THE EPIDEMIOLOGY AND ETIOLOGY OF VISITOR INJURIES

IN HAWAII VOLCANOES NATIONAL PARK

A Dissertation

by

TRAVIS WADE HEGGIE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2005

Major Subject: Recreation, Park & Tourism Sciences

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ABSTRACT

The Epidemiology and Etiology of Visitor Injuries in Hawaii Volcanoes National Park.

(December 2005)

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Chair of Advisory Committee: Professor Ronald A. Kaiser

The U.S. National Park Service has recognized visitor health and safety as an important component of protected area management. Despite this recognition, research investigating visitor health and safety issues in national parks is lacking. In order to improve the understanding of the factors contributing to visitor injuries, the purpose of this study was to: 1) identify the distribution of injuries in Hawaii Volcanoes National Park, 2) examine the relationship between visitor factors and the severity of visitor injuries in Hawaii Volcanoes National Park, 3) examine the relationship between environmental factors and the severity of visitor injuries in Hawaii Volcanoes National Park, and 4) determine the effectiveness of sign placement and indirect supervision on controlling visitor injuries in the park.

Data for this study consisted of 5,947 incident reports recorded in Hawaii Volcanoes between January 1, 1993 and December 31, 2002. The results found that even though 26% of the injuries in the park occur in frontcountry regions, 53% of all visitor injuries took place at the Eruption Site. As well, 130 of the 268 (49%) fatalities

occurred on roadway environments and 1,179 of the 1,698 (69%) severe injuries occurred at the Eruption Site.

Logistic regression analysis used to examine the relationship between visitor factors and injury severity in Hawaii Volcanoes National Park found that female visitors, visitors wearing minimal footwear and clothing, and visitors carrying no flashlight and minimal drinking water are factors significantly associated with fatal injuries. Visitors wearing minimal footwear and clothing, visitors carrying no flashlight and minimal drinking water, visitors entering restricted areas, visitors with pre-existing health conditions, and visitors aged 50-59 years of age are factors significantly associated with severe injuries.

Logistic regression analysis found no built environment factor to be significantly associated with visitor fatalities or severe injuries. However, darkness and rugged terrain were significantly associated with visitor fatalities. Chi-square tests of independence found the combined treatment of sign placement and indirect supervision to have no effect on reducing the frequency and severity of visitor injuries at the Eruption Site.

DEDICATION

For Jim, LaBeana, Tracey, Aidan, and Andrew

Kalavika, Lakei, Aikeni, Analu – ‘Ohana Mau Loa!

No Kahiki mai ka wahine o Pele
Mai ka aina mai o Polapola
Mai ka punohu a Kane mai ke ao lapa i ka lani
Mai ka opua lapa i Kahiki
Lapa ku i Hawaii ka wahine o Pele
Kalai i ka wa‘a o Honua-ia-kea
Ko wa‘a, e Kamohoali‘i, hoa mai ka moku
Ua pa‘a, ua oki, ka wa‘a o ke ‘kua
Ka wa‘a o kalai Honua-mea o holo
Mai ke au hele a‘e, ue a‘e ka lani
A i puni mai ka moku, a e a‘e kini o ke ‘kua
Iawai ka hope, ka uli o ka wa‘a? I na hoali‘i a Pele a e hue, e
Me la hune ka la, kela ho‘onoho kau hoe
O luna o ka wa‘a, o Ku ma laua o Lono Holo i honua aina, kau aku
I ho‘olewa ka moku, a‘e a‘e Hi‘iaka na‘i au ke ‘kua
Hele a‘e a komo I ka hale o Pele
Huahua‘i Kahiki lapa uila
Uila Pele e hua‘i e
Hua‘ina hoi e.

E ola mau, e Pele e!
'Eli'eli kau mai!

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CHAPTER I

INTRODUCTION TO INJURY AS A PUBLIC HEALTH PROBLEM

Introduction

Unintentional injury is a global public health problem.[1,2] In 1990, an estimated 5 million people worldwide died as a result of an injury.[1] Moreover, injuries account for 8-12% of all medical expenditures, 148,000 deaths, 2.6 million hospitalizations, and 30 million visits to hospital emergency centers in the United States each year.[3,4] In fact, a committee appointed by the U.S. National Research Council and the Institute of Medicine to study injury trauma in the United States reported that one in three Americans suffer nonfatal injuries each year, that one in eight hospital beds is occupied by an injured patient, and that injuries are the leading cause of deaths up to 44 years of age.[5]

Despite the above findings and the fact that injury deaths such as motor vehicle accidents, falls, and drownings have been listed in mortality statistics for decades, injuries have largely been ignored by public health researchers.[5] However, one aspect that stands out in the existing injury literature is that outside of the home environment, most injuries occur in recreation destinations and are associated with leisure activity.[2,6,7] This is especially alarming given that the popularity of recreating in outdoor and wilderness environments in the United States has steadily increased since the 1940s.[8,9] In fact, according to the 2002 National Survey on Recreation and the Environment, the number of Americans participating in hiking activities increased from 47.8 million participants in 1994 to 69.7 million participants in 2002.[10] The same

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This dissertation follows the style and format of *Wilderness & Environmental Medicine*.

survey further concluded that more than 207.9 million Americans aged 16 years and older actively participate in some form of outdoor recreation.[10]

In the United States, the history and development of recreation and tourism is closely tied to the development of national parks.[11] In fact, the popularity of U.S. National Parks as recreation destinations is reflected in the increase of annual recreational visits from 205 million in 1979 to 287 million visits in 1999.[12] An element of national parks that is often overlooked, however, is that the spectacular and rugged environments that attract visitors to a park can also increase the risk of injury to visitors.[13] Moreover, between 1971 - 2000 there were 4,680 visitor fatalities reported in U.S. National Parks and in 2003, the National Park Service conducted 3,108 search and rescue operations at a cost of $3.4 million and 69,749 personnel hours.[14]

National Park Service Policy

With visitation increasing and health and safety issues playing a more prominent role in the selection of holiday and recreation destinations, the U.S. National Park Service (NPS) has recognized visitor safety as a critical component of protected area management and expressed concern for visitor safety. In fact, the NPS has established a management policy stating that:

> The saving of human life will take precedence over all other management activities. The National Park Service and its concessionaires, contractors, and cooperators will seek to provide a safe and healthful environment for visitors and employees. The Park Service will work cooperatively with other federal, state, and local agencies, organizations, and individuals to carry out this responsibility. However, park visitors assume a certain degree of

> risk and responsibility for their own safety when visiting areas that are managed and maintained as natural, cultural, or recreational environments.[14]

In order to implement this policy, the NPS developed the 1997 NPS Strategic Plan which in Mission Goal IIa2 calls for a 10% reduction in the visitor safety accident rate from the NPS five-year average visitor accident rate established from 1992-1996.[14] As a result, each NPS unit was instructed to analyze their case incident report files in order to identify the primary sources of visitor accidents inside their unit and determine where the greatest improvements in visitor safety can be made.[14] Two Director's Orders consistent with the mission of the NPS were developed in order to provide operational policies, practices, and procedures for the management goals established in the 1997 Strategic Plan. First, Director's Order #83 established policies for public health and the operations of water supply, waste management, and food services systems.[15] Second, Director's Order and Reference Manual #50B established guidelines pertaining to occupational safety and health issues with section 14 specifically dealing with public safety and health.[15] In regard to public safety, this order specifically states that:

> It is the policy of the National Park Service to provide for an opportunity for the public to have an enjoyable experience while visiting National Park Service sites. Recognizing that accidents and injuries can compromise that experience, the NPS will provide information on risks in the recreating environment, maintain structures and facilities in safe condition, and generally provide for the safety of the visitor while recognizing our mandated responsibility to protect the resources and natural processes which can be inherently dangerous to the unwary.[14]

Health and Safety Research in National Parks

While there is an element of risk involved in many activities undertaken by people in their daily lives, recreating in outdoor such as those found in national parks exposes visitors to a number of hazards and a degree of risk that is difficult to remove.[16] In fact, risk is an acknowledged part of the outdoor recreation experience in national parks.[13] Despite this understanding, a review of the literature reveals that researchers have conducted a large amount of research on the motives and environmental impacts of leisure and recreational activities but very little research specific to visitor health and safety issues in national parks has been pursued. Furthermore, the research that does exist is primarily found within the medical literature. For example, Montalvo[17] performed a retrospective study of visitor incident reports over a three-year period in eight national park units in California, Kogut and Rodewald[18] investigated hiking injuries in Yosemite National Park, Backer and Collins[19] reported on the use of analyzers in diagnosing and treating heat stroke in the Grand Canyon, and Hunt[20] provided an epidemiology of rock climbing injuries in Yosemite National Park.

The Epidemiologic Model and Haddon Matrix Framework

While each of the above papers points to visitor injuries as the untold story of visitor safety in U.S. National Parks, each paper offers only a description of visitor injuries and fails to adequately look at the etiology factors contributing to visitor injuries in national parks. Thus, designing intervention and injury prevention strategies based on these papers is challenging. Instead, the public health and injury prevention literature recommends employing a conceptual framework based on the Haddon matrix in order to gain a better understanding of the epidemiology and etiology of injuries.[21,22] Although never yet applied to a recreational setting such as a national park, the Haddon matrix is extensively used in injury research.[23] The two-dimensional matrix was first developed as a conceptual model for understanding the origins of injury problems by Dr. William Haddon Jr. in the late 1960s and early 1970s. Rather than using a causal approach focusing specifically on host or environment factors, the idea behind the matrix is to examine both the host and environmental factors.[24]

Haddon grounded this matrix on the foundation of the epidemiologic model which in turn is based on the core concepts of the agent, host, and environment.[21] Just like an infectious disease, Haddon theorized that injuries are the product of the interaction between the host, agent, and the environment.[21,23,25] Haddon defined the *host* as the person injured or the person at risk of being injured, the *environment* as the elements of the physical surroundings that contribute to the occurrence of injury, and the *agent* as injury-producing energy transferred to the host by either an inanimate vehicle or animate vector.[21] In describing the *agent*, Haddon built on the work of Gibson[26] who suggested that injuries result from the transfer of mechanical, thermal, radiant, chemical, or electrical energy to a human host. According to Haddon,[27,28,29] the transfer of energy to people at rates and in amounts above or below the tolerance of human tissue is the necessary and specific cause of injury. For example, a lack of normal energy exchange could result in asphyxiation whereas an energy exchange above normal levels could result in a burn or fractured bone.

In order to create an awareness of the factors contributing to injuries, the severity of the injuries, and the timing involved in those factors, Haddon devised a two-dimensional matrix consisting of three columns and three rows.[21] The rows in the matrix represent time phases (pre-injury, injury, and post-injury) and the columns represent the host, agent, and environmental factors that contribute to the injury process.[21] During the pre-injury phase, host, agent, and environmental factors contribute to the increase in exposure to potentially damaging energy.[21,24] During the injury event phase, an excessive amount or lack of energy is transferred to the individual resulting in injury.[21,24] The post-injury phase begins directly after the energy transfer and involves the nature and severity of the injury and the attempts made to restore the injured host to pre-injury functioning.[21,24]

The benefit of using the Haddon matrix is that it provides a framework for enhancing our understanding of the underlying causes of injury and the risk factors that lead to injury. By employing the Haddon framework, one can identify and analyze the risk factors and causal origins of injury and eventually develop injury prevention strategies at each phase in the matrix. Another benefit is that the Haddon matrix is an interdisciplinary framework and is applicable to any health problem in any discipline.[21] For example, the Haddon matrix has been applied to studies on violence,[30] forensic science,[22] public policy,[24] planning,[31] and geriatrics.[32]

Purpose of Study

As the popularity of recreating in outdoor and wilderness environments such as national parks increases, the possibility for participant injury also increases.[9] Thus, it is increasingly important to investigate and understand the health and safety problems these users encounter so that they can be prevented in the future.[8] In recent years, researchers have started moving away from purely descriptive studies and started asking questions about the frequency and severity of injuries and the role that contributing environmental and host factors play in injuries.[5] This direction is considered more useful because researchers have found that a large number of minor injuries such as minor scrapes, abrasions, and cuts occur in circumstances that are substantially different from those resulting in more severe injuries. Thus, studies simply reporting the frequency and rate of injuries will only serve to misdirect prevention resources from the most severe and costly injuries. As well, other studies have shown more success in reducing injuries and the severity of injuries by concentrating on reducing the transfer of energy that produces the most severe injuries.[5,31]

Within the national park system, the challenge of keeping park visitors safe is most acute in parks such as Hawaii Volcanoes National Park where visitors to the park participate in recreation activities that often result in serious injury and even death.[16] Thus, in order to improve the understanding of the factors contributing to visitor injuries in national parks and to help Hawaii Volcanoes National Park identify areas of the park needing injury control implementation to meet the visitor safety goals outlined in the 1997 NPS Strategic Plan, the purpose of this study is to: 1) identify the distribution of injuries in the national park, 2) assess the relationship between host (visitor) and environmental factors and the severity of injuries in the park, and 3) determine the effectiveness of injury control measures implemented by park management.

The following chapters will review related literature that is relevant to the study, describe the study site and outline the methodology to be used in the study, detail the results and findings of the study, and discuss the results and implications of the study.

CHAPTER II

LITERATURE REVIEW

The History and Development of Injury Research and Theory

Injuries have always been a health problem.[33] Nonetheless, the history and development of injury research has witnessed a number of conceptual shifts over the last two hundred years.[33,34] Prior to the industrial revolution, injuries were regarded as random *Acts of God* or the unfortunate luck of being in the wrong place at the wrong time and could only be prevented through prayer and human improvement.[4,35] However, with the onset of industrialization and the development of machinery in the 19th century, injury frequency increased to the point that injuries became an accepted part of life and the risk factors for injury became more discernable.[4]

The industrial revolution exposed growing numbers of industrial workers to dangerous working conditions.[33,35] However, during the early days of the revolution, no reliable injury surveillance system was in place to monitor worker injuries.[33,35] This began to change between July of 1906 and June of 1907 when a Pennsylvania survey known as the *Pittsburgh Survey* kept track of all industrial deaths in the greater Pittsburgh area. The results of the survey discovered that the area had over 500 occupational deaths during the year, an equal number of disabling injuries, and strongly suggested that human error was to blame for most injuries.[34,36]

The notion that injuries were the result of human error was supported by the temperance and prohibition movements in England and the United States. For instance, these movements gained the strong support of industrialists who saw error related to alcohol consumption as the primary cause of injury.[33] It was also supported and the *chain-of-command principle* employed in western military establishments.[33] Under this principle it was believed that people caused injuries when they failed to follow orders.[33] The blame placed on human error was further reinforced with the release of industrial records reporting that employee error was responsible for 90% of all injuries and that an *Act of God* was responsible for the other 10%.[33] For example, a study of 1,490 injuries by an electrical equipment manufacturer indicated that only 13 of the injuries were the fault of the manufacturer.[37]

As industrialization progressed, the establishment of worker compensation and worker protection movements in Europe and the United States in the early 1900s resulted in the creation of the Royal Society for the Prevention of Accidents in England in 1916 and the National Safety Council in the United States in 1913.[4] These organizations then sparked the first systematic injury research efforts between 1915-1930 in what is now called the *Investigational Era*.[33] During this era, research was largely sponsored by insurance companies and followed two major themes. The first theme suggested that safety was cost effective and the second theme suggested that injuries had psychological causes. As a result, during this era human behavior was often described as the cause of an injury and eventually became known as the psychological or *behaviorist approach*.[33] Moreover, this approach dominated injury and safety research for the following few decades because: 1) psychologists felt that injuries could be prevented, 2) psychologists indicated that education was the key to the prevention of injuries, and 3) human behavior and "blame the victim" theories promised years of research work and had wide-spread support in academic communities.[33] In addition, the automobile industry openly promoted human behavior as the cause of motor vehicle accidents and the general public largely subscribed to the *single event theory*.[34] That is, they assumed that an injury resulted from a single event with a single cause.[34]

Despite the dominance of the human behavior approach, by the mid-1930s enthusiasm for this approach diminished somewhat following the investigations of Greenwood and Woods[38] and Newbold[39] into injuries sustained by factory workers in England. These researchers found that only a small portion of the workers incurred the majority of injuries and proposed what is known as the *determinant variable theory*. A key point of this theory is that there are common factors present in all injury events and that by examining the available data and making comparisons, conditions such as age, experience, individual attitude, attentiveness, and other factors that influence injuries will be identified. As a result, they theorized that certain individuals are *accident-prone*.[33] A major problem with this theory, however, is that researchers had difficulty identifying personality-types fitting any accident-prone definition.[33]

Following the development of the human behavior and the accident-prone approaches, Heinrich developed the *domino theory* in 1936.[40] Also referred to as the *chain-of-events theory,* Heinrich suggested that injuries are the result of a set of *unsafe conditions* which if set up in a row of vulnerable dominos would start to topple at the onset of an unsafe act.[41]

Heinrich's theory eventually led to the development of the *linear chain-of-events theory* by Baker in 1963 which in turn has been utilized in reconstructing highway traffic accidents.[42] However, the first real departure from the single factor, human error, and human behavior orientation came from the work of DeHaven in his analysis of falls from height in 1942.[43] DeHaven was the sole survivor of a World War I plane crash and rather than asking why his plane had crashed, he questioned why he was the sole survivor. Subsequently, in his analysis of eight case studies involving falls from heights ranging from 50 to 150 ft, DeHaven calculated that the human body could tolerate a force of 200 X gravity for brief intervals if the distribution of the force was spread out over the long axis of the human body.[43] DeHaven was eventually able to apply his findings to injury prevention in aircraft and automobile accidents.[33,43] However, the strength of DeHaven's approach is that it explained the survivals of many mysterious falls by showing that injuries depend solely on crash energy.[33] In addition, he proved that the severity of injuries could be reduced if the crash energy is spread out over time and anatomic area.[33,43]

Contemporary Research and Theory

The work of DeHaven in identifying the role of energy in injury severity eventually played an influential role in the development of contemporary injury research and theory. However, the basis of contemporary injury research first began with a medical doctor named John Gordon at Harvard University in 1948.[44] In studying the distribution and causes of injuries, Gordon recognized that there were known patterns to injury and saw that the study of injuries had many similarities to the study of infectious disease.[34] As a result, in his injury research Gordon emphasized the interaction of the host, agent, and environment in the epidemiologic model.[44] However, Gordon's framework failed to identify the agents required by the epidemiologic model because he viewed the agent of injury as the object involved in the injury.[45] For example, Gordon was puzzled because the list of potential agents such as alcohol, cars, bicycles, and stairs seemed unlimited.[34]

The challenge of understanding the agent of injury was eventually resolved by the psychologist, James Gibson, in 1961 when he identified and delineated the specific agents of injury.[26,28] In his work, Gibson specifically discussed that injuries to living organisms can be produced only by some energy exchange.[26] Consequently, Gibson noted that the most effective way of classifying sources of injury is according to the forms of physical energy involved.[26]

William Haddon and the Haddon Matrix

In the early 1960s, a medical doctor by the name of William Haddon independently arrived at the same conclusions as Gibson after familiarizing himself with the work of DeHaven. A former student of John Gordon, Haddon suggested that all injury events are attributable to the transfer of mechanical, thermal, radiant, chemical, or electrical energy to a human host at rates and in amounts above or below the tolerance of human tissue.[46,47] Likewise, Haddon supported the views of Gordon that just like disease, the etiology of injuries could be understood by investigating the interaction between the host, agent, and environment in the epidemiologic model.[46,47] Haddon defined the *host* in the epidemiologic model as the person injured or the person at risk of being injured, the *environment* as the elements of the physical surroundings that contribute to the occurrence of injury, and the *agent* as injury-producing energy transferred to the host by either an inanimate vehicle or animate vector.[21]

In addition to refining the work of Gordon and Gibson, Haddon added a temporal sequence to injuries and devised a two-dimensional matrix that is now popularly known as the Haddon matrix.[23,28,46] Haddon's intent in developing his theory was to develop a conceptual framework that would foster an understanding of the factors contributing to injuries, the temporal nature of the factors contributing to the injuries, and the severity of the injuries.[46] As a result, Haddon's basic matrix consisted of three rows and three columns with the rows in the matrix representing Haddon's temporal phases (pre-injury, injury, and post-injury) and the columns representing the host, agent, and environmental factors that contribute to the injury process (Figure 1).

Figure 1. The Basic Haddon Matrix.

	Factors		
	Host	Agent	Environment
Pre-event			
Event			
Post-event			

During the pre-injury phase, the host, agent, and environmental factors interact and contribute to an increase in exposure to potentially damaging energy.[46] During the injury event phase, an excessive amount or lack of energy is transferred to the individual resulting in injury.[46] The post-injury phase begins directly after the energy transfer and involves the nature and severity of the injury and the attempts made to restore the injured host to pre-injury functioning.[46]

In developing his ideas about the matrix, Haddon's initial matrix was focused on highway injuries and crossed the different phases of a crash with columns depicting variables such as the driver, passengers, pedestrians, bicyclists, motorcyclists, vehicles, highways, and police. However, Haddon and other researchers later refined his matrix to the basic model and revised it to consider topics other than traffic crashes.[21] In fact, the Haddon matrix has become the most utilized theoretical framework in injury research and has been used to conceptualize etiologic factors for injury and to identify potential research strategies.[21,23]

The Public Health Impact of the Haddon Matrix

The development of the Haddon framework had two immediate effects on injury research. First, it resulted in a paradigm shift from only the behavioral approach to one employing a biomechanical and epidemiological approach.[33] This approach eventually led to the implementation of air bags, head constraints, padded dashboards, stronger bumpers, reinforced doors, and protected fuel tanks in cars.[33] Second, the framework created an interdisciplinary partnership between epidemiology and biomechanical engineering by providing a logical framework for physicians and engineers to apply physics to injury severity and prevention. This alone led to the development of better gloves, hard hats, and shoes for workers, injury reducing sports equipment, and injury reducing eyewear.[33] In addition, the development of the matrix provided an interdisciplinary framework that could be used to identify and understand the causes and results of injuries and a framework that is applicable to any health problem in any discipline.[21] For example, over the years the Haddon matrix has been applied to studies on violence, forensic science, planning, and geriatrics and has been augmented to include socio-political factors, a third dimension to aid in policy decisions, and a spectrum designed for injury prevention.[22,24,30-32,48,49]

The Haddon Model for Injury Prevention

One of the more intriguing supplements to the Haddon matrix was suggested by Haddon himself. In a 1973 paper discussing the theoretical foundations of energy transfer resulting in injuries and countermeasure strategies that could control or possibly prevent injuries, Haddon suggested 10 potential strategies for injury prevention.[50] These strategies are detailed in Table 1.

