauritius, South Africa, Mozambique, Australia, and Antarctica (Earthquake Engineering Research Institute, 2004).

listed on the death certificate as a contributing cause of death, and the death is considered heat related (CDC, 1994b).

A heat wave is defined by the U.S. National Weather Service as three or more consecutive days of temperatures 90° Fahrenheit (32.2° centigrade) or higher (CDC, 1995a). Between 1979 and 1997, an average of 371 deaths per year in the United States were attributed to "excessive heat exposure," which translates into a mean annual death rate of 1.5 per 1,000,000 persons (CDC, 2000a). Of the 8,015 heat-related deaths in the United States between 1979 and 1999, 48% were due to weather conditions, yielding an average of 182 deaths per year (CDC, 2003a).

The criteria used to determine which deaths are attributable to hot weather and heat-related illness vary by state and among individual medical examiners and coroners. In Dallas, for example, at least one of three criteria must be met for a death to be listed as heat-related: (1) a core body temperature of 105° Fahrenheit (40.6° centigrade) or higher at the time or immediately following death, (2) substantial environmental or circumstantial evidence of heat as a contributory cause of death, or (3) the decedent is found in a decomposed condition without evidence of other causes of death and the decedent was last seen alive during a heat wave (CDC, 1997a). In the absence of consistent definitions for defining a heat-related death, the number of deaths caused by heat may be substantially over- or underreported.

Heat-related deaths are higher for persons older than 60 years of age and children younger than 5. Generally, elderly women are at greater risk of death, in part because they live longer than men, but this trend was reversed in the 1995 Chicago heat wave, in which elderly men died at disproportionate rates (Klinenberg, 2001). African Americans are at greater risk of heat-related death, largely reflecting living conditions associated with lower socioeconomic status and residence in densely populated urban centers without air conditioning. Among adults younger than 65 years of age, men are at greater risk of heat-related death (CDC, 1984a, 1984b, 1989a, 1995b, 1996b, 2000a, 2001).

Semenza et al. (1999) examined the hospital admissions in 47 non-VA hospitals in Cook County in 1995 and compared them to admissions during the same period in 1994. The majority of excess admissions were because of dehydration, heat stroke, and heat exhaustion. Persons older than 65 years of age with the underlying medical conditions of cardiovascular diseases, diabetes, renal diseases, and nervous system disorders were at higher risk of being admitted.

ICE AND SNOW

The impact of blizzards, ice, and snow on morbidity and mortality has not been widely studied. In the 1978 New England Ice Storm, total mortality did not increase but a third ($N = 37$) of all deaths were classified as storm related (CDC, 1982). Eight persons stranded in cars died, with five dying from carbon monoxide poisoning. Mortality from ischemic heart disease increased significantly in Rhode Island, although the number of visits to emergency rooms declined by 64% in Rhode Island and 65% in Eastern Massachusetts during the blizzard. No disease outbreaks occurred and no water or sanitation hazards could be verified, although seven were reported in Eastern Massachusetts.

Ice storms during 1994 in the Washington, D.C., area resulted in 53 National Institute of Health (NIH) employees having acute musculoskeletal injuries (CDC, 1995c). Of these, 22 (42%) were bruises and contusions, 24 (45%) were strains or sprains, and 7 (13%) were fractures. Thirty-nine of the 53 injuries resulted from falls on ice on the NIH campuses, including all seven fractures, 63% of the strains/sprains, and 77% of the bruises and contusions.

Rain combined with freezing temperatures caused trees and utility poles to fall in Maine in January 1998, leading to loss of power (CDC, 1998a). An assessment found that presumptive carbon monoxide poisoning increased from 0 to 101 cases compared to the 1997 reference period. Visits to emergency rooms increased 47% over the reference period, and most types of injuries showed absolute increases, but proportional increases were found only for cold exposure and burns.

WILDFIRES

Historically, wildfires in the United States occurred in unpopulated areas and were allowed to burn out. Starting in the 1940s and escalating during the last 20 years, development has occurred in areas traditionally considered wildlands. Areas where residential structures and fire-prone wildlands intermix are referred to as urban–wildland interfaces. One of the first fires to receive widespread attention was the Oakland, California, fire of 1991, which resulted in 25 deaths and 150 injuries ("Charring cross bottleneck was big killer," 1991; East Bay Hills Fire Operations Review Group, 1992).