The countermeasure strategies suggested by Haddon place a strong emphasis on the reduction of environmental hazards by reducing the transfer of energy.[50] However, it is important to note that Haddon only intended these strategies to be an aid in thinking about injury prevention strategies and a starting point for the development of other prevention strategies.[50] A discussion of other injury control and prevention strategies will follow later in this literature review

Table 1. Ten countermeasure strategies for reducing injuries.

1. Prevent the marshalling or creation of the form of energy hazard in the first place. For example, prevent the accumulation of snow where avalanches are possible and the build-up of hurricanes, tornadoes, or tectonic stresses.

2. Reduce the amount of energy being marshaled. For example, reduce the speed of vehicles or the height of divers above swimming pools.

3. Prevent the release of the energy. For example, prevent the descent of skiers or the undermining of cliffs.

4. Modify the rate of spatial distribution of release of the energy from its source. For example, reduce the slope of ski trails.

5. Separate the energy being released from the susceptible host by space and time. For example, evacuate hosts from hazardous areas, use lightning rods, and place electrical powerlines out of reach.

6. Separate the energy hazard from the host using a physical barrier. For example, wear the proper footwear, helmets, or safety glasses.

7. Modify the contact surface, subsurface, or basic structure. For example, improve automobile design and the design of walkway surfaces.

8. Strengthen the structure, living or non-living, that might otherwise be damaged by the energy transfer. For example, improve physical fitness and enforce better codes for earthquake, fire, and hurricane resistance.

9. Move rapidly to detect and evaluate the damage that has occurred or is occurring and counter its continuation and extension. For example, provide emergency medical care and emergency transportation.

10. Stabilize, repair, and rehabilitate the damaged host. This encompasses all the measures between the emergency period following the damaging energy transfer and the final stabilization. For example, stabilizing structurally or functionally altered states.

Individual Host Factors in the Haddon Matrix

Individual host characteristics such as age, gender, ethnicity, nationality, socioeconomic class, behavior, and experience have typically been reported as contributing individual factors to injury. For example, in a major study describing the epidemiology of injury in the Australian State of Victoria, males were calculated as 1.7 times more likely than females to sustain non-fatal injuries and accounted for 73% of 1,487 injury deaths and 62% of 466,000 total injuries.[6] The same study found that adults aged 25-44 years represented 31% of the population in Victoria and account for 29% of all injuries. Youth aged 15-24 comprise 16% of the Victorian population but accounted for 22% of all injuries, 20% of injury fatalities and hospitalizations, and 23% on non-hospitalized injuries.[6] Moreover, children under the age of 15 comprise 21% of the Victorian population but account for 30% of the total injured population. The highest risk of injury death and hospitalization was found in elderly populations 75 years of age and older despite comprising less than 5% of the Victorian population.[6]

When compared to the study in Victoria, research investigating injury mortality and morbidity in New Zealand and injuries documented in the U.S. State of Vermont show comparable results. For example, the New Zealand study found that males have the highest injury death and hospitalization rates with males aged 20-24 having the highest rate of injury deaths.[7] However, the same study found that after age 70, the risk of injury hospitalization was higher for females than males and that those least at risk were females in the 35-39 and 40-44 age categories.[7] Likewise, the study of 3,059 people from 22 communities in Vermont found males to have higher injury rates than females in all age categories except for individuals 60 years or older.[51]

Individual Host Factors in Recreational Injuries

It is interesting point made in each of the Victoria, New Zealand, and Vermont studies is that leisure and recreation injuries rank second behind home injuries in most age and gender categories. However, literature focusing specifically on recreation injuries is more ambiguous. For example, in a study of recreation tourism injuries among foreign visitors to New Zealand, Bentley found that men had a higher rate of injury than women in all age categories below 50 years of age and women had a significantly higher rate of injury than men above the age of 50.[52] In another study investigating gender differences and injury and illness rates on wilderness backpacking trips, females experienced a significantly higher rate of injury than males.[53] Likewise, a study of emergency medical care at Uluru (Ayers Rock) in Australia found the male to female injury ratio to be 7:5, a study of morbidity and mortality in seven national parks in California found males to account for only 52% of 1,769 non-fatal injuries but 61 of a total 78 injury deaths, and a five-year study of wilderness injuries among National Outdoor Leadership School participants in Alaska, British Columbia, and Chile found women to have higher injury and illness rates than men.[17,54,55]

In other research investigating individual host characteristics that could lead to injuries in recreation settings, visitors to Mt. Rainier National Park with higher levels of education were found more likely to comply with trailside signs whereas factors such as age, gender, socioeconomic status, and occupation were unrelated to levels of compliance.[56] Moreover, in other research completed in national parks, prior experience has been identified in improving the overall level of preparation of wilderness hikers leading to a reduction in injuries in Yosemite National park, inexperience was found to be a major contributing factor in climbing injuries in Teton National Park, and inexperience lead to a high rate of hiking injuries in Hawaii

Volcanoes National Park.[16,18,57] In fact, prior research in Hawaii Volcanoes National Park suggests that the overall lack of experience increased the willingness of over 90% of hikers to ignore warning signs and enter areas of the park considered extremely dangerous.[16]

A various number of explanations have been proposed for injury occurrence in recreation settings. For example, in one study investigating the etiology of injuries between men and women, it has been suggested that females may incur more injuries than males because they have a wider pelvis and Q angle at the knee, and are suspected of having increased ligament and joint laxity.[58] In addition, when compared to males in a second study, a lower level of physical fitness, less upper body strength, flexibility, and overall physical qualities have been used in explaining higher injuries in women.[59] Other studies have suggested that younger males are more likely to participate in recreation activities with high injury potential and that some individuals will have relaxed attitudes and alter their behavior when participating in recreational activities.[41,60]

Agent Energy Factors in the Haddon Matrix

Injuries result from the acute exposure to energy and the transfer of energy to a human host.[3,31] Injury may also be caused by the sudden absence of essentials such as heat and oxygen.[3] Therefore, the transfer of energy at rates and in amounts above or below the tolerance of human tissue is considered the final step leading to injury.[31] The five agents of energy defined by Haddon in 1964 and Gibson in 1961 are: 1) mechanical, 2) chemical energy, 3) radiant energy, 4) thermal energy, and 5) electrical energy.[26,45] In explaining mechanical energy, Gibson noted that the transfer of mechanical energy originates from physical events such as an impact, breakage, shear, and flow.[26] For example, injuries associated with motor vehicle accidents, plane crashes, falls from a cliff, steep slope, or standing position, and injuries resulting from being caught in an avalanche or struck by a falling object such as a rock are examples of mechanical energy transfer.[26,45] Likewise, sunburns and heat exhaustion are an example of radiant energy transfer, lightning strikes and electrocution are examples of electrical energy transfer, burns from fires, steam, and hot water are examples of thermal energy transfer, and insect stings and contact with toxic plants and animals such as poison ivy, centipedes, and jellyfish are examples of chemical energy transfer.[26,45]

Recreation Activities and Energy Transfer

Examples of the types of activities and energy transfer leading to injury can be found throughout the recreation and medical literature. For instance, the transfer of mechanical energy due to motor vehicle accidents has been identified as the second leading cause of death and the leading cause of serious injury among tourist populations in foreign countries.[61-67] In addition, injuries resulting from mechanical energy transfer involving snowmobiles, personal water craft, mopeds, and snow skis are increasingly common.[68-71] Although not organized in a manner using the Haddon or any other organizational framework, three studies reporting visitor morbidity and mortality in eight national parks units in California, adventure recreation injuries and fatalities involving overseas visitors in New Zealand, and the death of overseas visitors in Australia provide examples of the role energy transfer plays in recreational injuries and fatalities.[17,69,72] Again, it is important to note that these studies do not follow the Haddon framework, do not specifically recognize injuries as the result of energy transfer, and are examples of the endless list of potential agents that troubled John

Gordon.

The first study published in 1998 reports visitor injuries and fatalities in Lassen Volcanic National Park, the Channel Islands National Park, Point Reyes National Seashore, Redwood National Park, Santa Monica Mountains National Recreation Area, Sequoia and Kings Canyon National Parks, Whiskeytown - Shasta - Trinity National Recreation Area, and Yosemite National Park.[17] The findings of this study provides examples of the activities and injuries associated with thermal energy transfer (burn), chemical energy transfer (anaphylaxis-insect, volcanic fumes), radiant energy transfer (sunburn), mechanical energy transfer (avalanche, falls, motor vehicle accidents, airplane crash, boating), and energy transfer below the tolerance of human tissue (hypothermia, swimming / drowning).[17] Furthermore, the study found that the transfer of mechanical energy while hiking, driving, flying, climbing, skiing, snowboarding, horseback riding, biking, and sledding along with the lack of energy transfer while swimming and diving results in many visitor injuries and illnesses.[17]

In contrast to the national park unit study in California, the second study investigating adventure recreation injuries to overseas visitors in New Zealand was based primarily on public hospital discharge data for non-New Zealand residents.[69] The results of this study identified the predominance of mechanical energy transfer leading to injuries and fatalities. For example, reported falls while skiing or hiking, injuries involved with watercraft, bikes, and striking another object or person are examples of mechanical energy transfer. Moreover, fatalities that were classified under excessive hot / cold categories are examples of radiant energy exchange or the lack of energy exchange below the limits of human tolerance.[69] In the study of overseas fatalities in Australia, the transfer of mechanical energy in falls, land, and air transportation incidents, the transfer of chemical energy in poisoning incidents, and the lack of energy transfer in drowning incidents were frequently identified as the types of energy transfer resulting in fatalities.

Environmental Factors

Haddon described the environment in his matrix as the elements of the physical surroundings that contribute to the occurrence of potentially injury-producing events.[21] Likewise, Haddon recognized that the nature of the energy exchange resulting in injury is connected to the environment in which they occur. Thus, the potential for energy transfer exists in just about every environment but certain environmental characteristics increase the potential for energy exchange.[31] In 1996, Parks Canada identified the presence of topographic, geologic, hydrological, meteorological, floral and faunal, insect, parasitical, and disease hazards in Canadian national parks as potential sources of energy hazards.[73] In addition, Parks Canada recognized the man-made or built environment as part of the physical environment present in national parks and listed roads, buildings, trails, and other structural hazards as potential sources of energy in national parks.[73]

Topography and the Natural Environment

It is widely felt that as visitation to national parks increases and more people are exposed to the various environments found in national parks, the number of visitor injuries will also increase.[74] In a discussion about the presence of geographical and topographical hazards found in national parks and other rural recreation areas, Waller and Brink[75] and Dingwall, Fitzharris, and Owens[13] noted that the spectacular rugged landscapes and other geographic features that attract visitors to national parks may be precisely the features that make parks more hazardous and place visitors at higher degrees of risk. For example, the mountainous environment of Mt. Cook National Park, Mt. Aspiring National Park, Tongariro National Park, Arthur's Pass National Park, and Fiordland National Park in New Zealand were the location of at least 725 visitor deaths between 1885 - 1985.[76-77] Choosing to recreate in a mountainous environment can be challenging to both domestic and international visitors but the activity associated with the injury and eventual fatality varies between domestic and international visitors.[76,77] For instance, research into the deaths of international visitors in these national parks found that most of the international fatalities are to visitors from Australia, Canada, the United States, and the United Kingdom, and result from falls while mountain climbing.[77] In contrast, the majority of domestic fatalities were the result of falls and hunting accidents.[76]

Natural Hazards in the Natural Environment

In addition to the mountain environment, avalanches, landslides, flooding, mudflows, and volcanic activity have been a source of injury and death in parks in the United States, Canada, and New Zealand.[13,76,77] However, the risk posed by volcanic eruptions, floods, wildfires, thunderstorms, and hurricanes is an environmental factor that is often overlooked by visitors to national parks.[78] For example, there are twenty-one national park units within the U.S. National Park Service system with volcanic resources.[79] Some of the often unrecognized threats to visitors in parks with active volcanic activity are gases which can be a product of every eruptive phase.[80] Gases may also be emitted during periods of inactivity and gases such as carbon dioxide have been attributed to the deaths of mountain climbers and skiers on the near the slopes of Kusatsushirane volcano.[80] Although mostly composed of steam, large amounts of toxic sulfur dioxide, hydrogen sulfide, and smaller amounts of toxic hydrochloric and hydrofluoric acid gases are also present in volcanic areas.[80]

Disease, Insects, and Wildlife in the Natural Environment

When compared to the geographic factors found in national parks, visitor injuries and fatalities resulting from the interaction of people and wildlife receive considerable more attention in the media.[81] For instance, bear attacks on visitors in Yellowstone and Glacier National Parks and attacks by lions and other mammals in South African parks are typically popularized in the media.[81] The reality of this, however, is that there are relatively few injuries and fatalities resulting from animal attacks in national parks around the world.[81-84] In fact, two areas beginning to receive considerable more attention are injuries associated with insect stings and those associated with viral, bacterial, and parasitic contamination.

Conditions in backcountry and other wilderness environments present in national parks can often mimic those in the developing world in terms of contaminated water sources.[85] A recent study of backpackers on the Appalachian Trail found that 56% of the participants suffered gastrointestinal illnesses as a result of drinking untreated surface water.[85] Such exposure to viral, bacterial, and parasitic hazards is increasingly common to visitors in national parks and are commonly related to food, contact with small mammals, and water sources used for drinking or recreation.[86-89] Other pathogens such as giardia and cryptosporidium have been found in water resources in national parks and the hantavirus resulting from contact with small mammals or their infected feces or saliva has been identified as a health risk in national parks.[90,91]

In a similar fashion to diseases, exposure to insect stings are increasingly common in national parks with venomous insects such as wasps, bees, and centipedes causing the most severe problems.[92-93] Stings by wasps and bees are most commonly inflicted on the head and neck, feet, legs, hands, and arms. In addition, insect stings may cause vomiting, diarrhea, generalized edema, and hypotension.[92] Stings by centipedes produce burning pain, localized edema, and localized necrosis.[92] The most serious aspect of these stings is the possibility of the host victim going into anaphylactic shock.[94] However, it is estimated that only between 0.4% - 4% of the U.S. population have this degree of allergy to insect venoms.[94]

The Built Environment

The built or man-made environment is the part of the physical environment made by people for people.[32] It encompasses all of the spaces and products that are created or modified by people including buildings, transportation systems, and parks.[32] In a national park setting, this environment consists of visitor centers, restrooms, museums, hotels, picnic shelters, transportation systems such as roadways and parking areas, and trails maintained by the parks and used for hiking and walking.[95,96]

The U.S. National Park Service presently administers over an estimated 13,500 km of public roads ranging from well-developed road systems to parkways, highways, and unpaved roads. Beginning in the 1950s, expanding leisure time and the improvement of interstate highways brought increasing numbers of motor tourists into national parks. These motorized tourists demanded more roads and similar services to accommodate their desire for access to scenic and historic features.[97] However, over the years, the demands made by park visitors eventually overwhelmed the existing infrastructure in many national parks.[97] As a result, the national park service launched a ten-year program known as Mission 66 which was designed to upgrade national park facilities and roadways.[97] Much of this plan was developed because national parks recognized they could not meet the demands of increasing visitation and that the conditions of their roadways, trails, and other structures play a role in visitor safety.[97]

Motor vehicle accidents are the leading cause of death in national parks and the leading cause of death and serious injury among American tourists recreating in Mexico, Australians pursuing recreational interests outside of Australia, international visitors pursuing leisure activity in Greece, and tourists visiting recreation destinations in New Zealand.[61,63,64,66,67] Some roadway research contrasting motor vehicle accidents in urban and rural settings has stressed the role proper road design and signage play in increasing safety on public lands yet other studies have pointed in the human factors direction and the idea that visitors to national parks and other recreation destinations drive unfamiliar rental vehicles in areas where they face unfamiliar roads and traffic rules.[75, 98-100] The latter findings may be related to the fact that many visitors in national parks face an increased risk to motor vehicle accidents because they tend to spend more time in their cars in areas where they face unfamiliar conditions.[66,100] As well, factors such as the transition to driving on the opposite side of the road than one is accustomed, fatigue, alcohol and speed, international or domestic status, exterior distractions such as scenery, and gender have been used to explain motor vehicles accidents in national parks and recreation destinations.[63,64,101,102]

Another area of the built environment that is becoming a safety concern for national parks is trail safety. Increasing visitation to national parks is making it difficult to ensure safe trail conditions.[103] In fact, approximately 20% of all visitor injuries in national parks between 1993-1998 occurred while visitors were walking on trails and other walkways such as sidewalks. Many national parks recognize that trails form an important part of many visitor activities in such as hiking, biking, and horse riding and recognize that the material used to construct a trail, the gradient, width, degree of drainage and erosion control, the degree of difficulty, and the presence of side slopes, steps, warning signs, and handrails play a role in preventing visitor injuries.[103-104]

The Nature and Severity of Injuries

The identification of injuries is the first step in understanding factors contributing to injuries.[105] Over the years, many injury studies have reported the frequency, percentage, rate, and type of injury by age, gender, and ethnicity.[106] A national study of injuries in the United States performed by Chamblee[107] and others at the National Center for Health Statistics in 1983 reported that: 1) twenty-seven percent of males suffered intracranial injuries whereas only 17% of females suffered the same injury, 2) males have a higher rate of internal injuries, lacerations and open wounds than females but females sustain higher rates of fractures to their lower limbs than males, 3) Caucasians have higher percentages of fractures than any other race, 4) African Americans have a higher percentage of lacerations and open wounds, burns, internal injuries and injuries resulting from a foreign body entering through an orifice, 5) Caucasian females have higher rates of fractures to their lower limbs but a lower percentage of lacerations and open wounds than any other gender and ethnic group, 6) African American females have the highest rate of burn injuries, 7) fractures are the most frequent injury for those over the age of 65, and 8) intracranial injuries were more frequent in those aged 10-44 years. More recent national injury figures reported by the National Center for Injury Prevention and Control[108] in their 2001-2002 Injury Fact Book reports that: 1) males account for 80% of all drownings, 2) males older than 65 years are 22% more likely to die from falls than females and suffer twice the number of injuries in motor vehicle accidents than females, 3) females in the same age category are three times more likely to be hospitalized for hip fractures than males, 4) African

Americans have a higher rate of spinal cord injuries than Caucasians, 5) the drowning rate for African Americans is 1.6 times higher than for Caucasians, 6) the rate of drowning is 2.5 times higher for African American children between 5-9 years old than for Caucasian children, 7) the pedestrian injury and fatality rate for Hispanics is 1.77 times higher than Caucasians, 8) the pedestrian injury and fatality rate for African Americans is twice that of Caucasians, 9) the injury and fatality rate for American Indians (including Alaska Natives) is three times that of Caucasians, 10) American Indians have a higher risk of sustaining burn injuries in residential fires than any other ethnic group, and 11) motor vehicle injuries are the leading cause of death for infants and children between the ages 1-14.

In contrast to the national studies, the study of the eight national park units in California indicates that lower extremity injuries to the ankle and knee, lower back sprains, soft tissue injuries to the hands, face, and feet, and fractures and dislocations to the hands, ankles, and shoulders are the most frequent injuries.[55] In addition, ankles, knees, hands, facial, and the lower back are the anatomical regions with the highest number of injuries. Injuries to lower limbs accounted for 38.3% of 1,398 injuries followed by head and neck injuries (26.6%), upper limb injuries (27.1%), and injuries to the torso (7%).[55]

The reason many injury studies have concentrated on reporting the frequency, percentage, rate, and type of injury by age, gender, and ethnicity categories is because most studies are dependent on data classified as either N-codes or E-codes.[5] N-codes are diagnosis codes reporting the type and anatomical location of injuries and are usually coded from hospital records.[5] E-codes are information found on death certificates that report a broad category of circumstances such as a motor vehicle crash, a fall, or an assault as the cause of death. For example, code E966 would report an assault by cutting and piercing instruments and code N820 would report a fall resulting in a hip fracture.[107] A problem in using N-codes and E-codes, however, is that they often do not provide any information about how an injury occurred.[5] For instance, an N-code reporting a fracture often does not report if the injury was sustained in a motor vehicle accident or a fall and where the injury occurred.