Subsequent fires in Malibu, Laguna Hills, and those that occurred throughout Southern California in October 2003, which resulted in 20 deaths and 121 injuries, have emphasized the increased importance of wildfires as a type of natural disaster (Greenberg, 2003). There have been no systematic studies of the deaths and injuries that occurred in these fires; most available information is contained in press reports and other informal sources. It is clear that deaths occur because persons are unable to evacuate the area of fire and either do not consider or are unable to initiate procedures that would allow them to shelter in place. Most deaths appear to be caused by smoke inhalation and burns. How injuries occur and whether they occur pre-impact, during impact, or post-impact is unknown.

TERRORISM

Since September 11, 2001, the disaster community has examined the extent to which terrorist incidents do or do not resemble the natural disasters that have been studied over the last 60 years. Bombs, planes, arson, gases (e.g., sarin), pathogenic microbes including *Bacillus anthracis* (anthrax), variola virus (smallpox), *Yersinia pestis* (plague), *Francisella tularensis* (tularemia), *Clostridium botulinum* (botulism), the hemorrhagic fever viruses (e.g., Ebola), and nuclear devices have been hypothesized to be or actually have been selected as the agent of choice by terrorists. Clearly, cause of death and the kinds of morbidity experienced after a terrorist attack differ with the agent used. Devices are frequently delivered by individuals who intentionally commit suicide as part of the delivery process. Between 1980 and 2001, the FBI reported 482 terrorist attacks in the United States, with 67.2% being bombings (Federal Bureau of Investigations, n.d.). This section examines the deaths, injuries, and disease potentials associated with the 1993 bombing of the World Trade Center, the 1995 bombing of the Murrah Federal Office Building in Oklahoma City, and the 2001 attacks on the World Trade Center and Pentagon.

The majority of deaths in such events are caused by instantaneous dismemberment, crushing by debris, burns, and smoke inhalation. Morbidity is primarily the result of physical injuries, but disease syndromes associated with inhalation or other kinds of exposure to toxic substances are also of concern. In contrast to earthquakes, which result in similar kinds of injuries, the lethality of bombs is increased by the force with which the blast transforms parts of structures and other materials into projectiles.

Six persons were killed and 1,042 were injured when a truck bomb exploded at the World Trade Center in February 1993 (Parachini, 2000). There is no available information about what exactly caused the deaths, how the number of injuries was determined, or the nature of the injuries.

When the Murrah Federal Building was bombed on April 19, 1995, the Oklahoma State Health Commissioner "... mandated that physical injuries and other health conditions associated with the bombing be reportable conditions for the purpose of special study" (Mallonee et al., 1996, p. 383). Of the 167 fatalities, 162 persons died at the scene. The probable cause of death included multiple injuries (73%), head trauma, chest trauma, head and neck trauma, traumatic shock, and fractured spine.

Mallonee et al. (1996) defined a case as " ... any person with a physical injury directly related to the bomb blast that resulted in death or treatment at a medical facility or physician's office between April 19 and April 25, 1995" (p. 383). Of the 769 persons injured, 167 died, 83 were hospitalized, and 509 were treated and released. Similar to injuries observed in earthquakes, soft tissue injuries (lacerations, abrasions, contusions, and puncture wounds) were most common followed by musculoskeletal, head, ocular injuries, and burns. The most common locations of injuries were the extremities (74%), head and neck (48%), face (45%), and chest (35%). Eighty-eight percent of the persons who were in the building at the time of the blast were injured. Persons killed were disproportionately located on the upper floors (4 to 9) in the collapsed part of the building (risk ratio = 16.3, 95% CI 8.9 to 29.8).

In a later study, 8% of 684 survivors sustained an ocular injury, with 12 having injuries to both eyes (Mines, Thach, Mallonee, Hildebrand, & Shariat, 2000). Seventy-one percent of these persons were within 300 feet of the point of detonation, and glass caused two thirds of the injuries, with persons who were facing windows at the time of the blast being most likely to have open globe injuries.