Studies such as those reporting the frequency and nature of injury by age, gender, and ethnicity based on medical records and other sources reporting N=codes and E-Codes have been criticized for their lack of insight into the injury process.[5] For example, some studies have shown more success in reducing injuries and the severity of injuries by concentrating on reducing the transfer of energy rather than using age to determine differential risk factors to target injury reduction efforts.[5] As a result, it has been suggested that the most useful injury studies are those asking questions about the severity and nature of injuries as they relate to individual and environmental factors and the type of the energy transfer.[5,31] A large number of minor injuries such as minor scrapes, abrasions, and cuts occur in circumstances that are substantially different from those resulting in more severe injuries. Thus, from an injury prevention perspective, studies reporting the frequency and rate of injuries will only serve to misdirect resources from the most severe and injuries whereas studies asking questions about the who, when, where, how, and severity will help researchers and managers apply countermeasures more efficiently.[3,5,31,106]

Measuring Severity

Specifying the severity of an injury is an important element when utilizing the findings of injury research for injury prevention and control.[5] The development of injury severity scoring systems has changed with time depending on the needs of researchers and clinicians and been based on a wide variety of clinical signs and symptoms to an injured host such as blood pressure, heart rate, consciousness, respiration rate, the number of damaged organs, the injured part of the anatomy, and whether or not there is a need to be transported to a medical center.[5,109] For example, the earliest effort at developing an injury scoring system is generally credited to the *Abbreviated Injury Scale* (AIS) which was developed to categorize the nature and severity of an injury sustained in motor vehicle crashes.[109] Other scoring systems that have evolved from the AIS scale are the *Glasgow Coma Scale* (GCS) which is used in categorizing the severity of traumatic brain injury, and the *Trauma Score* (TS) which is widely used by emergency medical personnel for triage and an initial evaluation by physicians.[110-112]

Injury researchers use severity scores to: 1) establish minimal criteria used in the surveillance of injuries, 2) measure the effects of energy and other factors on injury severity including the effects of attempts at injury control, and 3) estimate injury effects on mortality, disability, and economic costs.[113] As a result, the *Abbreviated Injury Scale* (AIS) is the most used scale in injury research.[5] This scale uses a numerical method for categorizing injuries by severity. An AIS score of 0 would represent no injury, an AIS score of 1 would represent a minor injury such as superficial abrasions or lacerations, first-degree burns, minor sprains, and head trauma accompanied by a headache or dizziness but no other neurological signs.[5] These injuries are treatable on-site and require little medical attention and no transportation to a medical center. An AIS score of 2 represents moderate injuries such as major abrasions or lacerations, a crushed finger or toe, and unconsciousness for less than 15 minutes.[5] Further medical attention to these injuries is recommended but does not necessarily require emergency transportation. An AIS score of 3 represents serious injuries such as a major nerve laceration, multiple fractures, organ contusions, and broken arm, hand, or feet and require further medical attention.[5] An AIS score of 4 or 5 represents severe and critical injuries such as a ruptured spleen, crushed bones, unconsciousness less than 24 hours (severe), unconsciousness more than 24 hours (critical), spinal cord transections, deep lacerations to inner organs, and extensive second or third degree burns.[5] These injuries require further medical attention and emergency transport. Finally, an AIS score of 6 represents a fatal condition.[5]

Injury Control and Prevention

The ultimate goal of injury research is to identify and understand the factors contributing to an injury in order to develop effective prevention strategies.[114] However, the development of research prevention strategies did not begin until injuries were understood to be predictable and preventable.[115] Research has shown that injuries have been reduced through the control of energy, the vehicles or vectors that transfer energy to the host, and the characteristics of environments that contribute to the concentration of energy.[5] This understanding has led to the development of three fundamental injury prevention strategies.[115] These strategies are: 1) persuade persons at risk to change their behavior, 2) require behavior change by law or administrative rule, and 3) provide automatic protection through product and environmental design.

It is postulated by some injury researchers that while each of the above strategies plays a role in any comprehensive injury-control program, the second strategy requiring behavior change will be more effective than persuading individuals at risk to change their behavior and the third strategy of providing automatic protection will be the most effective.[115,116] For example, while embarking on large-scale public education campaigns has been effective in instances such as reducing home burn injuries to children in Chinese, Vietnamese, and Arabic speaking communities in Australia, the results of other studies such as driver education programs have shown conflicting results.[115-121] Nevertheless, despite the conflicting results of public education strategies, public education campaigns combined with changes required by law have proven successful and strategies focusing on product and environmental design have been the most successful.[116,122] The success of bicycle safety standards in reducing biking injuries within the United States and United Kingdom, the success of child-resistant medicine bottle caps in the United States and Sweden, the success of workplace safety regulations such as speed limits and installing handrails in reducing the overall rate of injury in locations regularly inspected by the U.S. Occupational Safety and Health Administration, and the success of Finnish loggers being required to wear protective safety equipment such as helmets, gloves, and eye protectors are all examples of these strategies.[123-127]

Following the development of the Haddon matrix, much of the early injury prevention success occurred in public environments such as the workplace and road environment and were the result of prevention strategies focused on engineering solutions and legislative changes.[122] However, the same level of success was not experienced in other areas that were less easy to regulate and less influenced by engineering.[122] This finding led Cohen and Swift[128] to develop what is known as a *spectrum of prevention* strategy. This strategy recommends developing injury prevention programs centered around: 1) strengthening individual knowledge and skills, 2) promoting community education, 3) educating providers, 4) fostering coalitions and networks, 5) changing organizational practices, and 6) influencing policy and legislation.

Strengthening Individual Knowledge and Skills

Strategies for strengthening individual knowledge and skills involves transferring information and know-how to increase an individual's resources and capacity of preventing injury or disease.[128] Examples of such strategies range from physicians giving travel health or household safety information during check up exams to sales personnel promoting safety equipment and *designated driver* peer programs.[128] In a national park setting, example strategies strengthening individual knowledge and skills include posting safety signs and uniformed personnel delivering safety messages to park visitors at the park entrance, trailhead, and visitor center.[78,102]

Promoting Community Education

A community education approach aims to reach groups of people with information and resources about improving health.[128] A strategy that is increasingly used in community education involves the use of mass media to deliver a message to a community rather than an individual.[128] Mass media campaigns have been shown to increase awareness, alert a community to new information, build mass support, and change attitudes.[129]

Educating Providers

Educating providers stresses the value of educating health, recreation, or other professional providers about injury prevention so they in turn can influence overall health and safety.[128] Such efforts have been employed with adventure recreation providers in New Zealand where adventure recreation activities is a fast growing sector of the tourism industry.[69,130] However, this strategy is showing mixed results due to a high employee turnover and a lack of government regulation.[69,130]

Fostering Coalitions and Networks

The aim of fostering collaborative approaches is to bring together the participants necessary to assure the success of an injury prevention initiative.[128] Coalitions and expanded networks such as the National Funding Collaborative have worked together to conserve resources that may be squandered through needless competition and develop a program awarding injury prevention grants across the United States.[131] In national park and other wilderness areas, collaborative efforts with gateway communities plays a significant role in injury prevention and emergency response.[75] For example, different groups in these communities can collaborate together to improve road safety, restrict the sale of alcoholic beverages, prohibit the consumption of alcohol within the park or recreation area, and improve emergency medical responses.[75]

Changing Organizational Practices

Examining the practices of organizations such as the National Park Service, health departments, law enforcement agencies, and even schools has the potential to prevent injuries.[128] For example, after the passage of United States regulations that raised the minimum drinking age to 21, new law enforcement procedures such as sobriety checkpoints have been credited with saving an estimated 15,667 lives between 1975 and 1995.[132] Likewise, hiring crossing guards at schools is also credited with reducing child pedestrian injuries.[128] Unfortunately, this is usually the least understood and more frequently ignored component of the spectrum.[128]

Influencing Policy and Legislation

Prevention strategies in this category involve changes to local, state, and national laws and in some cases, better enforcement or a change in policy toward laws that already exist.[128] For example, parent groups concerned with playground safety across the United States have proposed legislation to upgrade unsafe playground surfaces that cause injuries when children fall.[128] Moreover, a study of California's 1992 mandatory helmet laws for motorcycles and bikes indicates that the law has significantly reduced the number of serious and fatal head injuries.[133]

Strategies to Reduce Injuries in the Pre-Event, Event, and Post-Event Stage

Interventions in Haddon's pre-event phase aim to prevent the transfer of energy to the host. Prevention strategies in this phase can often be very effective because they protect the host from energy exposure and do not depend on host resilience or other factors that can increase the potential for injury.[31] For example, changes in the road environment such as adding skid-resistant surfaces to reduce the loss of traction, changing two-lane roadways into divided highways to avoid head-on collisions, grading curves and ditches to reduce the risk of cars running off the road and rolling over, and installing breakaway lighting poles have proven successful at reducing the frequency and severity of injuries.[31,134] As well, these strategies have also been utilized in the planning and design of Yellowstone National Park.[97] Other pre-event strategies that have proven successful include the modification of work environments by installing lighting, monitoring systems, bulletproof barriers, and access controls to prevent violence and crime, the use of fences and other barriers to separate pedestrians from traffic and children from driveways, and the use of speed bumps, roundabouts, and street closures to calm traffic.[31,135,136]

In the event phase, prevention strategies aim to reduce the amount of energy transferred to the host during the energy transfer process in order to reduce the severity of the injury. Although energy transfers resulting in an injury tend to happen quite rapidly, some effective strategies to reduce the amount of energy transferred to the host have been developed.[31] For example, the installation of smoke detectors in American homes has cut the risk of dying in a home fire by 40%, wrapping oneself in an aluminized fire shelter or flame-resistant clothing has been shown to reduce injury severity when escape from a wildland fire is impossible, and attempting to swim with or move to the side of an avalanche where forces and speeds are less has been shown to reduce the frequency of fatalities and the severity of injuries once the snow begins to move below an individual.[137-139]

Compared to the pre-event and event phases, post-event strategies are part of a cycle in which knowledge from an injury event is applied to reduce the consequences of a similar event in the future.[31] This ultimately requires aim to reduce the consequences of an injury event after the energy transfer has occurred. This objective can be accomplished a number of ways such as reducing the time between the injury event and the time an individual receives medical treatment, implementing rehabilitation programs to reduce physical impairment or disability, or providing services to reduce post-event trauma.[31,140] Moreover, the development and placement of trained medical personnel in wilderness field centers and the development of backcountry and mountain rescue teams with trained wilderness emergency medical technicians has proven successful in reducing the severity of wilderness injuries.[134,140]

CHAPTER III

STUDY SITE, RESEARCH QUESTIONS, AND METHODS

Applying the Haddon Matrix Framework to National Parks

The Haddon matrix highlights the diversity of factors that can lead to injuries or contribute to their severity. However, in order to apply the Haddon framework to a recreational setting such as a national park, it is important to view the Haddon matrix within a recreational activity system. For example, within this system individual host factors would consist of demographic and cultural characteristics, visitor actions and behaviors while visiting the park, and the degree of visitor preparedness. Likewise, environmental factors in a recreational activity system would consist of both natural conditions (wildlife, plant, insect, topography and terrain, existence of natural hazards such as fire) and built conditions (trails, roadway, parking areas, buildings and structures such as visitor centers and museums) present in a park. As was previously mentioned, the type of energy transfer in this system would depend on the type of activity the visitor participates in and/or the type of energy to which they are exposed during the activity. Injuries sustained from falls, slips, or trips while hiking or walking would be considered a mechanical energy transfer, exposure to fire would be a form of thermal energy transfer, insect stings from centipedes would be a form of chemical energy, exposure to natural fumes and gases would be a form of chemical energy transfer, and exposure to the sun resulting in sunburns or dehydration would be a form of radiative energy transfer.

Research Goals:

The research goals for this dissertation are to:

1) Identify the distribution of visitor injuries in Hawaii Volcanoes National Park from 1993-2002.

2) Assess the relationship between contributing environmental and visitor factors and the severity of visitor injuries in the park.

3) Determine the efficacy of indirect supervision and signs on the frequency and severity of visitor injuries.

Research Questions

1. What are the differences in the frequency, severity, and distribution of visitor injuries in Hawaii Volcanoes National Park from 1993-2002?

   Hypothesis 1a: The frequency of injuries will be higher in frontcountry destinations.

   Hypothesis 1b: Severe injuries will be more frequent in backcountry destinations.

2. What is the relationship between visitor factors and the severity of visitor injuries in Hawaii Volcanoes National Park?

   Hypothesis 2a: Injury severity will be higher for male visitors.

   Hypothesis 2b: Injury severity will be higher for visitors older than 50 years.

   Hypothesis 2c: Injury severity will be higher for visitors wearing minimal footwear.

   Hypothesis 2d: Injury severity will be higher for visitors entering restricted areas.

3. What is the relationship between environmental factors and the severity of visitor injuries in Hawaii Volcanoes National Park?

Hypothesis 3a: Injury severity will be less in the built environment.

Hypothesis 3b: Injury severity will be higher during minimal daylight conditions (darkness).

4. What is the effect of sign placement and indirect supervision on the severity of injuries?

Hypothesis 4a: Injury frequency and severity will be reduced in locations with signs and indirect supervision.

Study Site

Established as the 13th U.S. National Park on August 1, 1916, Hawaii Volcanoes National Park encompasses 330,000 acres of land on the Island of Hawaii (Figures 2-4). In 1980, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) named Hawaii Volcanoes National Park an International Biosphere Reserve. In 1982 the park was designated as a World Heritage Site. Over 50 percent of the park is classified as backcountry with terrain altering between volcanic, desert, and rainforest landscapes and extending from sea level up to the summit of Mauna Loa Volcano at 4168 m in elevation. The present eruption phase in the park releases between 1000 and 2500 tons of sulfur dioxide gas per day and has prompted the National Park Service to install an air quality monitoring system.[141,142] The infrastructure of Hawaii Volcanoes National Park consists of an entrance station, Kilauea Visitor Center, Jaggar Museum, Hawaii Volcanoes Observatory Geologic

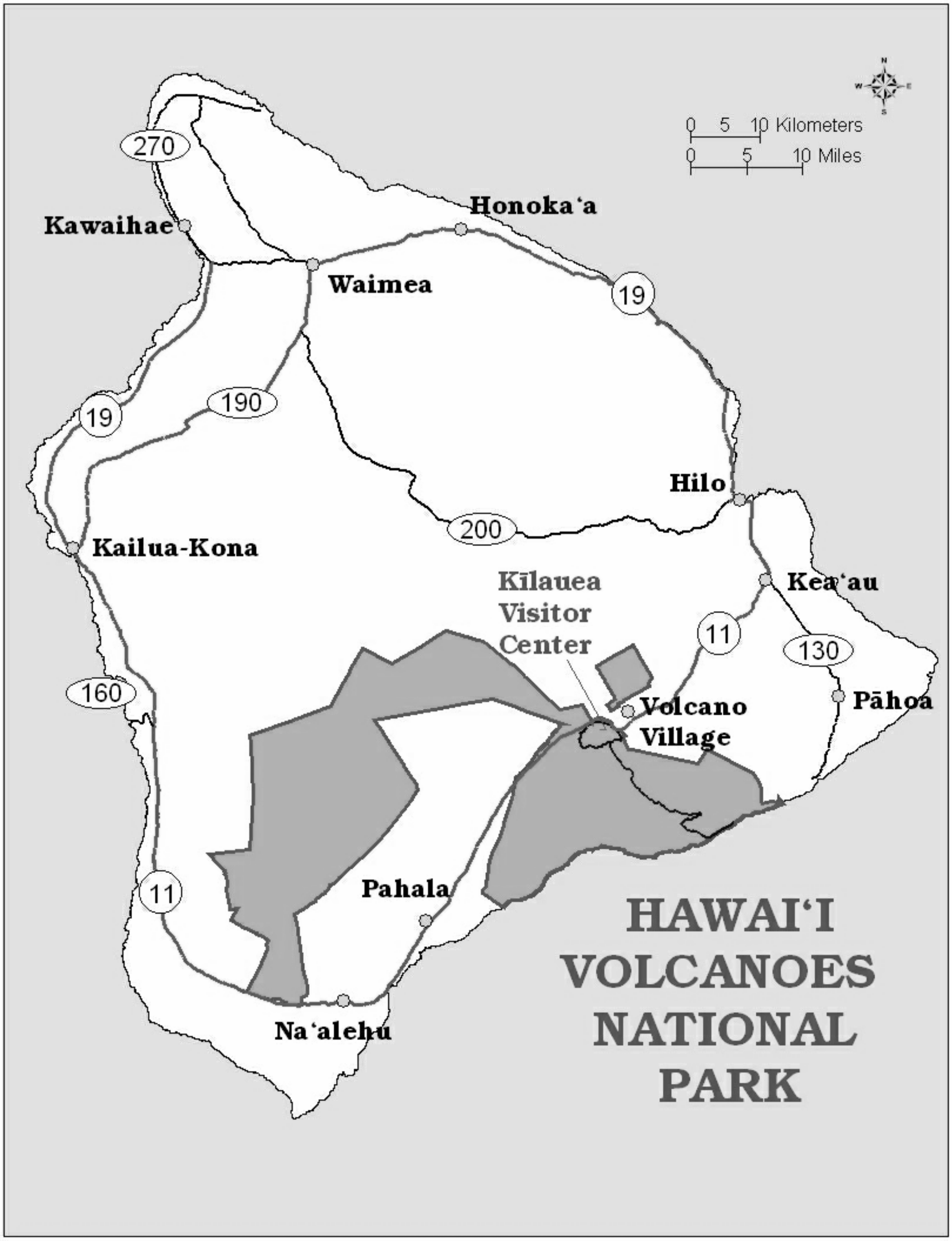

Figure 2. Location of Hawaii Volcanoes National Park on the Island of Hawaii.

Figure 3. Frontcountry region of Hawaii Volcanoes National Park.

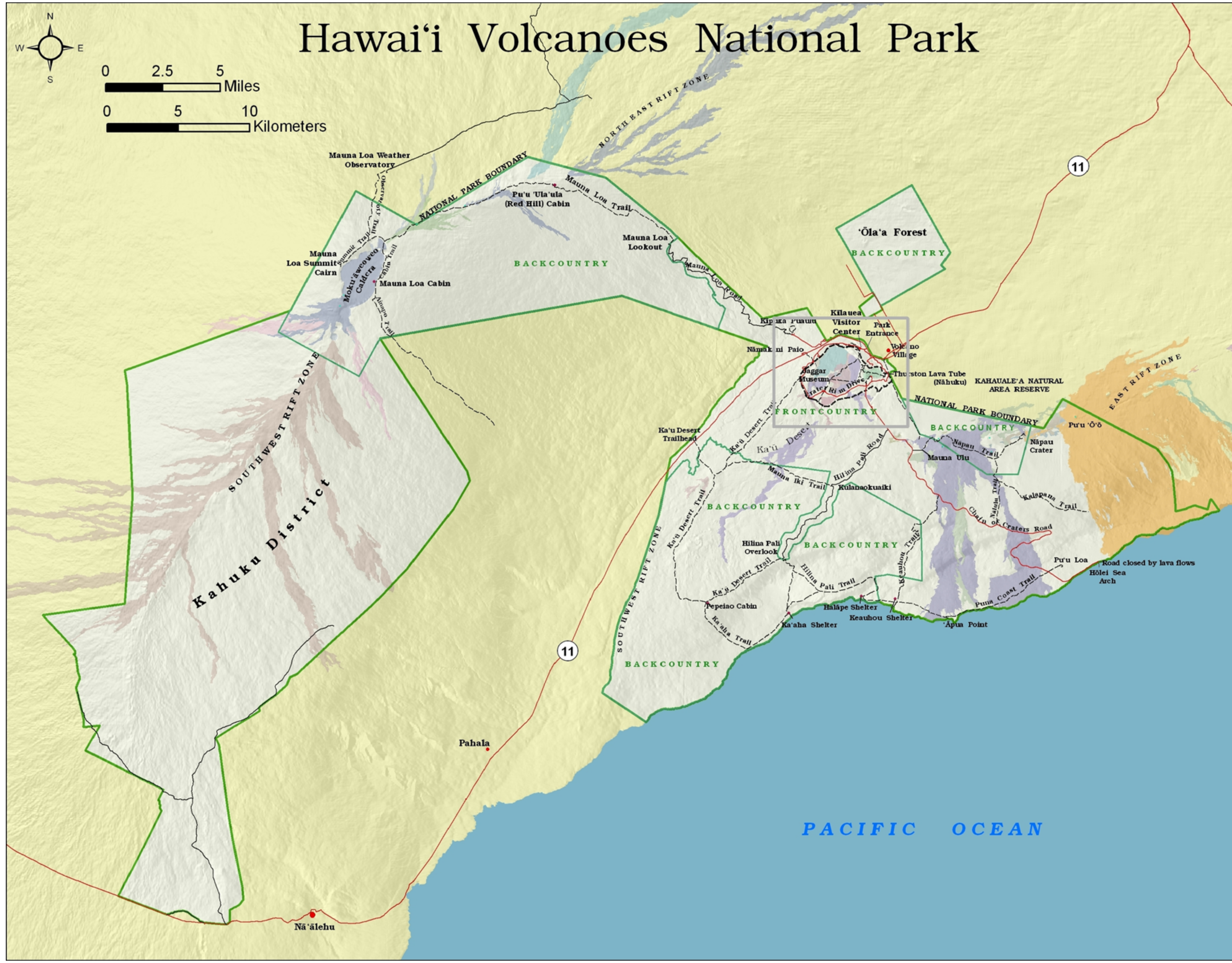

Figure 4. Backcountry region of Hawaii Volcanoes National Park.

Research Center, Volcano House Hotel, Kilauea Military Camp and Resort, a cultural education center, two small campgrounds, housing for seasonal employees, and various administrative offices for law enforcement, resource management, firefighting, and maintenance operations. Motor tourism is a popular activity in the park with the majority of visitors entering the park in private rental vehicles or on bus tours. The road infrastructure in the parks consists of two scenic roadways (Crater Rim Drive and Chain of Craters Road), a 19 km stretch of State Highway 11 running through the middle of the park, and two partially paved backcountry roads. Chain of Craters Road extends 32 km from the entrance of the park down to the coastal region of the park with large sections of this road winding along Hilina Pali cliff while dropping from 1130 m in elevation down to sea level. Crater Rim Drive is an 18 km circular drive around the summit and caldera of Kilauea Volcano. This scenic road winds through rainforest, fern forest, and desert environments and is used to access the park visitor center, museum, military camp, and hotel. All roadways in Hawaii Volcanoes National Park are two lane roads with narrow shoulders except for the two backcountry roads which are single lane roads. In addition, law enforcement rangers in Hawaii Volcanoes National Park have jurisdiction over all roadways including the 19 km stretch of state highway.

Hiking activities and air tours are popular in Hawaii Volcanoes National Park. All air tours originate outside of the park and consist largely of helicopter tours. All air tours are commercially operated and limited in the number of flights allowed per day. Following a number of fatal helicopter crashes and expensive rescues in the early 1990s, in 1996 park managers recognized that the volcanic fumes present in the park could be highly corrosive to aircraft engines and restrict air engine intake. As a result, all aircraft were restricted from flying below 300 m from the surface in order to be high enough to maneuver to a soft landing if power is lost and to minimize exposure to fumes.

Within the boundaries of Hawaii Volcanoes National Park there are 15 trails totaling 240 km. These trails are divided into frontcountry and backcountry trails. Frontcountry trails are trails located within one kilometer of either side of a park road or building and are typically short interpretive and educational trails. Popular frontcountry trails are Devastation Trail, Thurston Lava Tube, Sandalwood Trail, Halemaumau Overlook, Pu'u Loa Trail, and Kipuka Puaulu Trail. Devastation Trail is a 30 minute, 1.5 km walk over cider outfall from the 1959 eruption of Kilauea Iki, Sandalwood Trail is a 2 km long gentle trail that extends through a rain forest and passes by steam vents, earthcracks, fault scarps, and cliffs, Kipuka Puaulu Trail is a 1.5 km long dirt path trail with a gentle incline that passes through an old growth rainforest, Halemaumau Overlook is a 0.5 km dirt and cinder trail that is a 10 minute walk from the parking area to Halemaumau Crater, Pu'u Loa Trail is a 2 km long trail over an uneven 800 year old lava flow leading to petroglyphs, and Thurston Lava Tube is a 20-minute walk on a surfaced trail that passes through a fern forest and lava tube. Thurston Lava Tube requires visitors to enter and exit via cement stairs, follow along a portion of a trail with a moderate slope, and walk in an area that is frequently wet and slippery from precipitation.

Backcountry regions of Hawaii Volcanoes National Park are primitive and undeveloped portions of a park where activities such as backpacking and wilderness hiking activities are common. Popular backcountry trails in Hawaii Volcanoes National Park are Kilauea Iki Trail, Halemaumau Trail, Crater Rim Trail, Napau Trail, Mauna Iki Trail, Halape Trail, and Mauna Loa Trail. Kilauea Iki Trail is a 2-4 hour 6.5 km long trail that has a steep 200 m descent through a rainforest leading to an uneven and rocky crater trail with earth cracks and a steep ascent, Halemaumau Trail is a 6 km long trail that begins with a 200 m descent through a rain forest that leads to a crater trail over an uneven pahoehoe lava surface surrounded by dense sulfuric fumes, Crater Rim Trail is an 18 km long trail that passes through areas with dense volcanic fume and over uneven pahoehoe and a'a type lava flows, and Napau Trail is a 23 km long over recent uneven lava flows in an area with dense volcanic fumes. In contrast, Mauna Iki Trail is a 6 km long trail over a compacted ash terrain through the Ka'u Desert, Halape Trail is a 23 km two-day round trip hike over rugged, uneven, rocky terrain that descends 800 m over a moderate gradient down to sea level, and Mauna Loa Trail is a strenuous 59 km long four day round trip hike over steep and rugged volcanic landscapes that ascends from 2100 m to 4400 m in elevation. All hikers on backcountry trails in Hawaii Volcanoes National Park are required to register and check out at the park visitor center.

The main attraction at Hawaii Volcanoes National Park is the current eruption of the Pu’u O’o Vent. This eruption began on January 3, 1983, and has destroyed 187 homes and structures. Within the park, lava flows from the current eruption have destroyed the Wahaula Visitor Center and the Kamoamoa campground and covered tens of thousands of archeological features including Hawaiian temple sites, petroglyph fields, and Hawaiian village complexes. In addition, lava flows up to 30m deep have covered 18 km of the Chain of Craters Road. Over the past 12 years, hiking to active lava flows has become an increasingly popular activity among visitors to Hawaii Volcanoes National Park.[16] This activity occurs in a coastal section of the park where lava flows have covered the Chain of Craters Road and is referred to by park employees as the *Eruption Site*. Because the lava flows in the area are dynamic, there are no marked trails for park visitors at the eruption site. However, depending on the conditions, hikers wishing to view active lava flows on the surface or entering the ocean typically hike between 4 - 16 km roundtrip. Hiking to active lava flows at the eruption site requires park visitors to hike over rugged and unstable basaltic terrain that is underlined by unseen lava tubes while exposing themselves to volcanic fumes, hydrochloric steam explosions, methane gas explosions, intense heat, and unstable coastal benches.[16] Out of concern for visitor safety at the eruption site, in May 1995 Hawaii Volcanoes National Park placed a large warning sign at the eruption site informing visitors of the health hazards in the area and recommending that all hikers carry proper amounts of water, wear footwear that will protect them from injury, and carry flashlights if hiking during night hours. In addition, the park placed two park rangers at the Eruption Site between 1300-2100 hours each day and placed a series of warning signs in English and Japanese along dangerous coastal areas and 0.5 km from the point lava enters the ocean.

Data Source and Analysis

Injuries in this dissertation will be defined as any physical harm or physiological illness suffered by a visitor to Hawaii Volcanoes National Park. The data used for this study consists of all case incident reports (CIRs) recorded in Hawaii Volcanoes National Park between January 1, 1993, and December 31, 2002. Case incident reports (NPS Form 10-343) are filed by protection rangers for all visitor incidents in Hawaii Volcanoes National Park and include information about the date, time, and location of the incident, the age, gender, race, nationality, place of residence, and number of visitors involved in the incident, a description of the environment and conditions at the scene of the incident, the nature of the activity that the visitor was engaged in at the time of the incident, the type and severity of the injury incurred by the visitor, and the actions taken in response to the incident by park personnel and others. Case incident reports also provide space for narrative descriptions of the incident, cost summaries of major incidents, photos of the injury scene and any visible injury, and include emergency medical log records, emergency medical services (EMS) reports filled out by paramedics and wilderness emergency medical technicians, search and rescue (SAR) reports, coroners' reports, and follow-up reports with hospital personnel.

The data used in this study was coded and interpreted from the information recorded in the case incident reports. To ensure the quality and validity of the case incident reports, data from the reports was compared to personal records and run sheets maintained by protection rangers prior to transferring the information onto case incident reports. A total of 1,500 incident reports (150 per year) were checked for consistency in reporting between the personal records and run sheets and the final case incident report. The information transferred to the case incident reports was found to be highly consistent (98% agreement) with that contained in the personal records and run sheets. The primary source of error involved the misspelling of international visitor names. The visitor factors for the injured park visitors will consist of gender (male/female), age group (10-year intervals), race and ethnicity (African-American, Asian, Asian Pacific Islander, Caucasian, Hispanic, and Indian), nationality, behavior (whether or not an injured visitor entered a restricted area of the park, has a pre-existing health condition that contributed to their injury, made a judgment error, or is running) and preparation (did the visitor wear minimal footwear or clothing, carry minimal amounts of water or other electrolyte refreshment, carry no flashlight, and be under-conditioned for the activity). The environmental factors investigated in this study will consist of natural and built environmental factors. Natural environment factors will include volcanic gases and fumes, lava, natural fire, steam and/or hot water, insects, vegetation, dark conditions, rugged terrain, geologic factors, and weather conditions. The built environment factors will include trail conditions, roadway conditions, parking lot conditions, building / structural conditions, and aircraft failure.

Only case incident records reporting injuries to park visitors will be used in this study and all other reports pertaining to park employees and individuals in the park for business purposes will be excluded. Information from each case incident report will be coded as a physical injury (scrape and abrasion, blister, concussion, laceration, sprain/strain, thermal burn, fractured/broken bone, dislocation, contusion) to the upper extremities, lower extremities, head and neck, and front or back torso regions of the body or an illness (dehydration/heat exhaustion, heat stroke, respiratory irritation, anaphylactic reaction, insect irritation, headache/migraine, nausea, cardiac distress). The injury severity in each incident report will be measured using a version of the *Abbreviated Injury Scale* adapted for a recreational setting.[5] Incidents involving the death of a park visitor will be coded as: 1) *fatal*, 2) incidents where the park visitor requires treatment and emergency medical transport to advanced medical facilities will be interpreted and coded as *serious*, 3) incidents where the visitor is treated, requires further medical attention but can be self-transported will be classified as *moderate*, 4) and incidents where the visitor is treated on-site and requires no further medical attention or transport will be coded as *minor*.

To examine the geographic differences in the frequency, severity, and distribution of visitor injuries in Hawaii Volcanoes National Park, the incident location will be classified as: 1) frontcountry environment, 2) backcountry environment, 3) roadway environment, 4) airway environment, and 5) the eruption environment (Eruption Site). Following the methods used by Taunton et al.[145] and Niemcryk et al.[146], basic descriptive statistics will be used to classify the nature and type of injury associated with the visitor and environmental factors and to identify the differences in the frequency, severity, and distribution of injuries throughout the different environments within the park. In addition, four logistic regression analyses will be used to assess the relationship between visitor factors, environmental factors, and injury severity, to estimate odds ratios (OR), and to compute confidence intervals (CI). Logistic regression is a multiple regression but with a dependent outcome variable that is a categorical dichotomy and independent predictor variables that are either continuous or categorical. This method is frequently used in injury research and has been used to assess the relationship between similar variables and the severity of intentional and unintentional injuries throughout different regions of the State of Nevada, to assess the relationship between socio-demographic variables and the risk of developing brain tumors patterns, and to assess the relationship between injury severity in Arab and Jewish populations in Israel.[146-148]

Injury severity (Fatal, Severe, Moderate, Minor) will be the categorical dependent outcome variable used in this study. The covariates (independent predictor variables) used in each analysis will consist of both visitor and environmental factors. Specifically, the visitor factors will be gender, age (10 year age groupings), visitor behavior (entering restricted areas, judgment / driving errors, pre-existing health conditions, and running), and visitor preparedness (minimal footwear, minimal clothing, minimal physical conditioning, minimal drinking water, and no flashlight). The environmental factors will consist of both natural and built environmental factors. Specifically, the natural environmental factors will consist of volcanic fumes, lava, natural fire, steam/hot water, insects, darkness, weather, rugged terrain, animal contact, and geologic factors such as earthquakes and coastal bench collapses. The built environmental factors will consist of trail factors, roadway factors, building / structural factors, parking lot factors, and aircraft failure. In all regressions, backward elimination will be used to exclude variables that are not significantly related to the respective outcome.

Chi-square tests of independence will be used to determine the effectiveness of indirect supervision and sign placement on the severity of injuries at the Eruption Site in Hawaii Volcanoes National Park.

CHAPTER IV

RESULTS

Distribution of Injuries by Frequency and Severity

Understanding the distribution of injuries in a national park is the first step in identifying the locations most in need of interventions. In addition, understanding the distribution of injuries by their frequency and severity will help park managers best direct their prevention resources to areas with the most severe injuries rather than to areas that have a high frequency of minor injuries.

Between January 1, 1993, and December 31, 2002 there were 5,947 case incident reports for injured visitors in Hawaii Volcanoes National Park. The injury frequency ranged from a low of 471 incidents in 1993 to 996 incidents in 2002 (Figure 5). Out of the 5,947 injuries, 268 were fatalities, 1,698 were severe injuries, 2,043 were moderate injuries, and 1,938 were classified as minor injuries (Figure 6). Table 2 displays the distribution of injuries in Hawaii Volcanoes National Park by location. Table 2 shows the highest injury occurrence at the Eruption Site, Kilauea Visitor Center, Highway 11, and Thurston Lava Tube. Most fatalities in the park result from motor vehicle accidents and close to 84% of all visitor fatalities occur on Highway 11, the Eruption Site, and Mauna Loa. The most severe injuries requiring emergency medical transport also occur at the Eruption Site and on Highway 11, the most moderate injuries occur at the Eruption Site, Kilauea Visitor Center, and Thurston Lava Tube, and the most minor injuries are recorded at the Eruption Site and Kilauea Visitor Center.

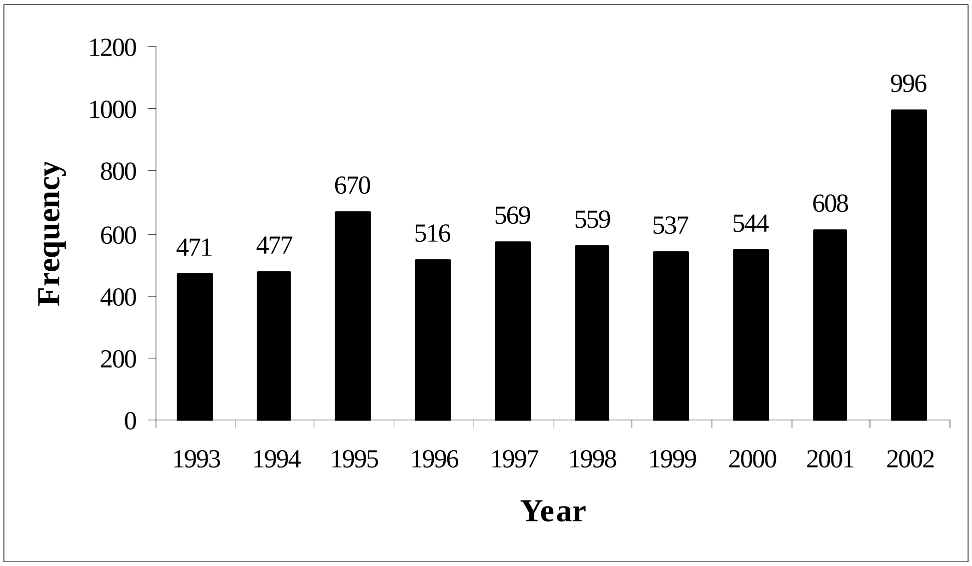

Figure 5. Distribution of injuries by year in Hawaii Volcanoes National Park, 1993-2002. N = 5,947.

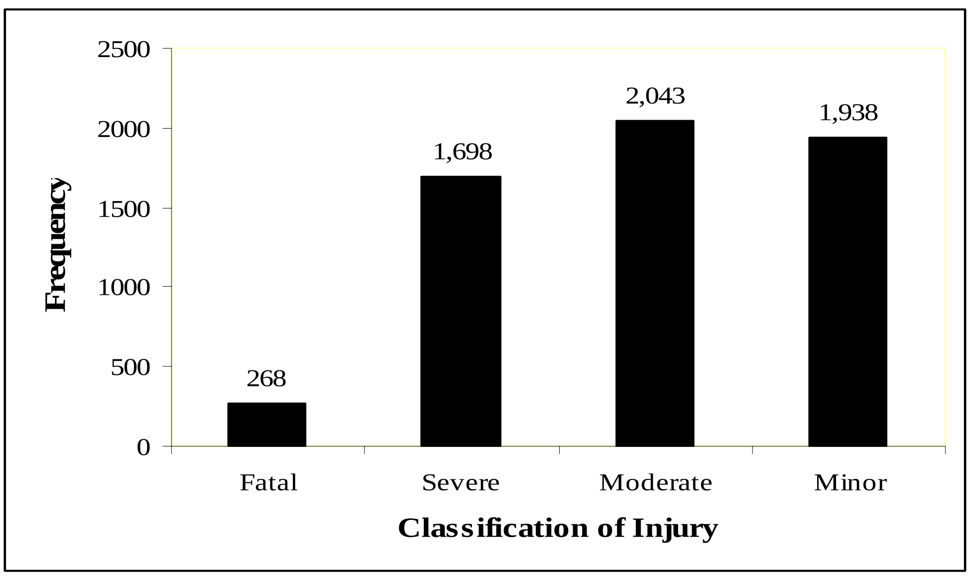

Figure 6. Classification of injuries by severity in Hawaii Volcanoes National Park, 1993-2002. N = 5,947.

Table 2. Distribution of injury severity by specific location in Hawaii Volcanoes National Park.

Location	Fatal	Severe	Moderate	Minor	Total
Apua Point	0	3	0	0	3
Byron Ledge	0	0	5	3	8
Chain of Craters Road	3	41	35	30	109
Crater Rim Drive	0	14	34	88	136
Crater Rim Trail	0	7	0	10	17
Devastation Trail	0	1	5	48	54
Dormitory	0	4	5	10	19
Eruption Site	59	1179	1358	541	3137
Footprint	0	0	0	4	4
Glenwood Trail	0	0	0	16	16
Golf Course	0	0	0	5	5
Halape	5	10	10	5	30
Halemaumau Crater	2	20	25	61	108
Highway 11	122	125	35	19	301
Hilina Pali	2	0	4	1	7
Holei Sea Arch	0	0	4	5	9
Jaggar Museum	0	19	45	83	147
Ka’u Desert	0	0	0	5	5
Kaaha	0	0	0	4	4
Kalapana	3	0	0	5	8
Kilauea Iki Trail	2	38	72	143	255
Kipuka Puaulu Trail	0	4	10	8	22
Kilauea Caldera	9	0	0	0	9
Kilauea Military Camp Resort	3	9	25	69	106
Kilauea Visitor Center	0	56	110	289	455
Kilauea Overlook	0	0	4	14	18
Kipuka Puaulu Trail	0	4	10	8	22
Kealakomo Picnic Shelter	0	0	0	14	14
Mauna Loa	39	5	14	20	78
Mauna Loa Strip Road	5	10	0	19	34
Mauna Ulu	0	5	9	10	24
Namakani Paio Campground	0	0	10	10	20
Olaa	0	0	4	3	7
Park Entrance Station	0	0	5	39	44
Puna Coast Trail	0	0	0	10	10
Pu’u Hululu	0	0	10	9	19
Pu’u Loa Petroglyphs and Trail	0	5	5	0	10
Pu’u O’o Vent	2	9	11	12	34
Rainshed	0	0	0	5	5
Sulfur Banks	2	54	29	69	154
Steam Vents	4	7	15	30	56
Southwest Rift Zone	0	0	4	28	32
Thurston Lava Tube	6	30	96	100	232
Volcano House Hotel	0	39	30	86	155
Waldron Ledge	0	0	6	0	6
Total	268	1698	2043	1938	5947

Distribution of Injuries by Gender, Age, Nationality, and Ethnicity

Just as understanding the distribution of injuries in a national park can aid park managers in identifying the locations most in need of prevention interventions, understanding the characteristics of injured visitors can further aid in the profiling of most at-risk visitor groups and the development of prevention techniques. In the case of Hawaii Volcanoes National Park, female visitors were involved in 3,448 (58%) of all incidents and males were involved in 2,449 (42%) of all incidents (Table 3). Female visitors were also involved in more fatal, severe, moderate, and minor incidents than their male counterparts (Table 3). The mean age of all injured visitors was 38.8 years (SD = 21.4; range, 0-88 years). Moreover, the mean age of all injured female visitors was 39.7 years of age (SD = 21; range, 1-82 years) and the mean age of all injured male visitors was 37.6 years of age (SD = 21.8; 0-88 years).

The distribution of injury severity by age group in Hawaii Volcanoes National Park indicates that visitors aged 50-59, 60-69, and 0-9 years of age experience the most frequent number of incidents and park visitors aged 50-59 years account for the most fatal, severe, moderate, and minor injuries (Table 4). Visitors aged 20-29 years recorded the second highest total number of fatalities, visitors aged 60-69 recorded the second highest number of severe injuries, and visitors aged 0-9 years have the second highest total of moderate and minor injuries. When broken down by gender and age, the data from the case incident reports indicate that males aged 50-59 and 0-9 years account for the most frequent number male injuries and that males aged 50-59 record the highest number of fatalities (Table 5). Male visitors aged 50-59 and 60-69

Table 3. Distribution of injury severity by gender in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Gender	No.	No.	No.	No.	No.
Male	112	709	819	859	2499
Female	156	989	1224	1079	3448
Total	268	1698	2043	1938	5947

Table 4. Distribution of injury severity by age group in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Age Group	No.	No.	No.	No.	No.
0-09	3	145	355	428	931
10-19	38	172	253	192	655
20-29	73	218	263	213	767
30-39	12	112	144	121	389
40-49	35	135	184	93	447
50-59	81	533	460	476	1550
60-69	10	292	315	325	942
70-79	15	71	49	80	215
80-89	1	20	20	10	51
Total	268	1698	2043	1938	5947

recorded the most severe injuries, and males aged 0-9 and 50-59 account for the most moderate and minor injuries (Table 5). From a female perspective, female visitors aged 50-59 years recorded the highest total number of injuries in all severity categories with female visitors aged 60-69 accounting for a large number of severe, moderate and minor injuries (Table 6). Females visitors aged 0-9 years also account for a large number of the total female injuries but the majority of these were recorded as moderate and minor incidents (Table 6).

Hawaii Volcanoes National Park is one of the leading tourist attractions on the Big Island of Hawaii. According to the case incident reports, visitors from the United States are by far the most frequently injured tourists in the park accounting for 4,643 or the total 5,947 incidents (Table 7). Visitors from Japan and Germany are the only other countries to register more than 250 injuries (Table 7). When looking specifically at fatalities, the United States, Germany, and Australia are the only countries registering more than ten fatalities. In all other severity categories, it is the United States, Japan, and Germany with the most frequent number of injuries.

When looking beyond the country of origin and at the distribution of injuries and injury severity by race in Hawaii Volcanoes National Park, Table 8 indicates that Caucasian visitors are the most frequently injured visitors followed by Asian and Asian Pacific Islanders. Caucasian visitors were involved in over half of all fatal incidents and Caucasian and Asian visitors recorded the highest number of severe, moderate, and minor injuries, the highest number of moderate injuries.