As of August 22, 2002, 2,819 persons were estimated to have died in the September 11 attack on the World Trade Center, and a total of 2,734 death certificates had been issued (CDC, 2002a). In the Pentagon attack, 125 occupants of the Pentagon and 64 occupants of the plane were killed, and 106 persons were treated for injuries in local hospitals (Jordan, Hollowed, Turner, Wang, & Jeng, 2005; Wang, Sava, Sample, & Jordan, 2005). Fifty-four patients were treated and released, 47 were admitted, and 7 were transferred to other sites. Injuries treated were primarily burns, respiratory problems (smoke inhalation), and orthopedic injuries.

It is more difficult to determine the number and type of injuries that occurred in New York. CDC reported in January 2002 that 790 survivors with injuries were treated within 48 hours at four hospitals and one burn center. Of the 790, 49% had inhalation injuries and 26% had ocular injuries, primarily attributable to smoke, dust, debris, or fumes. Of the 139 hospitalized, the distribution of injuries was as follows: 37% inhalation, 7% ocular, 18% lacerations, 12% sprain or strain, 21% contusions, 19% fractures, 19% burns, 6% closed head injuries, and 4% crush syndrome. Two hundred and thirty-nine rescue workers sought care, with the majority suffering from inhalation (42%) and ocular (39%) injuries (CDC, 2002f). Since the original studies reported by the CDC, more detailed reports about patients seen in a number of hospitals have been published (Cushman, Pachter, & Beaton, 2003; Kirschenbaum, Keene, O'Neill, & Astiz, 2005) but no single article has attempted to describe all of the injured who sought care.

In the years since 9/11, numerous articles have reported on attempts to monitor the long-term health effects of the World Trade Center attack on the population of New York City. The majority have reported efforts to monitor the impact of environmental contamination on health. Reports of asthma, respiratory symptoms, eye irritations, and rashes by persons who lived or worked in the immediate area increased after 9/11, but researchers have not been able to establish a link to the attack itself or to changes in ambient air in the months following the attack (CDC, 2002e, 2002g, 2003b; Trout, Nimgade, Mueller, Hall, & Earnest, 2002).

Fifteen months after the attack, firemen and other rescue and recovery workers exhibited lower-airway hyperresponsiveness which may be due to high levels of airborne contaminants from smoldering fires, dust resuspension, and diesel exhaust from heavy equipment. Respiratory medical leaves by firefighters increased fivefold during the 11 months after the attacks (CDC, 2002b, 2002c, 2004b; Prezant et al., 2002).

A NOTE ON PSYCHOLOGICAL MORBIDITY

This chapter has considered the impact of disasters on physical health. Not surprisingly, the type of disaster has a strong influence on the particular health outcomes that occur. In contrast, the impact of disasters on mental health is less differentiated by type of disaster and more strongly affected by the pre-disaster characteristics of the individual and the parameters (severity, suddenness, human intent) of the disaster event. This section provides an overview on the research concerned with the influence of disasters on mental health. The interested reader is referred to two excellent papers by Norris and colleagues (Norris, Friedman, & Watson, 2002; Norris, Friedman, Watson et al., 2002) for a more detailed review of this literature.

Despite considerable diversity in circumstances, methods, and outcome measures, some commonalities emerge from the research on the mental health impact of disasters, both in regard to characteristics of individuals and parameters of the disaster events. Persons surviving natural disasters generally do not meet criteria for psychiatric disorders. Posttraumatic stress disorder (PTSD) is by far the most common disorder studied, followed by depression, anxiety, and panic disorders (Norris, Friedman, Watson et al., 2002; Vlahov et al., 2002).