Table 5. Distribution of male injury severity by age group in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Age Group	No.	No.	No.	No.	No.
0-09	2	77	163	192	434
10-19	17	58	121	78	274
20-29	25	90	126	123	364
30-39	0	60	34	78	172
40-49	23	66	69	43	201
50-59	32	180	153	180	545
60-69	2	133	118	130	383
70-79	10	30	20	35	95
80-89	1	15	15	0	31
Total	112	709	819	859	2499

Table 6. Distribution of female injury severity by age group in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Age Group	No.	No.	No.	No.	No.
0-09	1	68	192	227	488
10-19	20	115	132	114	381
20-29	47	129	147	90	413
30-39	12	52	110	43	217
40-49	12	70	115	50	247
50-59	51	349	297	305	1002
60-69	8	160	197	195	560
70-79	5	41	29	45	120
80-89	0	5	5	10	20
Total	156	989	1224	1079	3448

Table 7. Distribution of injury severity by nationality in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Nationality	No.	No.	No.	No.	No.
Australia	13	5	5	5	28
Austria	5	0	0	28	33
Belgium	0	0	0	4	4
Canada	5	14	5	37	61
China	0	4	5	14	23
Netherlands	0	15	20	5	40
Germany	19	115	64	72	270
Greece	0	5	5	0	10
Hong Kong	0	14	19	25	58
India	0	14	5	10	29
Ireland	0	0	5	0	5
Israel	0	0	0	4	4
Italy	0	0	15	5	20
Japan	3	120	112	215	450
South Korea	0	20	20	47	87
Mexico	0	5	4	0	9
New Zealand	0	0	10	14	24
Poland	0	4	23	9	36
Russia	0	0	9	10	19
Samoa	0	5	0	0	5
Spain	0	5	0	5	10
Switzerland	0	0	0	5	5
Taiwan	4	4	5	5	18
United Kingdom	0	9	24	15	48
United States	217	1340	1686	1400	4643
Vietnam	2	0	2	4	8
Total	268	1698	2043	1938	5947

Table 8. Distribution of injury severity by race in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Race	No.	No.	No.	No.	No.
African American	0	20	44	48	112
Asian	24	203	253	349	829
Asian Pacific Islander	87	72	71	137	367
American Indian	0	0	5	4	9
Caucasian	157	1345	1627	1371	4500
Hispanic	0	25	23	9	57
Indian	0	28	20	20	68
Unknown	0	5	0	0	5
Total	268	1698	2043	1938	5947

Nature of Injuries

Identifying the nature of injuries in a national park such as Hawaii Volcanoes National Park is one of the first steps to understanding which factors contribute to injuries and assists park managers in developing injury countermeasures. Out of the 5,947 injuries incurred by visitors to Hawaii Volcanoes National Park between 1993-2002, the most common injuries were lacerations, scrapes and abrasions, fractures and broken bones, and sprains and strains (Figure 7). Fractures and broken bones are the most common injury associated with visitor fatalities, lacerations and fractures and broken bones are the most frequent severe injuries, lacerations, scrapes and abrasions are the most frequent moderate injuries, and scrapes and abrasions and sprains and strains are the most frequent minor injuries (Table 9).

The breakdown of injuries by gender and age grouping displayed in Tables 10 and 11 show that lacerations, scrapes and abrasions, sprains and strains, and fractures and broken bones are the most common injuries among male visitors. Lacerations, scrapes and abrasions, fractures / broken bones, and sprains and strains are the most common female injuries followed by dehydration, respiratory irritation, allergic reactions, and thermal burns. Respiratory irritations and allergic reactions are common in male visitors aged 0-9 years of age, dehydration is common in males aged 20-29 years, whiplash is common in male visitors aged 50-59 years, and dehydration and cardiac distress are common in visitors aged 60-69 years. Dehydration, respiratory irritation, thermal burns, and fractures / broken bones are most common in females aged 50-59 years whereas allergic reactions are the most frequent in female visitors aged 0-9 years.

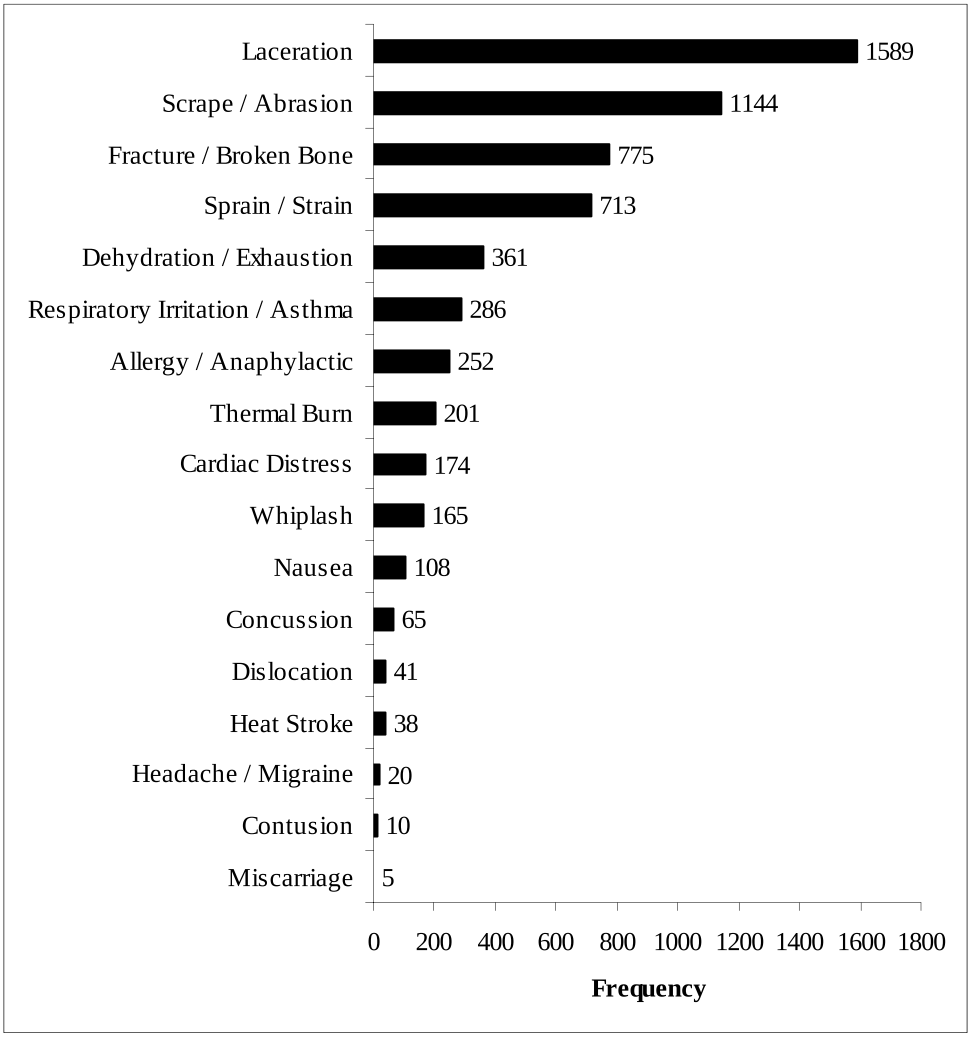

Figure 7. Nature and type of injuries sustained by visitors to Hawaii Volcanoes National Park.

Table 9. Most common fatal, severe, moderate, and minor injuries in Hawaii Volcanoes National Park.

Fatal Injuries	Frequency
1. Fracture / broken bone	183
2. Respiratory irritation / asthma	34
3. Thermal burn	19
4. Cardiac distress	14

Severe Injuries	Frequency
1. Laceration	564
2. Fracture / broken bone	444
3. Thermal burn	182
4. Cardiac distress	120

Moderate Injuries	Frequency
1. Laceration	882
2. Scrape / abrasion	457
3. Sprain / strain	244
4. Fracture / broken bone	132

Minor Injuries	Frequency
1. Scrape / abrasion	638
2. Sprain / strain	400
3. Dehydration / exhaustion	271
4. Laceration	138

Table 10. Nature of male injuries by age group in Hawaii Volcanoes National Park.

	Age Group									
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	Total
Dehydration / Exhaustion	0	4	50	5	5	25	44	5	0	138
Heat Stroke	1	0	5	0	0	0	0	0	0	6
Respiratory Irritation / Asthma	25	5	12	5	16	24	5	0	5	97
Allergy / Anaphylactic	36	1	5	5	4	9	5	5	0	70
Headache / Migraine	0	0	0	0	5	0	0	0	0	5
Cardiac Distress	0	5	0	0	14	22	39	9	1	90
Scrape / Abrasion	164	65	51	35	15	63	34	25	10	462
Concussion	5	0	5	0	0	5	15	0	0	30
Laceration	170	119	62	34	54	111	93	25	5	673
Sprain / Strain	17	24	58	24	46	127	80	10	0	386
Thermal Burn	1	3	25	11	6	22	5	0	0	73
Fracture / Broken Bone	15	38	72	24	24	73	43	10	0	299
Dislocation	0	0	0	5	6	14	0	5	0	30
Contusion	0	0	0	0	0	5	0	0	5	10
Whiplash	0	5	20	24	6	40	20	0	0	115
Nausea	0	5	0	0	0	5	0	0	5	15
Total	434	274	365	172	201	545	383	94	31	2499

Table 11. Nature of female injuries by age group in Hawaii Volcanoes National Park.

	Age Group									
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	Total
Dehydration / Exhaustion	10	24	36	19	5	89	24	11	5	223
Heat Stroke	0	0	15	1	0	6	5	5	0	32
Respiratory Irritation / Asthma	35	10	37	20	22	40	25	0	0	189
Allergy / Anaphylactic	78	25	20	5	10	24	20	0	0	182
Headache / Migraine	0	5	0	0	0	5	5	0	0	15
Cardiac Distress	0	5	10	0	0	34	30	5	0	84
Scrape / Abrasion	148	69	74	35	30	171	130	20	5	682
Concussion	0	0	0	10	0	4	21	0	0	35
Laceration	142	93	51	69	105	266	136	44	10	916
Sprain / Strain	20	50	50	10	30	102	60	5	0	317
Thermal Burn	0	20	21	15	1	65	6	0	0	128
Fracture / Broken Bone	36	50	70	18	29	160	93	20	0	476
Dislocation	0	0	0	0	0	6	5	0	0	11
Miscarriage	0	0	5	0	0	0	0	0	0	5
Whiplash	0	10	5	5	10	20	0	0	0	50
Nausea	19	20	19	10	5	10	0	10	0	93
Total	488	381	413	217	247	1002	560	120	20	3448

Geographic Distribution of Injuries

The first research question examining the differences in the frequency, severity, and distribution of visitor injuries in Hawaii Volcanoes National Park hypothesizes that the frequency of visitor injuries will be higher in frontcountry destinations and that severe injuries will be more common in backcountry destinations. The results clearly show, however, that even though 26% of the all park injuries occur in frontcountry destinations, over half of the injuries take place at the Eruption Site (Table12). The roadway environment recorded the highest number of fatal injuries and the most severe injuries took place at the Eruption Site (Table 12). However, when the roadway environment is excluded, the Eruption Site has the most fatalities. Backcountry regions account for the fewest number of park fatalities and the second fewest number of severe injuries which likely reflects that frontcountry use in the park is heavier than backcountry use (Table 12).

Frontcountry Incidents

Even though the results of this dissertation do not support the hypothesis that the frequency of injuries will be higher in frontcountry destinations, it is important to note that over one quarter of the total number of park injuries did occur in frontcountry destinations. A closer look at the 1,542 frontcountry injuries shows a similar number of fatal and severe injuries between male and female visitors but a much higher number of moderate and minor female injuries (Table 13). Visitors aged 60-69, 50-59, and 0-9 years of age were more frequently injured in frontcountry destinations than other age groupings (Table 13). These same ages accounted for the most moderate and minor

Table 12. Injury distribution by region and severity in Hawaii Volcanoes National Park.

Environment	Fatal	Severe	Moderate	Minor	Total	(%)
Frontcountry	23	234	434	851	1542	(26%)
Backcountry	8	55	102	192	357	(6%)
Roadway	130	220	138	334	822	(14%)
Airspace	48	10	11	20	89	(1%)
Eruption Site	59	1179	1358	541	3137	(53%)
Total	268	1698	2043	1938	5947	

Table 13. Distribution of frontcountry injuries by gender, age group, and severity in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Gender					
Male	10	120	136	249	515
Female	13	114	298	602	1027
Sub-total	23	234	434	851	1542
Age Group					
0- 9	0	10	52	234	296
10-19	0	10	19	55	84
20-29	6	21	45	30	102
30-39	0	4	0	48	52
40-49	5	25	34	30	94
50-59	6	50	97	212	365
60-69	0	88	148	173	409
70-79	5	21	24	64	114
80-89	1	5	15	5	26
Sub-total	23	234	434	851	1542

frontcountry injuries but vistors aged 60-69 years had by far the most severe frontcountry injuries (Table 13). The distribution of fatal frontcountry incidents is spread almost evenly between visitors aged 20-29 years, 40-49 years, 50-59 years, and 70-79 years (Table 13).

The majority of injuries in frontcountry destinations of Hawaii Volcanoes National Park are minor injuries dominated by scrapes and abrasions and sprains and strains (Table 14). Respiratory, allergy, and broken bone issues are also common in frontcountry areas (Table 14). Injuries in frontcountry areas such as dehydration and exhaustion is most common in visitors aged 50-59 years, respiratory irritation is most common in visitors aged 50-59 years and 0-9 years of age, allergic reactions are highest among visitors 0-9 years old, cardiac issues are most common in visitors aged 60-69 years and 50-59 years, lacerations are most common in visitors 0-9 years of age, sprains and strains are highest in visitors age 60-69 years, and fractures and broken bones are most common in visitors aged 60-69 years. Moreover, the most common behavioral and preparedness related aspects reported to be involved in frontcountry injuries are visitors carrying minimal amounts of water or electrolyte refreshment, visitors wearing minimal footwear, visitors committing driving errors, and visitors participating in activities despite pre-existing health conditions (Table 15). Visitors entering restricting areas is associated with ten of the 23 frontcountry fatalities, pre-existing health conditions are associated with 34 of the 234 severe injuries, minimal footwear is associated with 35 of the 434 moderate injuries, and a lack of water was associated with 85 of the 851 minor injuries (Table 15).

Table 14. Nature of frontcountry injuries sustained in Hawaii Volcanoes National Park.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	1	9	72	82
Respiratory Irritation / Asthma	6	20	39	103	168
Allergy / Anaphylactic	0	18	14	128	160
Cardiac Distress	6	84	20	8	118
Scrape / Abrasion	0	5	55	310	370
Concussion	0	10	5	11	26
Laceration	0	46	171	23	240
Sprain / Strain	0	0	39	121	160
Thermal Burn	0	2	0	0	2
Fracture / Broken Bone	11	39	63	16	129
Dislocation	0	0	9	0	9
Miscarriage	0	5	0	0	5
Nausea	0	4	10	59	73
Total	23	234	434	851	1542

Table 15. Behavioral and preparedness factors most frequently involved in frontcountry incidents in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Factor	No.	No.	No.	No.	No.
Enter Restricted Area	10	4	15	20	49
Driving Error	0	10	5	66	81
Pre-existing health	3	34	15	14	66
Running	0	0	5	40	45
Minimal Footwear	0	10	35	55	100
Minimal Clothing	2	0	0	0	2
Physical Exertion	0	5	0	5	10
Minimal Water / Electrolyte Refreshment	0	1	19	85	105
No Flashlight	0	5	5	4	14

Out of all the frontcountry destinations in Hawaii Volcanoes National Park, Kilauea Visitor Center, Thurston Lava Tube, Sulfur Banks, and Jaggar Museum are the destinations with the most frequent number of incidents (Table 16). While no fatalities are recorded at Kilauea Visitor Center, female visitors incur more injuries than males at the visitor center and visitors aged 0-9 years incur more injuries than any other age group (Table 17). A total of only 20 injuries at Kilauea Visitor Center took place during darkness whereas 435 are reported during daylight hours (Table 17). Scrapes and abrasions, sprains and strains, allergic reactions, lacerations, fractures and broken bones, and respiratory irritations are the most frequent injuries reported at the visitor center (Table 18). In addition, a total of 24 of the 27 respiratory irritations were attributed to exposure to volcanic fumes, 50 of the 54 allergic reactions were attributed to insect stings, and 221 of the scrapes and abrasions, lacerations, sprains and strains, and fractures and broken bones were attributed to slips, trips, and falls on speed bumps and high curbs in the parking lot of the visitor center.

Compared to Kilauea Visitor Center, there are six recorded fatalities at Thurston Lava Tube (Table 19). There are more female injuries than male injuries at Thurston Lava Tube with visitors to aged 60-69 incurring the highest number of incidents. However, visitors 70-79 years of age account for five of the six fatalities and half of the serious injuries (Table 19). Lacerations, scrapes and abrasions, and sprains and strains are the most common injuries with head trauma resulting from bumps on cave walls inside the lava tube accounting for 14 of the 15 lacerations that resulted in severe injuries (Table 20).

Table 16. Frontcountry destinations in Hawaii Volcanoes National Park with the highest number of total injuries.

	Fatal	Severe	Moderate	Minor	Total
Location	No.	No.	No.	No.	No.
Kilauea Visitor Center	0	56	110	289	455
Thurston Lava Tube	6	30	96	100	232
Sulfur Banks	2	54	29	69	154
Jaggar Museum	0	19	45	83	147

Table 17. Distribution of injuries at Kilauea Visitor Center by gender, age group, and light conditions.

	Fatal	Severe	Moderate	Minor	Total
Location	No.	No.	No.	No.	No.
Gender					
Male	0	21	34	94	149
Female	0	15	60	231	306
Sub-total	0	36	94	325	455
Age Group					
0- 9	0	5	27	195	227
10-19	0	0	14	9	23
20-29	0	0	0	15	15
30-39	0	0	0	15	15
40-49	0	1	0	10	11
50-59	0	10	13	55	78
60-69	0	15	35	26	76
70-79	0	0	0	0	0
80-89	0	5	5	0	10
Sub-total	0	36	94	325	455
Conditions					
Daylight	0	31	94	310	435
Darkness	0	5	0	15	20
Sub-total	0	36	94	325	455

Table 18. Nature of injuries sustained at Kiluaea Visitor Center.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	0	0	3	3
Heat Stroke	0	0	0	0	0
Respiratory Irritation / Asthma	0	7	0	20	27
Allergy / Anaphylactic	0	2	0	52	54
Headache / Migraine	0	0	0	0	0
Cardiac Distress	0	8	0	0	8
Scrape / Abrasion	0	0	12	184	196
Concussion	0	0	3	0	3
Laceration	0	9	30	4	43
Sprain / Strain	0	0	20	42	62
Thermal Burn	0	0	0	0	0
Fracture / Broken Bone	0	10	20	0	30
Dislocation	0	0	0	0	0
Miscarriage	0	0	0	0	0
Whiplash	0	0	9	13	22
Nausea	0	0	0	7	7
Total	0	36	94	325	455

Table 19. Distribution of injuries at Thurston Lava Tube by gender, age group, and light conditions.

	Fatal	Severe	Moderate	Minor	Total
Location	No.	No.	No.	No.	No.
Gender					
Male	6	10	33	30	79
Female	0	20	63	70	153
Sub-total	6	30	96	100	232
Age Group					
0- 9	0	0	4	4	8
10-19	0	0	5	5	10
20-29	0	0	0	0	0
30-39	0	0	0	9	9
40-49	0	0	9	5	14
50-59	0	5	15	14	34
60-69	0	10	49	59	118
70-79	5	15	14	4	38
80-89	1	0	0	0	1
Sub-total	6	30	96	100	232

Table 20. Nature of injuries sustained at Thurston Lava Tube.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	0	0	4	4
Heat Stroke	0	0	0	0	0
Respiratory Irritation / Asthma	0	0	0	5	5
Allergy / Anaphylactic	0	0	4	0	4
Headache / Migraine	0	0	0	0	0
Cardiac Distress	6	5	0	4	15
Scrape / Abrasion	0	0	20	44	64
Concussion	0	0	0	11	11
Laceration	0	15	58	0	73
Sprain / Strain	0	0	9	27	36
Thermal Burn	0	0	0	0	0
Fracture / Broken Bone	0	10	5	5	20
Dislocation	0	0	0	0	0
Miscarriage	0	0	0	0	0
Whiplash	0	0	0	0	0
Nausea	0	0	0	0	0
Total	6	30	96	100	232

The distribution of injuries at Sulfur Banks indicates that males suffer more severe injuries than females but female visitors incur more injuries than their male counterparts (Table 21). Visitors aged 50-59 years and 60-69 years incur the highest number of injuries and account for 40 of the 54 severe injuries (Table 21). It is interesting to note that out of the 154 injuries recorded at Sulfur Banks, 144 occurred during daylight conditions with respiratory irritation and cardiac distress resulting from exposure to sulfur gases accounting for 105 of the 154 injuries and 40 of the 54 severe injuries (Table 22).

During the same time frame, no fatalities are recorded at Jaggar Museum (Table 23). Injuries were more common to female visitors in all severity categories, visitors aged 60-69 years have the highest number of severe, moderate, and minor, injuries, and all 147 injuries occurred during daylight hours (Table 23). Concussions and lacerations are the only severe injuries to occur at Jaggar Museum, lacerations are the most common moderate injury, and scrapes and abrasions are the most common minor injury (Table 24).

Backcountry Incidents

More females were injured in the backcountry than male visitors but with a much less pronounced margin than in frontcountry destinations (Table 25). However, unlike other frontcountry destinations where injuries are more common in visitors above 50-69 and 0-9 years of age, backcountry visitors aged 20-29 and 50-59 years are the only age category with a pronounced number of injuries. These two age groups also

Table 21. Distribution of injuries at Sulfur Banks by gender, age group, and light conditions.

	Fatal	Severe	Moderate	Minor	Total
Location	No.	No.	No.	No.	No.
Gender					
Male	0	39	5	9	53
Female	2	15	24	60	101
Sub-total	2	54	29	69	154
Age Group					
0- 9	0	4	5	10	19
10-19	0	0	0	5	5
20-29	0	10	5	5	20
30-39	0	0	0	0	0
40-49	0	0	5	0	5
50-59	2	20	9	15	46
60-69	0	20	5	29	54
70-79	0	0	0	5	5
80-89	0	0	0	0	0
Sub-total	2	54	29	69	154
Conditions					
Daylight	2	44	29	69	144
Darkness	0	10	0	0	10
Sub-total	2	54	29	69	154

Table 22. Nature of injuries sustained at Sulfur Banks.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	0	0	0	0
Heat Stroke	0	0	0	0	0
Respiratory Irritation / Asthma	2	10	19	48	79
Allergy / Anaphylactic	0	9	5	5	19
Headache / Migraine	0	0	0	0	0
Cardiac Distress	0	30	5	4	39
Scrape / Abrasion	0	0	0	0	0
Concussion	0	0	0	0	0
Laceration	0	0	0	0	0
Sprain / Strain	0	0	0	5	5
Thermal Burn	0	0	0	0	0
Fracture / Broken Bone	0	0	0	0	0
Dislocation	0	0	0	0	0
Miscarriage	0	5	0	0	5
Whiplash	0	0	0	0	0
Nausea	0	0	0	7	0
Total	2	54	29	69	154

Table 23. Distribution of injuries at Jaggar Museum by gender, age group, and light conditions.

	Fatal	Severe	Moderate	Minor	Total
Location	No.	No.	No.	No.	No.
Gender					
Male	0	9	5	34	48
Female	0	10	40	49	99
Sub-total	0	19	45	83	147
Age Group					
0- 9	0	0	5	5	10
10-19	0	0	0	5	5
20-29	0	0	0	5	5
30-39	0	0	0	0	0
40-49	0	0	0	15	15
50-59	0	0	15	10	25
60-69	0	14	25	28	67
70-79	0	0	0	15	15
80-89	0	5	0	0	5
Sub-total	0	19	45	83	147
Conditions					
Daylight	0	19	45	83	147
Darkness	0	0	0	0	0
Sub-total	0	19	45	83	147

Table 24. Nature of injuries sustained at Jaggar Museum.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	0	5	5	10
Heat Stroke	0	0	0	0	0
Respiratory Irritation / Asthma	0	0	0	5	5
Allergy / Anaphylactic	0	0	0	15	15
Headache / Migraine	0	0	0	0	0
Cardiac Distress	0	0	0	0	0
Scrape / Abrasion	0	0	0	34	34
Concussion	0	10	0	0	10
Laceration	0	9	20	0	29
Sprain / Strain	0	0	10	19	34
Thermal Burn	0	0	0	0	0
Fracture / Broken Bone	0	0	5	0	5
Dislocation	0	0	5	0	5
Miscarriage	0	0	0	0	0
Whiplash	0	0	0	5	5
Nausea	0	0	0	0	0
Total	0	19	45	83	147

Table 25. Backcountry injuries by gender, age group, race, light conditions and severity.

	Fatal	Severe	Moderate	Minor	Total
Gender					
Male	2	25	44	105	176
Female	6	30	58	87	181
Sub-total	8	55	102	192	357
Age Group					
0- 9	1	0	14	10	25
10-19	0	0	14	9	23
20-29	0	25	24	54	103
30-39	1	0	9	19	29
40-49	1	10	10	20	41
50-59	5	20	22	55	102
60-69	0	0	9	20	29
70-79	0	0	0	5	5
80-89	0	0	0	0	0
Sub-total	8	55	102	192	357
Conditions					
Daylight	8	40	102	150	300
Darkness	0	15	0	42	57
Sub-total	8	55	102	192	357

account for the majority of severe, moderate, and minor backcountry injuries (Table 25). The vast majority of backcountry injuries to park visitors took place during daylight conditions (Table 25) with dehydration related injuries the most common backcountry injury (Table 26). Cardiac distress is commonly associated with backcountry fatalities, thermal burns are the leading severe injury in backcountry areas, and sprains and strains and lacerations are the leading moderate backcountry injury, and dehydration related incidents are the leading minor backcountry injury. Visitors carrying minimal amounts of water, wearing minimal footwear, and entering restricted areas are the behavioral and preparedness most frequently associated with backcountry injuries (Table 27).

Roadway Incidents

The roadways in Hawaii Volcanoes National Park with the highest number of incidents are Highway 11, Crater Rim Drive, and Chain of Craters Road (Table 28). Each of these roadways are the only roads in the park to record more than 100 incidents over the study period. Highway 11 accounts for 300 of the total 833 (36%), almost all of the roadway fatalities, and the vast majority of the severe injuries (Table 28). As well, unlike other regions of the park, more males visitors are injured females park roads even though females account for more fatalities (Table 29).

Visitors aged 50-59 years are injured more than any other age group but visitors aged 20-29 years also account for a high number of roadway incidents (Table 29). In fact, visitors aged 20-29 years account for the most roadway fatalities followed by

Table 26. Nature of injuries sustained in backcountry areas of Hawaii Volcanoes National Park.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	5	10	124	139
Heat Stroke	2	0	0	0	2
Respiratory Irritation / Asthma	0	10	0	10	20
Allergy / Anaphylactic	0	0	14	0	14
Cardiac Distress	6	5	0	1	12
Scrape / Abrasion	0	0	12	30	42
Laceration	0	0	28	13	41
Sprain / Strain	0	10	30	14	54
Thermal Burn	0	15	0	0	15
Fracture / Broken Bone	0	10	8	0	18
Total	8	55	102	192	357

Table 27. Behavioral and preparedness factors commonly associated with backcountry incidents in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Factor	No.	No.	No.	No.	No.
Enter Restricted Area	0	15	0	41	56
Pre-existing health	1	5	15	0	21
Minimal Footwear	0	15	58	37	100
Physical Exertion	5	5	5	1	16
Minimal Water / Electrolyte Refreshment	2	10	5	96	113
No Flashlight	0	10	0	4	14

Table 28. Distribution of roadway incidents by specific road and severity in Hawaii Volcanoes National Park.

Location	Fatal	Severe	Moderate	Minor	Total
Chain of Craters Road	3	41	35	30	109
Crater Rim Drive	0	14	34	86	134
Eruption Site Parking Area	1	5	0	8	14
Golf Course Parking Lot	0	0	0	5	5
Halemaumau Crater Parking Lot	0	0	0	5	5
Highway 11	121	125	35	19	300
Kilauea Military Camp	0	0	5	29	34
Kilauea Visitor Center Parking Lot	0	15	19	41	75
Mauna Loa Strip Road	5	10	0	19	34
Park Entrance Station	0	0	10	34	44
Park Housing Roadway Area	0	0	0	5	5
Mauna Ulu Parking Lot	0	5	0	0	5
Halemaumau Parking Lot	0	0	0	5	5
Thurston Lava Tube Parking Lot	0	0	0	23	23
Volcano House Hotel Parking Lot	0	5	0	25	30
Total	130	220	138	334	822

Table 29. Roadway injuries by gender, age group, race, and severity in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Gender					
Male	52	148	97	257	554
Female	78	72	41	77	268
Sub-total	130	220	138	334	822
Age Group					
0- 9	1	12	9	10	32
10-19	30	39	10	33	112
20-29	55	19	30	68	172
30-39	0	25	11	29	65
40-49	5	15	5	25	50
50-59	34	70	43	102	249
60-69	0	25	30	67	122
70-79	5	10	0	0	15
80-89	0	5	0	0	5
Sub-total	130	220	138	334	822
Race					
African American	0	0	0	0	0
Asian	84	83	67	174	408
Asian Pacific Islander	8	47	10	42	107
American Indian	0	0	0	0	0
Caucasian	38	90	61	113	302
Hispanic	0	0	0	0	0
Indian	0	0	0	5	5
Sub-total	130	220	138	334	822

visitors aged 50-59 and 10-19 years (Table 28). Aside from age, it is interesting to note that Asian drivers are involved in 50% of all roadway injuries and accounted for 65% of the roadway fatalities (Table 29). Roadway injuries in Hawaii Volcanoes National Park are most frequent between 1000-1600 hours and peak between 1300-1500 hours (Table 30). Fatal roadway incidents peak between 1100-1300 hours, 1400-1500 hours, and 2300-2400 hours and over half of the fatalities occurred during minimal lighting conditions (Table 30). Fractures and broken bones are the injuries most commonly associated with fatal and severe roadway incidents (Table 31).

Airway Incidents

Airway incidents involving tourists tend to receive a lot of media attention and fortunately for Hawaii Volcanoes National Park this type of incident accounts for only 1% of all visitor injuries. Out of the 89 visitors involved in airway incidents in Hawaii Volcanoes National Park, close to 87% were involved in helicopter crashes and the rest were involved in fatal airplane crashes. No gender pattern emerges for airway incidents but visitors aged 50-69 years are killed or injured more than any other age category (Table 32). All airway incidents occurred during daylight hours and involved visitors from the United States (72), Australia (8), Germany (5), and Taiwan (4). It is also interesting to note that out of all the airway incidents, over half of the injuries were fatal injuries with fractures and broken bones the most common injury (Tables 33 & 34).

Table 30. Roadway incidents by time of day, light conditions, and severity in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Time of Day					
0000-0100	0	10	0	0	10
0100-0200	6	5	0	10	21
0200-0300	0	5	0	0	5
0300-0400	0	5	0	0	5
0400-0500	0	5	0	5	10
0500-0600	0	5	0	0	5
0600-0700	10	0	0	0	10
0700-0800	0	11	10	10	31
0800-0900	9	4	0	10	23
0900-1000	4	15	5	0	24
1000-1100	0	5	15	34	54
1100-1200	15	15	15	29	74
1200-1300	15	15	10	38	78
1300-1400	5	20	34	45	104
1400-1500	15	35	5	51	106
1500-1600	0	15	10	38	63
1600-1700	5	14	0	14	33
1700-1800	5	9	13	5	32
1800-1900	5	5	2	5	17
1900-2000	11	5	0	10	26
2000-2100	0	0	5	5	10
2100-2200	10	4	5	0	19
2200-2300	0	0	9	15	24
2300-2400	15	13	0	10	38
Sub-total	130	220	138	334	822
Conditions					
Daylight	83	144	106	279	612
Darkness	47	76	32	55	210
Sub-total	130	220	138	334	822

Table 31. Nature of roadway injuries sustained in Hawaii Volcanoes National Park.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Type of Injury					
Respiratory Irritation / Asthma	0	5	0	0	5
Allergy / Anaphylactic	0	0	0	5	5
Headache / Migraine	0	5	5	10	20
Scrape / Abrasion	0	0	5	5	10
Concussion	0	15	0	5	20
Laceration	0	10	9	0	19
Sprain / Strain	5	38	61	205	309
Fracture / Broken Bone	125	122	24	0	271
Dislocation	0	15	0	0	15
Miscarriage	0	0	0	0	0
Whiplash	0	10	34	104	148
Total	130	220	138	334	822

Table 32. Airway injuries by gender, age group, nationality, and light conditions in Hawaii Volcanoes National Park.

	Fatal	Severe	Moderate	Minor	Total
Gender					
Male	22	3	5	14	44
Female	26	7	6	6	45
Sub-total	48	10	11	20	89
Age Group					
0- 9	0	0	0	0	0
10-19	6	5	0	0	11
20-29	1	0	0	0	1
30-39	1	1	0	0	2
40-49	4	1	0	8	13
50-59	26	3	11	12	52
60-69	10	0	0	0	10
70-79	0	0	0	0	0
80-89	0	0	0	0	0
Sub-total	48	10	11	20	89
Nationality					
Australia	8	0	0	0	8
Germany	4	0	0	1	5
Taiwan	4	0	0	0	4
United States	32	10	11	19	72
Sub-total	48	10	11	20	89
Conditions					
Daylight	48	10	11	20	89
Darkness	0	0	0	0	0
Sub-total	48	10	11	20	89

Table 33. Airway injuries sustained in Hawaii Volcanoes National Park.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Type of Injury					
Laceration	0	1	0	0	1
Sprain / Strain	0	5	11	18	34
Fracture / Broken Bone	48	4	0	0	49
Whiplash	0	0	0	2	2
Sub-total	48	10	11	20	89

Eruption Site Incidents

As was previously noted when looking at the distribution of injuries in Hawaii Volcanoes National Park, over half of the visitor incidents in the park occur at the Eruption Site. Female visitors incur more injuries than male visitors and visitors aged 50-59 and 0-9 incur more injuries than any other age group (Table 34). While visitors aged 40-49 sustained the most fatalities, visitors aged 50-59 sustained the most severe and moderate injuries (Table 34). Visitors aged 0-9 years of age also have a high number of moderate and minor injuries.

Caucasian visitors account for more injuries than any racial group followed by Asian visitors at the Eruption Site (Table 34). Visitors from the United States account for 86% of the total number of injuries in all severity levels at the Eruption Site followed distantly by visitors from Japan and Germany (Table 35). The injury pattern by time of day at the Eruption Site shows that injuries are most common between 1900-2000 hours and during minimal light conditions (Table 36). In fact, 58% of the visitor fatalities, 66% of the severe injuries, and 51% of the moderate injuries occur under minimal lighting conditions (Table 36). The most fatalities occur between 0600-0700 and 1900-2000 hours and the most severe and moderate injuries occur between 1900-2000 hours (Table 36). Minor injuries are most frequent between 1400-1500 hours (Table 36).

Lacerations and fractures and broken bones are the injuries most commonly associated with severe injuries, lacerations are the most common moderate injury, and

Table 34. Injuries by gender, age group, race, and severity at the Eruption Site.

	Fatal	Severe	Moderate	Minor	Total
Gender					
Male	31	404	532	243	1210
Female	28	775	826	298	1927
Sub-total	59	1179	1358	541	3137
Age Group					
0- 9	5	124	280	160	569
10-19	1	119	210	95	425
20-29	11	154	164	71	400
30-39	10	82	124	25	241
40-49	20	85	135	10	250
50-59	7	390	287	95	779
60-69	0	175	128	70	373
70-79	5	40	25	10	80
80-89	0	10	5	5	20
Sub-total	59	1179	1358	541	3137
Race					
African-American	0	20	39	20	79
Asian	12	102	137	31	282
Asian Pacific Islander	1	10	56	55	122
American Indian	0	0	5	0	5
Caucasian	46	1014	1088	425	2573
Hispanic	0	15	18	5	38
Indian	0	13	15	5	33
Unknown	0	5	0	0	5
Sub-total	59	1179	1358	541	3137

Table 35. Distribution of injury severity by nationality at the Eruption Site.

	Fatal	Severe	Moderate	Minor	Total
Nationality	No.	No.	No.	No.	No.
Australia	5	5	0	0	10
Canada	0	14	5	10	29
China	0	4	0	0	4
Netherlands	0	0	5	0	5
Germany	0	87	31	5	123
Greece	0	0	5	0	5
Hong Kong	0	0	9	5	14
India	0	9	0	0	9
Ireland	0	0	5	0	5
Israel	0	0	0	0	0
Italy	0	0	5	0	5
Japan	1	74	57	12	144
South Korea	0	5	10	0	15
Mexico	0	5	4	0	9
New Zealand	0	0	0	1	1
Poland	0	4	14	0	18
Russia	0	0	5	0	4
Taiwan	0	0	5	0	5
United Kingdom	0	4	14	5	23
United States	52	968	1184	500	2704
Vietnam	1	0	0	4	5
Total	59	1179	1358	541	3137

Table 36. Visitor injuries by time of day, light conditions, and severity at the Eruption Site.

	Fatal	Severe	Moderate	Minor	Total
Time of Day					
0000-0100	0	40	10	0	50
0100-0200	0	10	0	0	10
0200-0300	0	0	0	5	5
0300-0400	0	0	0	0	0
0400-0500	0	15	0	4	19
0500-0600	0	0	0	0	0
0600-0700	15	0	4	0	19
0700-0800	0	0	5	0	5
0800-0900	0	15	10	0	25
0900-1000	2	5	5	0	12
1000-1100	0	4	25	10	39
1100-1200	0	11	35	10	56
1200-1300	0	62	66	25	153
1300-1400	0	87	104	50	241
1400-1500	5	67	142	100	314
1500-1600	7	59	143	62	271
1600-1700	0	48	83	44	175
1700-1800	6	106	78	36	226
1800-1900	0	128	103	30	261
1900-2000	11	183	161	54	409
2000-2100	6	99	148	35	288
2100-2200	1	61	117	20	199
2200-2300	1	108	85	47	241
2300-2400	5	71	34	9	119
Sub-total	59	1179	1358	541	3137
Conditions					
Daylight	25	399	665	342	1431
Darkness	34	780	693	199	1706
Sub-total	59	1179	1358	541	3137

scrapes and abrasions are the most common minor injury (Table 37). Problems such as dehydration are most common in visitors aged between 50-69 years, heat stroke common in visitors aged 20-29 years, respiratory irritation / asthma issues are most common in those aged 0-9 years as are conditions associated with allergic reactions and scrapes and abrasions (Table 38). Injuries such as lacerations and thermal burns are also common in visitors 0-9 years of age (Table 38). The most common behavioral and preparedness factors associated with visitor injuries at the Eruption Site are visitors wearing minimal footwear and visitors entering restricted areas (Table 39). In fact, visitors entering restricted areas were involved in 32 fatalities and 393 severe injuries at the Eruption Site and visitors with minimal footwear was a factor in 489 moderate injuries and 195 minor injuries (Table 39).

Relationship between Injury Severity and Visitor Factors

The second research question asked in this dissertation focuses on the relationship between visitor factors and the severity of visitor injuries in Hawaii Volcanoes National Park. Hypotheses 2a – 2d state that injury severity will be higher for male visitors, visitors older than 50 years of age, visitors wearing minimal footwear, and visitors entering restricted areas. The results of the logistic regression analysis in Table 40 shows female visitors and visitors wearing minimal footwear and clothing, and visitors carrying minimal drinking water and no flashlight to be significantly associated with fatal injuries. Moreover, Table 41 shows visitors wearing minimal footwear and minimal clothing, visitors carrying minimal drinking water and no flashlight, visitors

Table 37. Nature of injuries sustained at the Eruption Site.

	Severity				
	Fatal	Severe	Moderate	Minor	Total
Dehydration / Exhaustion	0	30	35	75	140
Heat Stroke	11	25	0	0	36
Respiratory Irritation / Asthma	28	40	20	5	93
Allergy / Anaphylactic	0	10	58	5	73
Cardiac Distress	2	36	1	5	44
Scrape / Abrasion	0	34	390	303	727
Concussion	0	10	5	4	19
Laceration	0	507	679	102	1288
Sprain / Strain	0	11	103	42	156
Thermal Burn	17	164	0	0	181
Fracture / Broken Bone	1	270	37	0	308
Dislocation	0	12	5	0	17
Nausea	0	30	25	0	55
Total	59	1179	1358	541	3137
Body Region					
Head & Neck	0	85	23	5	113
Upper Extremity	5	100	258	125	488
Lower Extremity	5	818	971	321	2115
Torso	8	10	5	0	23
Illness	41	166	101	90	398
Total	59	1179	1358	541	3137

Table 38. Nature of injuries by age group at the Eruption Site.

	Age Group								
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89
Dehydration / Exhaustion	5	19	27	5	0	45	34	5	0
Heat Stroke	0	0	20	0	0	6	5	5	0
Respiratory Irritation / Asthma	25	10	15	10	23	5	5	0	0
Allergy / Anaphylactic	42	6	1	10	0	9	5	0	0
Cardiac Distress	0	0	10	0	2	26	6	0	0
Scrape / Abrasion	199	115	155	55	35	129	64	5	10
Concussion	0	0	0	10	0	4	5	0	0
Laceration	264	193	96	94	139	299	163	35	5
Sprain / Strain	6	20	15	10	10	60	25	10	0
Thermal Burn	0	21	46	26	6	71	11	0	0
Fracture / Broken Bone	23	16	45	16	24	114	50	20	0
Dislocation	0	0	0	0	6	11	0	0	0
Contusion	0	0	0	0	0	0	0	0	5
Nausea	5	25	10	5	5	0	0	0	0
Total	569	425	400	241	250	779	373	80	20

Table 39. Behavioral and preparedness factors associated with visitor injuries at the Eruption Site.

	Fatal	Severe	Moderate	Minor	Total
Factor	No.	No.	No.	No.	No.
Enter Restricted Area	32	393	161	71	657
Pre-existing health	11	37	59	20	127
Running	0	10	53	39	102
Minimal Footwear	5	222	489	195	911
Minimal Clothing	0	14	44	0	58
Physical Exertion	0	0	1	10	11
Minimal Water / Electrolyte Replacement	11	65	35	59	170
No Flashlight	5	525	271	70	871

Table 40. Logistic regression analysis of visitor factors related to fatal injuries.

Independent variables	Odds ratio	95% Confidence Interval
Gender		
Male	R	R
Female*	0.50	0.35-.073
Age Group		
0-9	0.17	0.11-2.43
10-19	0.21	0.15-2.62
20-29	0.97	0.10-9.38
30-39	R	R
40-49	0.63	0.06-6.61
50-59	2.24	0.24-21.4
60-69	0.83	0.09-7.65
70-79	0.14	0.01-1.54
80-89	3.89	0.39-38.7
Behavior		
Enter restricted area	13.6×10^{-4}	0.00-0.00
Judgment / Driving error	24.9×10^{-5}	0.00-0.00
Pre-existing health condition	R	R
Running	0.03	0.00-0.00
Preparedness		
Minimal footwear*	100.6	26.5-381.9
Minimal clothing*	14.97	3.30-68.1
Minimal Physical conditioning	R	R
Minimal drinking water*	2900.2	481.0-17486.0
No flashlight*	44.94	10.7-188.6

R Indicates the category serving as a reference category.
* $P < .05$.

Table 41. Logistic regression analysis of visitor factors related to severe injuries.

Independent variables	Odds ratio	95% Confidence Interval
Gender		
Male	+	+
Female	+	+
Age Group		
0-9	0.89	0.45-1.76
10-19	0.58	0.29-1.13
20-29	R	R
30-39	0.56	0.28-1.28
40-49	0.56	0.28-1.11
50-59*	0.47	0.24-0.93
60-69	1.03	0.54-1.99
70-79	1.22	0.63-2.37
80-89	1.39	0.67-2.85
Behavior		
Enter restricted area*	2.27	1.23-4.17
Judgment / Driving error	1.65	0.93-2.92
Pre-existing health condition*	2.50	1.33-4.71
Running	R	R
Preparedness		
Minimal footwear*	0.34	0.26-0.44
Minimal clothing*	0.32	0.24-0.43
Physical conditioning	R	R
Minimal drinking water*	0.27	0.12-0.60
No flashlight*	0.20	0.14-0.29

+ Indicates that the covariate was removed from the model during the backward elimination procedure.
R Indicates the category serving as the reference category.
* $P < .05$.

entering restricted areas, visitors having pre-existing health conditions, and visitors aged 50-59 years of age to be significantly associated with the risk of incurring a severe injury and most likely to happen to visitors with pre-existing health conditions, visitors aged 50-59 years, and visitors wearing improper footwear.