In a careful study of two communities (one affected by a tornado and the other by a flood), Steinglass and Gerrity (1990) found that symptoms of PTSD were a normative reaction to disaster exposure, yet few respondents reached the threshold for a diagnosable disorder. Following Hurricane Andrew, a majority of adolescents in a multiethnic sample reported symptoms of PTSD, yet only a small proportion met criteria for the disorder (Garrison et al., 1995). Likewise, very few respondents met criteria for PTSD after the Northridge earthquake, although scores were elevated on a measure of psychological distress (Siegel, 2000). Most studies reveal a significant drop in symptoms over time (Briere & Elliott, 2000; Norris, Friedman, Watson et al., 2002). For example, three successive surveys in New York City 1 month, 4 months, and 6 months after the 2001 terrorist attack yielded PTSD prevalence rates of 7.5%, 1.7%, and 0.6%, respectively (Galea et al., 2003). These and other findings have led some researchers (see McMillen, North, & Smith, 2000) to propose a subthreshold, or partial PTSD diagnostic entity that would apply to survivors who are impaired yet do not meet diagnostic criteria.

Human-initiated disasters tend to yield higher rates of mental impairment, with mass violence being the most disturbing of all (Norris, Friedman, Watson et al., 2002). Beyond the lack of prediction and control that is characteristic of all disasters, human-initiated events shatter fundamental beliefs about vulnerability, mortality, and human nature, leaving survivors with a sense that their lives have spun out of control (Difede, Apfeldorf, Cloitre, Spielman, & Perry, 1979; Ursano, Fullerton, & Norwood, 1995). These disasters also raise continuing uncertainty about the future (Ofman, Mastria, & Steinberg, 1995) and appear to result in episodes of impairment that are lengthier as well as more severe than those that arise from natural disasters (Kopala & Keitel, 1998).

Two studies of survivors of the Oklahoma City bombing reported PTSD rates of 34% (North et al., 1999) and 8% (Sprang, 1999), respectively. The study yielding the higher rate included only survivors who had been *directly* exposed to the blast, whereas the latter sample *excluded* respondents who were direct victims of the bombing or had experienced another traumatic event in the 5 years preceding data collection. A study of the rescue and recovery workers, including volunteers, from the 2001 attack on the World Trade Center indicated that 13% met criteria for PTSD, a rate about four times what would be expected in the population (CDC, 2004a). Stress-related illness increased 17-fold among FDNY rescue workers in the year following the attack (CDC, 2002d). Nonetheless, communities exposed to chronic threat of terrorism do appear to adapt. Sixty percent of a nationally representative sample in Israel felt that their lives were in danger, yet rates of PTSD were less than 10% (Bleich, Gelkopf, & Solomon, 2003).

Similar to research on other major stressors, the disaster literature shows that vulnerable persons are particularly prone to post-disaster stress, with vulnerability encompassing prior distress, social class, gender, and linguistic or social isolation. Disasters enhance socially structured inequalities already in place and generate new, secondary stressors that further tax coping capacity (Kaniasty & Norris, 1995; Norris, Friedman, Watson et al., 2002; Tierney, 2000), particularly among community members who experience chronic adversity (Richmond, 1993). Paramount among these secondary stressors is disruption of social networks. After a disaster, demand for support can exceed the network's capacity to provide support (Kaniasty & Norris, 1993; Norris, Friedman, Watson et al., 2002). In the face of disaster stressors, instrumental, as opposed to emotional, support is especially important (Haines, Hurlbert, & Beggs, 1999), yet potential support providers may not be in a position to provide instrumental support.

A national survey, fielded 5 days after the September 11 attacks, confirmed the greater vulnerability of certain groups, but also found significant distress among most of those surveyed, even respondents who lived far from the affected areas (Schuster et al., 2001). In other research on 9/11, women who were already experiencing chronic stress were most likely to respond with anxiety and increased alcohol use (Richman, Wislar, Flaherty, Fendrich, & Rospenda, 2004). Female survivors of the Oklahoma City bombing were twice as likely as men to meet criteria for PTSD, depression, and generalized anxiety (North et al., 1999). These findings are compatible with a meta-analysis of psychological impairment following disaster which showed that effect sizes were directly proportional to the number of females in the sample (Rubonis & Bickman, 1991).