The visitor factors significantly associated with moderate injuries are age groups 10-19 years and 80-89 years, visitors with pre-existing health conditions, visitors with minimal footwear and clothing, and visitors with no flashlight and minimal drinking water (Table 42). Moderate injuries are also most likely to happen to visitors wearing improper clothing, visitors with pre-existing health conditions, and visitors aged 10-19 years (Table 42). In contrast, the visitor factors significantly associated with minor injuries are female status, all age groups except 30-39 years and 50-59 years, visitors entering restricted areas, visitors making judgment errors, and visitors wearing minimal footwear and clothing, and visitors carrying insufficient amounts of water and no flashlight (Table 43). Minor injuries are most likely to occur to visitors aged 0-9 years, visitors carrying insufficient amounts of water, female visitors, and visitors entering restricted areas (Table 43).

Relationship between Injury Severity and Environmental Factors

The third research question in this dissertation investigates the relationship between environmental factors and the severity of visitor injuries. Specifically, hypothesis 3a suggests that, "injury severity will be less in the built environment" and hypothesis 3b states that, "visitor injury severity will be higher during minimal daylight

Table 42. Logistic regression analysis of visitor factors related to moderate injuries.

Independent variables	Odds ratio	95% Confidence Interval
Gender		
Male	+	+
Female	+	+
Age Group		
0-9	R	R
10-19*	0.54	0.3-1.02
20-29	0.82	0.45-1.56
30-39	0.96	0.53-1.83
40-49	0.82	0.44-1.60
50-59	0.88	0.47-1.68
60-69	0.58	0.33-1.11
70-79	0.60	0.34-1.20
80-89*	0.33	0.17-0.66
Behavior		
Enter restricted area	1.41	0.99-2.04
Judgment / Driving error	1.04	0.70-1.61
Pre-existing health condition*	0.32	0.21-0.52
Running	R	R
Preparedness		
Minimal footwear*	1.78	1.40-2.30
Minimal clothing*	2.42	1.85-3.15
Physical conditioning	R	R
Minimal drinking water*	0.45	0.18-1.16
No flashlight*	0.49	0.32-0.73

+ Indicates that the covariate was removed from the model during the backward elimination procedure.
R Indicates the category serving as a reference category.
* $P < .05$.

Table 43. Logistic regression analysis of visitor factors related to minor injuries.

Independent variables	Odds ratio	95% Confidence Interval
Gender		
Male	R	R
Female*	1.17	1.03-1.34
Age Group		
0-9*	5.25	2.44-11.3
10-19*	2.83	1.31-6.14
20-29*	2.84	1.30-6.18
30-39	R	R
40-49*	3.11	1.41-6.85
50-59	1.53	0.69-3.37
60-69*	2.31	1.08-4.92
70-79*	2.20	1.02-4.69
80-89*	2.97	1.34-6.68
Behavior		
Enter restricted area*	0.66	0.45-0.96
Judgment / Driving error*	0.51	0.33-0.79
Pre-existing health condition	0.82	0.52-1.29
Running	R	R
Preparedness		
Minimal footwear*	1.78	1.28-2.48
Minimal clothing*	1.46	1.03-2.08
Physical conditioning	R	R
Minimal drinking water*	4.13	1.98-8.65
No flashlight*	11.4	7.56-17.3

R Indicates that this category serves as a reference category.
* $P < .05$.

conditions." The results from logistic regression displayed in Tables 44-47 show that despite the hypothesis, no built environmental factors are significantly associated with visitor fatalities (Table 44). Instead, natural environmental factors such as minimal light conditions and rugged terrain are significantly associated with visitor fatalities (Table 44). Moreover, no natural or built environmental factors are significantly associated with severe injuries, and no built environmental factors are significantly associated with moderate or minor injuries (Tables 45 - 47). However, natural environmental factors such as lava, steam, and hot water were significantly associated with moderate injures (Table 46) whereas weather and rugged terrain were significantly associated with minor injuries (Table 47).

The Effect of Indirect Supervision and Sign Placement on Injury Severity

The final research question asked in this dissertation investigates the effectiveness of a combined treatment of sign placement and indirect park personnel supervision on visitor injury severity at the Eruption Site. Hypothesis 4a suggests that both the frequency and severity of injuries will be reduced in areas of the park treated with a combined presence of parks signs and indirect supervision by park staff. However, the results of the chi-square tests of independence performed to examine the effect of indirect supervision and sign placement on the severity of visitor injuries at the Eruption Site (Tables 48-51) show no significant effect on fatal injuries ($X^2 = 0.00$; df = 1; P = 0.985), severe injuries ($X^2 = 0.635$; df = 1; P = 0.426), moderate injuries ($X^2 = 0.001$; df = 1; P = 0.972), or minor injuries ($X^2 = 1.262$; df = 1; P = 0.261). Out of a

Table 44. Logistic regression analysis of environmental factors related to fatal injuries.

Independent variables	Odds ratio	95% Confidence Interval
Natural environment		
Volcanic fumes	3.11	0.27-35.6
Lava	3.80	0.37-38.7
Natural fire	6.06	0.61-60.3
Steam / hot water	0.00	0.00-0.00
Insect	0.00	0.00-0.00
Darkness*	119.7	6.10-235.9
Weather	2.08	0.20-21.9
Rugged terrain*	10.6	0.97-115.7
Animal contact	R	R
Geologic	0.00	0.00-0.00
Built environment		
Trail	0.00	0.00-0.00
Roadway	0.33	0.06-0.78
Building / Structure	R	R
Parking lot	0.00	0.00-0.00
Aircraft failure	0.11	0.04-0.21

R Indicates that this category serves as a reference category.
* $P < .05$.

Table 45. Logistic regression analysis of environmental factors related to severe injuries.

Independent variables	Odds ratio	95% Confidence Interval
Natural environment		
Volcanic fumes	1.00	0.00-0.00
Lava	1.00	0.00-0.00
Natural fire	1.00	0.00-0.00
Steam / hot water	R	R
Insect	1.00	0.00-0.00
Darkness	1.00	0.00-0.00
Weather	1.00	0.00-0.00
Rugged terrain	1.00	0.00-0.00
Animal	1.00	0.00-0.00
Geologic	1.00	0.00-0.00
Built environment		
Trail	1.00	0.00-0.00
Roadway	R	R
Building / Structure	1.00	0.00-0.00
Parking lot	1.00	0.00-0.00
Aircraft failure	1.00	0.00-0.00

R Indicates that this category serves as a reference category.
* P < .05.

Table 46. Logistic regression analysis of environmental factors related to moderate injuries.

Independent variables	Odds ratio	95% Confidence Interval
Natural environment		
Volcanic fumes	0.54	0.19-1.50
Lava*	0.18	0.07-0.47
Natural fire	0.03	0.01-0.10
Steam / hot water*	0.24	0.06-1.03
Insect	R	R
Darkness	0.55	0.21-1.46
Weather	0.77	0.30-1.98
Rugged terrain	0.49	0.19-1.30
Animal	0.81	0.32-2.05
Geologic	0.00	0.00-0.00
Built environment		
Trail	0.00	0.00-0.00
Roadway	R	R
Building / Structure	0.00	0.00-0.00
Parking lot	0.00	0.00-0.00
Aircraft failure	0.00	0.00-0.00

R Indicates that this category serves as a reference category.
* $P < .05$.

Table 47. Logistic regression analysis of environmental factors related to minor injuries.

Natural environment		
Volcanic fumes	0.45	0.17-1.22
Lava	0.54	0.21-1.38
Natural fire	0.00	0.00-0.00
Steam / hot water	1.89	0.45-8.03
Insect	0.00	0.00-0.00
Darkness	0.77	0.29-2.05
Weather*	0.23	0.09-0.60
Rugged terrain*	0.28	0.11-0.74
Animal contact	R	R
Geologic	3.30	0.74-14.86
Built environment		
Trail	0.00	0.00
Roadway	R	R
Building / Structure	0.00	0.00
Parking lot*	0.26	0.10-0.68
Aircraft failure	0.00	0.00

R Indicates that this category serves as a reference category.
* P < .05.

Table 48. Chi-square test of independence examining the effect of indirect supervision and sign placement on fatal injuries at the Eruption Site.

			FATAL		Total
			No	Yes	
Indirect Supervision and Sign Placement	No	Count	1178	22	1200
		Expected Count	1177.4	22.6	1200.0
		% within Treatment	98.2%	1.8%	100.0%
		% within FATAL	38.3%	37.3%	38.3%
		% of Total	37.6%	.7%	38.3%
	Yes	Count	1900	37	1937
		Expected Count	1900.6	36.4	1937.0
		% within Treatment	98.1%	1.9%	100.0%
		% within FATAL	61.7%	62.7%	61.7%
		% of Total	60.6%	1.2%	61.7%
Total		Count	3078	59	3137
		Expected Count	3078.0	59.0	3137.0
		% within Treatment	98.1%	1.9%	100.0%
		% within FATAL	100.0%	100.0%	100.0%
		% of Total	98.1%	1.9%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.024[b]	1	.878		
Continuity Correction [a]	.000	1	.985		
Likelihood Ratio	.024	1	.877		
Fisher's Exact Test				1.000	.497
Linear-by-Linear Association	.024	1	.878		
N of Valid Cases	3137				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 22.57.

Table 49. Chi-square test of independence examining the effect of indirect supervision and sign placement on severe injuries at the Eruption Site.

			SEVERE		
			No	Yes	Total
Indirect Supervision and Sign Placement	No	Count	760	440	1200
		Expected Count	749.0	451.0	1200.0
		% within Treatment	63.3%	36.7%	100.0%
		% within SEVERE	38.8%	37.3%	38.3%
		% of Total	24.2%	14.0%	38.3%
	Yes	Count	1198	739	1937
		Expected Count	1209.0	728.0	1937.0
		% within Treatment	61.8%	38.2%	100.0%
		% within SEVERE	61.2%	62.7%	61.7%
		% of Total	38.2%	23.6%	61.7%
Total		Count	1958	1179	3137
		Expected Count	1958.0	1179.0	3137.0
		% within Treatment	62.4%	37.6%	100.0%
		% within SEVERE	100.0%	100.0%	100.0%
		% of Total	62.4%	37.6%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.697[b]	1	.404		
Continuity Correction [a]	.635	1	.426		
Likelihood Ratio	.698	1	.404		
Fisher's Exact Test				.426	.213
Linear-by-Linear Association	.696	1	.404		
N of Valid Cases	3137				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 451.00.

Table 50. Chi-square test of independence examining the effect of indirect supervision and sign placement on moderate injuries at the Eruption Site.

			MODERATE		
			No	Yes	Total
Indirect Supervision and Sign Placement	No	Count	681	519	1200
		Expected Count	680.5	519.5	1200.0
		% within Treatment	56.8%	43.3%	100.0%
		% within MODERATE	38.3%	38.2%	38.3%
		% of Total	21.7%	16.5%	38.3%
	Yes	Count	1098	839	1937
		Expected Count	1098.5	838.5	1937.0
		% within Treatment	56.7%	43.3%	100.0%
		% within MODERATE	61.7%	61.8%	61.7%
		% of Total	35.0%	26.7%	61.7%
Total		Count	1779	1358	3137
		Expected Count	1779.0	1358.0	3137.0
		% within Treatment	56.7%	43.3%	100.0%
		% within MODERATE	100.0%	100.0%	100.0%
		% of Total	56.7%	43.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.001[b]	1	.972		
Continuity Correction [a]	.000	1	1.000		
Likelihood Ratio	.001	1	.972		
Fisher's Exact Test				1.000	.501
Linear-by-Linear Association	.001	1	.972		
N of Valid Cases	3137				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 519.48.

Table 51. Chi-square test of independence examining the effect of indirect supervision and sign placement on minor injuries at the Eruption Site.

			MINOR		
			No	Yes	Total
Indirect Supervision and Sign Placement	No	Count	981	219	1200
		Expected Count	993.1	206.9	1200.0
		% within Treatment	81.8%	18.3%	100.0%
		% within MINOR	37.8%	40.5%	38.3%
		% of Total	31.3%	7.0%	38.3%
	Yes	Count	1615	322	1937
		Expected Count	1602.9	334.1	1937.0
		% within Treatment	83.4%	16.6%	100.0%
		% within MINOR	62.2%	59.5%	61.7%
		% of Total	51.5%	10.3%	61.7%
Total		Count	2596	541	3137
		Expected Count	2596.0	541.0	3137.0
		% within Treatment	82.8%	17.2%	100.0%
		% within MINOR	100.0%	100.0%	100.0%
		% of Total	82.8%	17.2%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.373[b]	1	.241		
Continuity Correction [a]	1.262	1	.261		
Likelihood Ratio	1.366	1	.243		
Fisher's Exact Test				.244	.131
Linear-by-Linear Association	1.373	1	.241		
N of Valid Cases	3137				

a. Computed only for a 2x2 table

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 206.95.

total 3,137 recorded injuries at the Eruption Site, 59 were fatal injuries, 1,179 were severe injuries, 1,358 were moderate injuries, and 541 were minor injuries. Out of those injuries, 1,200 involved visitors who did not experience the indirect supervision and sign placement treatment and 1,937 visitors who did. For the fatal injuries, 22 (1.8%) were non-treated visitors and 37 (1.9%) were treated visitors (Table 48). For the severe injuries, 440 (36.7%) were non-treated and 739 (38.2%) were treated visitors (Table 49). For moderate injuries, 519 (43.3%) were non-treated visitors and 839 (43.3%) were treated visitors (Table 50). For minor injuries, 219 (18.3%) were non-treated visitors and 322 (16.6%) were treated visitors (Table 51).

CHAPTER V

DISCUSSION AND CONCLUSIONS

Differences in the Frequency, Severity, and Distribution of Visitor Injuries

This dissertation is among the first studies to examine visitor injuries in national parks and the first to utilize the Haddon framework to examine visitor injuries and the factors contributing to these injuries in Hawaii Volcanoes National Park. The Haddon Matrix offers a foundation for injury research and because of its simplicity and comprehensiveness, it is an ideal framework to use when investigating injuries in national parks. The idea behind the Haddon Matrix is to examine injuries in terms of contributing factors and when used correctly, identify the host, agent, and environmental factors that lead to unhealthy outcomes. When translated into a recreational context such as that found in a national park, host factors become visitor factors, environmental factors become the natural and built environmental factors present in a park, and the agent / energy factors depend on the type of activity the visitor participates in and / or the type of energy to which the visitor is exposed to during the activity.

In this dissertation, data from all visitor case incident reports in Hawaii Volcanoes National Park were analyzed to examine the visitor and environmental factors contributing to visitor injuries and the differences in the frequency, severity, and distribution of visitor injuries within the park from 1993-2002. The results of this dissertation clearly do not support Hypothesis 1a that frontcountry destinations within the park will have the more injuries than other areas of the park. As was shown in the results in Chapter IV, even though 26% of all visitor injuries in Hawaii Volcanoes

National Park do occur in frontcountry destinations, the majority of injuries (53%) occur at the Eruption Site. Even though baseline visitation numbers for the different regions of Hawaii Volcanoes National Park do not exist, the high occurrence of injuries at the Eruption Site is a concern for park management who feel that less that half of the total number of visitors to Hawaii Volcanoes National Park ever visit the Eruption Site. Close to half of the park visitors enter the park on tour buses that are unable to and not permitted to access the lower half of Chain of Craters Road leading to the Eruption Site.

In contrast to injury frequency, Hypothesis 1b suggests that the severity of injuries in Hawaii Volcanoes National Park will be highest in backcountry regions. The results in Chapter IV, however, demonstrate that fatal incidents are most common in roadway environments and severe injuries are most common at the Eruption Site. In fact, with only eight of the 268 fatalities and 55 of the 1,698 severe injuries, backcountry regions in Hawaii Volcanoes National Park account for the fewest number of fatal injuries and the second fewest severe injuries. Thus, Hypothesis 1b and ideas put forth by Dingwall, Fitzharris, and Owens[13] and Waller and Brink[75] suggesting that severe injuries will be more frequent in remote backcountry destinations is not supported by the findings of this dissertation

Despite the lack of support for Hypothesis 1a and Hypothesis 1b, when looking at the occurrence and distribution of visitor injuries in Hawaii Volcanoes National Park the results do identify a number of injury patterns and key areas of concern within the park. For example, when combined together, the data indicates that the Eruption Site and frontcountry destinations account for 79% of the all injuries in the park. Specifically, it is the Eruption Site and Kilauea Visitor Center (frontcountry destination) that have the highest number of injuries in the park. Moreover, the emerging severity pattern demonstrates that most fatal incidents occur on roadway environments, the most severe injuries occur at the Eruption Site and in frontcountry destinations, the most moderate injuries occur at the Eruption Site and in frontcountry destinations, and the most minor injuries occur in frontcountry areas and at the Eruption Site. Closure examination of the severity pattern highlights that 122 of the 130 (94%) roadway fatalities and 122 of the 268 (46%) total park fatalities occur on Highway 11 while the only other locations within the park with more than 10 fatalities are the Eruption Site (65) and the slopes of Mauna Loa Volcano (39). Moreover, the emerging severe, moderate, and minor injury trends show that in contrast to fatal injuries, the most severe injuries in the park occur at the Eruption Site, Highway 11, Kilauea Visitor Center, Sulfur Banks, and Chain of Craters Road, the most moderate injuries occur the Eruption Site and Kilauea Visitor Center, and the most minor incidents transpire at the Eruption Site and Kilauea Visitor Center.

Relationship between Visitor Factors and Injury Severity

The second research question and Hypotheses 2a-2d focus on the relationship between visitor factors and the severity of visitor injuries in Hawaii Volcanoes National Park. Specifically, Hypothesis 2a suggests that injury severity will be higher for male visitors, Hypothesis 2b suggests that injury severity will be higher in visitors older than 50 years of age, Hypothesis 2c suggests that injury severity will be higher for visitors wearing minimal footwear such as slippers, and Hypothesis 2d suggests that injury severity will be higher for visitors entering restricted areas.

The findings from the logistic regression presented in Chapter IV demonstrate that female status is in fact a statistically significant visitor factor in fatal and minor incidents and that male status is not a significant in any severity category. In addition, both gender categories were removed during the backward elimination process for severe and moderate injuries. This suggests that in contrast to the findings of other researchers in Australia[6], New Zealand[7], and Vermont[51], more female visitors to Hawaii Volcanoes National Park incurred fatal and minor injuries than male visitors. This finding is further supported by the injury tabulations which indicate that female visitors incurred 949 more injuries than males and a higher injury number of injuries than males in all severity categories. Likewise, more female visitors are injured than males in frontcountry destinations, backcountry destinations, airway environments, and at the Eruption Site. The lone exception to this trend is the roadway environment where injuries to male visitors are more than double that of female visitors despite female visitors sustaining more roadway fatalities than males.

In regard to visitor factors other than gender, the findings of the logistic regression show that no age category is a significant factor in visitor fatalities in Hawaii Volcanoes National Park which is likely the result of the small number of fatalities in the analysis. However, visitors aged 50-59 years is a significant factor in severe injuries and supports Hypothesis 2b. Park visitors aged 10-19 years and 80-89 years are significant in moderate injuries, and visitors aged 0-9 years, 10-19 years, 20-29 years, 40-49 years, 60-69 years, 70-79 years, and 80-89 years are significant in minor injuries. With the exception of visitor fatalities, this indicates a trend of increasing injury severity for visitors older than 50 years of age that supports the findings of the previous studies in Australia[6], New Zealand[7], and Vermont[51] and the hypothesis that severe injuries will have a significant relationship with visitors older than 50 years. As well, it also points to the vulnerability of younger and elderly age groups.

It is interesting to note the different trends exhibited in different regions of the park. For example, the majority of frontcountry injuries in this study were minor injuries predominated by visitors aged 0-9 and 50-59 years, the majority of backcountry injuries were also minor injuries predominated by those 50-59 years and 20-29 years of age, and the majority of airway incidents were fatal incidents predominated by visitors aged 50-59 years. Moreover, roadway trends show visitors aged 20-29, 50-59, and 10-19 accounting for most of the fatalities, visitors aged 50-59 accounting for the most frequent number of severe injuries, and visitors aged 50-59, 60-69, and 20-29 accounting for the majority of moderate injuries and minor injuries. With the exception of fatalities, the trend at the Eruption Site also reflects the vulnerability of youth and age. Visitors to the Eruption Site aged 0-9 years account for the most minor injuries, visitors age 50-59 and 0-9 years account for the most moderate injuries, and visitors aged 50-59 and 60-69 account for the most severe injuries.

When looking at the role behavioral factors play in injury severity in Hawaii Volcanoes National Park, the findings of the logistic regression report no significant relationship between any behavioral factor and visitor fatalities. However, pre-existing health conditions and visitors entering restricted areas are both significant factors related to severe injuries, pre-existing health factors are significant in moderate injuries, and entering restricted areas is significant factors in minor injuries. The impact of pre-existing health conditions is most pronounced in frontcountry areas of the park where it is a contributing factor in 34 of the 234 severe frontcountry incidents. Moreover, the impact of visitors entering restricted areas is most pronounced in frontcountry areas where it is a contributing factor in 10 of the 23 frontcountry fatalities, and at the Eruption Site where it is a contributing factor in 32 of 59 (54%) fatalities and 393 of the 1,179 (33%) severe injuries. It is important to note that even though the injury tabulations point to visitors entering restricted areas as a frequent factor contributing to fatal and severe injuries at the Eruption Site and fatalities in frontcountry destinations, the findings of the logistic regression does not support Hypothesis 2d that injury severity will be higher for visitors entering restricted areas. Instead, the analysis indicates that pre-existing health conditions are most likely to contribute to severe injuries. This finding, however, should not marginalize the contribution of restricted area access to visitor injuries but rather serve notice to the importance of pre-existing health conditions.

In comparison to behavioral factors, visitor preparedness factors play a more obvious role in injury severity. The logistic regression indicates that visitors carrying minimal amounts of drinking water, visitors wearing minimal footwear and clothing, and visitors with no flashlight are all significant factors contributing to fatal, severe, moderate, and minor injuries. Therefore, while these findings appear to support Hypothesis 2c that injury severity will be higher for visitors wearing minimal footwear, it is important to note from the analysis that minimal drinking water is more likely to contribute to visitor fatalities than minimal footwear. Conversely, the hypothesis is supported by the analysis of severe injuries which indicates that minimal footwear is the preparedness factor most likely to contribute to severe injuries.

Outside of the logistic regression analysis, a look at the tabulated data indicates that preparedness factors play a minimal role in frontcountry injuries by contributing to only 231 of the 1,542 frontcountry incidents. However, preparedness factors were more pronounced in backcountry incidents where they contribute to 249 of the 357 total injuries. In both frontcountry and backcountry regions, minimal footwear and minimal amounts of drinking water are the most frequent preparedness factors contributing to visitor injuries. However, at the Eruption Site, minimal footwear and no flashlight are the two preparedness factors contributing most to visitor injuries. The absence of a flashlight contributes to 525 of the 1,179 (45%) severe injuries whereas minimal footwear contributes to 222 of the 1,179 (19%) severe injuries. Moreover, minimal footwear and the lack of a flashlight contribute to 36% and 20% of the moderate injuries and minimal footwear contributes to over a third of the minor injuries. This suggests that even though preparedness factors play a minimal role in frontcountry regions of the park, factors such as drinking water and footwear play an important role in backcountry areas, footwear plays an import role in injuries at the Eruption Site, and flashlights play an important role in severe injuries at the Eruption Site.

Relationship between Environmental Factors and Injury Severity

Similar to the visitor factors, the findings of the logistic regression also identifies a number of trends. For example, the findings support Hypothesis 3a that injuries in the built environment will be less severe than those in the natural environment. No statistically significant relationship is identified between built environmental factors and fatal, severe, or moderate injuries. In fact, parking lot factors are the only built environmental factor contributing to minor injuries. Moreover, most of these minor injuries occur in parking areas at Kilauea Visitor Center and Jaggar Museum and consist of slips, trips, and falls on unpainted speed bumps and brick-style curbs.

The findings of the logistic regression also supports Hypotheses 3b that injury severity will be higher during minimal light conditions. For example, the logistic regression identifies a significant relationship between natural environmental factors such as minimal light conditions, rugged terrain, and fatal incidents. However, no natural factor displays a significant relationship with severe injuries. Contact with steam / hot water and active lava flows contribute to moderate injuries and rugged terrain and weather factors do display a significant relationship with minor injuries. It is interesting to note that minimal light conditions play a minimized role in airway incidents, backcountry incidents, and at popular frontcountry destinations such as Kilauea Visitor Center, Jaggar Museum, Thurston Lava Tube, and Sulfur Banks. However, minimal lighting is a factor identified in 47 of 130 fatal road incidents and 76 of the 220 and 58% of fatalities, 66% of severe injuries, and 51% moderate injuries at the Eruption Site.

Nature and Type of Injuries

As discussed in Chapter II, the study of visitor injuries in eight national park units in California found lacerations, scrapes and abrasions, sprains, fractures, and broken bones to be the most common types of injury.[55] This dissertation also shows frequent lacerations, scrapes and abrasions, fractures and broken bones, and sprains and strains to be the most common types of injuries. In addition, the findings of this dissertation also mirror the injury research carried out by the National Center for Health Statistics[107] that were discussed in Chapter II. For example, one of the findings of the work done by the National Center for Health Statistics is that females were more likely to sustain a higher number of fractures than males. When broken down by gender, this dissertation indicates that lacerations, scrapes and abrasions, and sprains and strains were the most frequent male injuries and lacerations, scrapes and abrasions, and fractures and broken bones are the most frequent injuries to females visitors in Hawaii Volcanoes National Park.

Further examining the nature and type of injuries to male and female visitors in Hawaii Volcanoes National Park, the data shows that lacerations are more common in male visitors aged 0-9, 10-19, and 50-59 years of age and female visitors aged 50-59 and 0-9 years. Moreover, scrapes and abrasions are most common in males aged 0-9 years and females aged 50-59, 0-9, and 60-69 years, sprains and strains are most common in male and female visitors aged 50-59 years and 60-69 years, and fractures and broken bones are most common in female visitors aged 50-59 and 60-69 years. This again points to the vulnerability of the youth and elderly in the park and is a pattern further identified in less common injuries. For example, dehydration and heat exhaustion is most common in females aged 50-59 years, respiratory irritations and asthmatic incidents are most frequent in male and female visitors aged 0-9 and 50-59 years, and allergic reactions are most common in male and female visitors aged 0-9 and 50-59 years of age.

Distribution of the Nature and Type of Injuries by Location

As displayed in Chapter IV, injuries in Hawaii Volcanoes National Park are most common at the Eruption Site followed by injuries in frontcountry areas, roadway environments, backcountry areas, and the airway environment. In addition, fatalities are most common in roadway environments, severe and moderate injuries are most common at the Eruption Site, and minor injuries are most common in frontcountry areas. When looking at the nature and type of injuries in each of these areas individually, fractures and broken bones are the most common injuries in the roadway environment. Minor sprains and strains account for 205 of the 309 total sprains and strains whereas fractures and broken bones account for 125 of the 130 roadway fatalities. Likewise, fractures and broken bones are the most common airway injuries with head and neck injuries accounting for 40 of the 48 airway fatalities and fractures and broken bones contributing to all of the fatalities. Compared to the nature and type of airway and roadway injuries, most of the backcountry incidents were minor incidents with dehydration and exhaustion accounting for 139 of the total 357 backcountry incidents of which 124 were classified as minor incidents.

The only two regions within the park that initially appear to have any similarities in the nature and type of injuries sustained by visitors are the Eruption Site and frontcountry regions. Lacerations, and scrapes and abrasions are the most common injuries sustained in these areas yet closer examination of the nature and types of injuries actually shows a number of distinctions between these areas. For example, in frontcountry areas of the park, fractures and broken bones are the leading cause of death, cardiac distress is the most common serious injury, lacerations are the most common moderate injuries, and scrapes and abrasions are the most common minor injury. At the Eruption Site, respiratory irritation and asthma incidents are the leading cause of death, lacerations are the most common severe and moderate injury, and scrapes and abrasions are the most common minor injuries. An explanation for the differences between the two areas is the increased presence of volcanic gases at the Eruption Site which could lead to more respiratory and asthmatic problems for visitors. In fact, the only frontcountry destination with increased levels of volcanic fumes is Sulfur Banks and the nature and type of injuries at this location is vastly different than other frontcountry areas. For example, respiratory irritation and asthmatic reactions are the most frequent incident at Sulfur Banks followed by cardiac distress which accounts for 30 of the 34 severe incidents at Sulfur Banks. The type of substrate and terrain found at the Eruption Site and at frontcountry areas could account for further injury differences. For example, the substrate and terrain at the Eruption Site consists of a rugged uneven basaltic terrain with a silica composition of approximately 44%. When compared to the relatively smooth surfaces and trails found at Kilauea Visitor Center and Jaggar Museum, any slip, trip, or fall at the Eruption Site would result in a more serious injury.

Injury Control and Prevention

As previously discussed in Chapter II, the ultimate goal of research investigating the factors contributing to injuries is to develop strategies that reduce the occurrence and severity of injuries.[114] This dissertation concentrates largely on the assessment of visitors injuries at Hawaii Volcanoes National Park but also examines the efficacy of sign placement and indirect supervision by park personnel in reducing the occurrence and severity of injuries at the Eruption Site. Hypothesis 4a suggests that injury frequency and severity will be reduced in locations with a combined treatment of signs and indirect supervision by park staff. The Eruption Site in Hawaii Volcanoes National Park is the only location in the park where this type of injury control approach is employed and unfortunately, the results of this dissertation indicate that the combination of sign placement and indirect supervision has no significant effect on the reduction of fatal, severe, moderate, or minor injuries. This does not mean that this combination will not be effective in other situations but it does suggest that the use of signs and indirect supervision to control and prevent injuries to visitors at the Eruption Site is not as effective as desired.

Included in the Haddon Matrix are three temporal phases representing the pre-injury event phase, the injury event phase, and the post-injury event stage. Haddon's fifth countermeasure strategy recommending the separation of a susceptible host from the injury environment by space and time and the three fundamental injury prevention strategies discussed in Chapter II all point to injury prevention measures taken during the pre-injury phase. The three fundamental injury prevention strategies discussed in Chapter II are: 1) persuade persons at risk to change their behavior, 2) require change by law or administrative rule, and 3) provide automatic protection through product and environmental design.[115] Given the failure of the signs and indirect supervision of the first strategy, the lack of significance found among the environmental factors, and the significance of visitor factors contributing to visitor injuries, an approach requiring change by law or administrative rule at the Eruption Site may be the best approach for Hawaii Volcanoes National Park. Specifically, closing public access to the Eruption Site has the potential for reducing 53% of all injuries in the park, 22% of all fatalities in the park, and 69% of all severe injuries in the park. The present mission statement of Hawaii Volcanoes National Park states that the mission of the park is to, "protect, conserve, and study the volcanic landscapes and associated natural and cultural resources and processes in the park, and to facilitate safe public access to active volcanism, diverse geographic settings, and wilderness for public education and enjoyment." Given the discretionary authority of park superintendents in national parks, if the superintendent of Hawaii Volcanoes National Park deems the Eruption Site to be an unsafe location or a location in conflict with the National Park Service management policy and Director's Order 50B described in Chapter I, the park has the full authority to close the Eruption Site to public access. This may require the park to change their organizational practices and policies but developing strategies involving more direct supervision and the barriers suggested by Haddon in his countermeasures may be more effective than developing visitor education strategies unless they are done in combination with a change of law or administrative rule. In addition, such an approach would enable the park to take a preventative approach in the pre-injury phase of the Haddon Model rather than the reactive approach in the post-injury phase in which the park is presently functioning.

Even though this dissertation does not examine injury prevention and control techniques in areas of the park other than the Eruption Site, the results display a need for such countermeasures to be developed. For example, developing countermeasure strategies that prevent visitors from entering restricted areas and informing them of the potential consequences of their actions, the activities they are participating in, and the potential for injury due to their pre-existing health conditions could help reduce the frequency and severity of cardiac and respiratory incidents in frontcountry destinations such as Sulfur Banks. Likewise, other Haddon countermeasures that involve modifying the contact surface, subsurface, or basic structure would likely reduce the number of minor scrapes and abrasions and sprains and strains at Kilauea Visitor Center and Jaggar Museum.

Limitations of Data

This dissertation has a number of limitations. First, when possible, injuries are reported as rates per population which in this particular study would be the rate per the number of visitors to the park or the number of visitors to a specific region of the park. The absence of denominator data reporting the number of visitors to Hawaii Volcanoes National Park and the number visits to different regions of the park make it impossible to determine the actual risk of an injury occurring in the future or the rate of injuries that have occurred in the past. As well, it prevents the comparison of different rates between frontcountry, backcountry, roadway, airway, and Eruption Site incidents. Denominator data could be collected for Hawaii Volcanoes National Park by systematically monitoring visitor levels at different destinations in the park throughout the year. The lack of denominator data, however, should not devalue the findings of this dissertation because an injury rate is essentially the occurrence per specified unit of exposure and standing alone, such a rate does not indicate anything about whether or not the factors contributing to an injury can be mitigated.

A second possible limitation of this study is the use of case incident reports and the potential for biases that must be considered when using secondary data. For example, the study of wilderness injuries by Montalvo et al.,[17] in eight national park units in California raises concerns about the potential for reporting biases such as the underreporting of injuries when visitors feel they are either to blame for their injury, are too embarrassed to report their injury, or view their injury as too minor to report. As was deemed the case in the California study, if there is any underreporting bias in the case incident reports in Hawaii Volcanoes National Park, it is probable that minor injuries are less likely to be formally reported than severe injuries. Moreover, it is important to recognize the potential difficulty in working with secondary databases that have been developed or collected for purposes other than the present research. For instance, the case incident reports from Hawaii Volcanoes National Park do not include information about visitor's previous knowledge, experience, perceptions, and attitudes unless they were specifically mentioned in the narrative statement section of the report. Thus, any analysis of the potential role these factors could play in a visitor injury is impossible. Nonetheless, it is important to point out that previous researchers state that knowing the frequency and severity of injuries, the nature and type of injuries, and the factors contributing to injuries is more important to designing prevention programs than understanding the perceptions and attitudes of individuals because these latter factors do not necessarily translate into action.[5] In addition, even though the information in secondary databases may appear restrictive, they do generally provide information for a larger number of people, are less expensive and time consuming than primary data collection, and they were not collected for present research purposes may actually be a strength because they lack biases that might exist in the data.

Recommendations

There are a number of recommendations that can be made as a result of this dissertation. First, given that the vast majority of visitors injured in Hawaii Volcanoes National Park are tourists, it could be beneficial for the park to develop community relations and visitor education strategies with local tourism providers. Such a strategy could include supplying local tour guides, hotels, and rental agencies with a clear and simple, current information sheet about the nature of each access area in Hawaii Volcanoes National Park. For example, information about the hazards associated with driving on Highway 11, the hazards present in the park that could exacerbate pre-existing health conditions, the hazards associated with entering restricted areas, and the need to have proper footwear, clothing, water, and flashlights prior to arriving at particular locations in the park could help increase awareness. Hawaii Volcanoes National Park has recently started employing an Eruption Update telephone service allowing visitors to call ahead and receive updated recorded message about the conditions at the Eruption Site as well as visitor safety information. Efforts such as these should be continued.

A second recommendation is for Hawaii Volcanoes National Park to further investigate the use and effect of warning signs. Even though the results of this dissertation suggest that a combined treatment of indirect supervision and sign placement have no effect on the reduction of injuries at the Eruption Site, nothing is known about the effectiveness of the messages presented to visitors on the signs. Research examining a differentiation between safety signs and general information signs as well as graphic signs illustrating a clear consequence and text signs could be helpful in determining the best risk communication strategy to use at the Eruption. Such information could be attained by conducting a visitor survey assessing the awareness of existing and introduced signage and visitor behavior.

A third recommendation for Hawaii Volcanoes National Park is to examine the possibility of controlling access to the Eruption Site and directing visitors via rope closures to the least hazardous part of the area. This would involve an increased monitoring of the conditions at the Eruption Site as well as additional staff resources. The presence of more uniformed rangers at the Eruption site may increase visitor compliance on entering restricted areas and serve as a non-confrontational source of safety information from a credible source.

A final recommendation is for the management at Hawaii Volcanoes National Park to explore the concept of acceptable risk. The concept of acceptable risk is not particularly easy to define but is essentially a measure of the risk of injury arising from a visit to Hawaii Volcanoes National Park that will be tolerated by park management. This risk may be considered from a number of angles such as an economic or legal perspective. From an economic perspective, the park may decide to tolerate minor and moderate incidents and concentrate on reducing severe and fatal incidents that often have high manpower costs, search and rescue costs, and helicopter or emergency ground transport costs associated with them. From a legal perspective, Hawaii Volcanoes National Park may consider concentrating on injuries or potential situations that could result in an injury and tort claim filed against the park. For example, some tort claims result from negligence in failing to give adequate warnings or to protect visitors against hazardous conditions. The Federal Tort Claims Act defines liability by reference to state liability standards so Hawaii Volcanoes National Park would need to reference the state liability standards set in the Hawaii Recreational Use Statute.

Conclusion

With the popularity of recreating in U.S. National Parks increasing, the U.S. National Park Service has recognized visitor safety as a critical component of protected area management. While it is the policy of the National Park Service to provide an opportunity for the public to have an enjoyable experience when visiting National Park Service sites, the service also recognizes that accidents and injuries can compromise that experience.[14] Thus, the National Park Service has established management policies stating that the saving of human life will take precedence over all other management policies.[14] A challenge in meeting these policies, however, is that prior research investigating injuries in national parks is limited and does not investigate the factors contributing to visitor injuries. In order to reduce this knowledge gap, the objective of this dissertation was to use the Haddon Model framework and injury data collected from Hawaii Volcanoes National Park to identify the distribution of injuries within Hawaii Volcanoes National Park, assess the relationship between visitor factors and environmental factors and the severity of injuries within the park, and determine the effectiveness of injury control measures implemented by park management. Specifically, this dissertation examined the differences in the frequency, severity, and distribution of visitor injuries throughout Hawaii Volcanoes National Park, the relationship between visitor factors and injury severity, the relationship between environmental factors and severity of visitor injuries, and the effectiveness of indirect supervision and sign placement on the severity of visitor injuries.

This dissertation reveals a number of key findings about visitor injuries in Hawaii Volcanoes National Park. First, the occurrence of injuries within the park is highest at the Eruption Site rather than frontcountry destinations. However, other than the Eruption Site, the specific location in Hawaii Volcanoes National Park with the second highest number of injuries is a frontcountry destination (Kilauea Visitor Center). When comparing injury severity at the two locations, the majority of injuries at Kilauea Visitor Center are minor injuries whereas the injuries at the Eruption Site are more severe. Second, severe injuries in Hawaii Volcanoes National Park are more common in the roadway environment rather than in the backcountry. In fact, a severity pattern emerging from the data indicates that most frequent fatalities in the park occur in the roadway environment and the most severe, moderate, and minor injuries occur at the Eruption Site. Of specific concern is Highway 11 because it accounts for nearly half of the 268 park fatalities between 1993-2002.

This dissertation also reveals that injury severity in Hawaii Volcanoes National Park is higher for female visitors than male visitors. In fact, with the exception of the road environment, female visitors account for more injuries in all areas of the park and the logistic regression analysis shows female status to be a significant factor in fatal and minor incidents. Male status, on the other hand, is not significant in any severity category. While no age category is significant in fatal incidents, age category 50-59 years is a significant factor contributing to severe injuries, ages 10-19 and 80-89 are significant categories contributing to moderate injuries, and ages 0-9, 10-19, 20-29, 40-49, 60-69, 70-79, and 80-89 years are significant categories contributing to minor injuries. When comparing age and injury severity categories in different areas of the park, the majority of frontcountry injuries are minor injuries involving visitors 0-9 and 50-59 years, the majority of backcountry injuries are minor injuries involving visitors 50-59 years and 20-29 years of age, and the majority of airway incidents were fatal incidents involving visitors aged 50-59 years. Roadway trends show visitors aged 20-29 and 50-59 accounting for the majority of roadway fatalities and visitors aged 50-59 years accounting for the most severe injuries. Moreover, visitors to the Eruption

Site aged 50-59 and 60-69 incur the most severe injuries, visitors age 50-59 and 0-9 years incur the most moderate injuries, and visitors 0-9 years of age incur the most minor injuries.

Visitor factors such as visitors wearing minimal footwear and clothing and visitors carrying minimal drinking water and no flashlight were found to be significant factors contributing to fatal, severe, moderate, and minor injuries in Hawaii Volcanoes National Park. Injuries associated with minimal footwear and drinking water are most pronounced in backcountry destinations whereas minimal footwear and failing to carry a flashlight is most pronounced at the Eruption Site. In addition, visitors entering restricted areas and visitors with pre-existing health conditions are significant factors contributing to severe injuries. Pre-existing health conditions such as cardiac, allergy, asthma, and other respiratory conditions are a specific concern for visitors to frontcountry destinations such as the Sulfur Banks and visitors entering restricted areas is a specific concern for the Eruption Site where it is a contributing factor in over half of the fatalities and one-third of the severe injuries. Moreover, built environmental factors appear to play a lesser role than visitor factors in visitor injuries. For example, the only built environmental factor found to significantly contribute any visitor injury are parking lot factors such as the unpainted speed bumps and brick-style curbs at Kilauea Visitor Center and Jaggar Museum contributing to minor injuries. As well, minimal light conditions and rugged terrain are the only environmental factors contributing to fatal injuries, contact with lava and steam / hot water are the only environmental factors contributing to moderate injuries, and weather conditions and rugged terrain are the only environmental factors found to have a significant relationship to minor injuries. No significance is identified with between any environmental factor and severe injuries and the impact of minimal light / darkness conditions is most pronounced at the Eruption Site where it is a contributing factor identified in 58% of visitor fatalities and 66% of severe injuries.

The absence of denominator data reporting the number of visitors entering Hawaii Volcanoes National Park and the number of visits to different areas within the park limits the ability of this dissertation to determine the actual risk encountered by visitors to the park. As well, the use of case incident reports makes the study vulnerable to any reporting bias and does not include information about the knowledge, attitudes, perceptions, and experience of the injured visitor. However, any reporting bias most likely consists of an underreporting of minor injuries. The strength of this dissertation is that it provides a framework that can be used to assess injuries in other national parks or recreation destinations and it identifies information about the frequency and severity of injuries, the nature and type of injuries, and the factors contributing to injuries in Hawaii Volcanoes National Park. In fact, the ultimate goal of research investigating the factors that contribute to visitor injuries is to develop strategies that reduce the frequency and severity of injuries. The findings of this dissertation indicate that the use of signs and indirect supervision at the Eruption Site has no significant effect on the reduction of injuries at this location. However, given the significance of visitor factors in visitor injuries, the development of legal and administrative techniques that require visitors to stay outside of restricted areas and visit the area during maximum lighting conditions is strongly recommended. As well, future research concentrating on the development of countermeasures that prevent visitors from entering restricted areas and informing visitors of the potential injuries they may encounter throughout the park is also recommended.

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