Epidemiologic studies identify degree of involvement with the disaster as the most consistent predictor of individual response (Bromet & Dew, 1995; Burkle, 1996; McDonnell et al., 1995). Physical injury, witnessing death or injury, and property loss are the most robust predictors of mental health sequelae, and are more important in this regard than the type of disaster (Briere & Elliott, 2000). Following the Armenian earthquake, an especially severe natural disaster, two thirds of survivors met criteria for PTSD (Goenjian et al., 1994). Health and disaster services were inadequate, and death tolls in this earthquake approached 100,000. Among survivors of a severe earthquake in Western India, 59% met criteria for a psychiatric diagnosis, six times the usual rate in rural India (Sharan, Chaudhary, Kavathekar, & Saxena, 1996). Early reports from the December 2004 tsunami indicate that rates of disaster-related mental disorder are high relative to those following other natural disasters. After the September

11 attacks, several studies documented higher prevalence of PTSD among those with greater exposure (Galea et al., 2002; Schlenger et al., 2002). It is worth noting that research on psychological responses to the events of September 11, 2001, shows that one third of those with PTSD had *not* been directly exposed to the World Trade Center or Pentagon attack (Galea et al., 2003). The immediacy and extensive nature of the media coverage, coupled with the profound psychological impact of the event, appeared to have expanded the boundaries of disaster impact.

The available literature on post-disaster mental health interventions converges to suggest that resources should be devoted to facilitating a speedy return to normalcy in affected communities (Norris, Friedman, & Watson, 2002; Siegel, 2000). In instances of international aid, mental health workers may be most effective when they contribute to the local relief effort by providing information and reassurance, rather than attempting to adapt Western therapeutic techniques to other cultures (Barron, 2004). Survivors of disasters need concrete and timely information on how to find shelters and access other forms of assistance (Joh, 1997). Social support and social resources are also effective in ameliorating distress (Tyler & Hoyt, 2000), as social cohesion improves when other social structures return to their pre-disaster forms (Sweet, 1998). Family, friends, and religious institutions are especially important in light of data that relatively few disaster survivors utilize mental health services (Bourque, Siegel, & Shoaf, 2001; Sprang, 1999).

CONCLUSIONS

In most disasters, the majority of deaths occur because people drown, are crushed by collapsing buildings or other structures, are hit by moving objects, or are thrown against structures and objects. People drown in hurricanes, tsunamis, and floods, with death often occurring instantaneously. People die from crush and multiple traumatic injuries in tornadoes, earthquakes, hurricanes, tsunamis, and terrorist bombings. In hurricanes, floods, and tornadoes, people who are in motor vehicles, motor homes, and outdoors are at greater risk of injury or death; in earthquakes, people who are outdoors are at less risk of injury or death. Burns and asphyxiation are major causes of death and injury following volcanoes and in terrorist bombings, and probably in wildfires. Many of these deaths could be avoided if warnings and evacuation plans were better and more effectively disseminated.

Physical injuries are the primary cause of nonfatal casualties after all disasters, and the majority are soft tissue injuries and fractures, generally to the arms and legs. When electrical service is disrupted, the use of generators and other sources of light and heat lead to increased incidents of carbon monoxide poisoning and burns.

After every disaster, certain myths emerge about how disasters affect the health of populations. Prominent among them are the misconceptions that dead bodies cause disease, epidemics and plagues follow every disaster, local populations are in shock and unable to function, and outsiders are needed to search for bodies and bring supplies. In particular, our review did not find any evidence to support the popular belief about disasters and the occurrence of infectious disease outbreaks. Jean Luc Poncelet, Claude de Ville de Goyet, and Eric Noji have been among the most persistent in trying to address these misconceptions (e.g., de Ville de Goyet, 2004; Noji, 2005, September; Pan American Health Organization, n.d.; Poncelet, 2000), but the beliefs persist, nonetheless.

Despite the unpredictability of disasters, it is incumbent on researchers in this area to utilize strong research designs that are population based and incorporate pre-disaster measures, where feasible. Standardized methods of data collection are imperative, as is increased reliance on multivariate analytic strategies that can be replicated across time and events. Questions about who is at greatest risk of morbidity (physical and psychological) and mortality during and after a natural hazard or terrorist event can be adequately addressed only when researchers and practitioners agree on what constitutes an event-related health effect, and utilize research designs that allow for generalizations to the larger or denominator population.