Analysis of Search Incidents and Lost Person Behavior in Yosemite National Park

By

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Abstract

Every year thousands of people are reported lost or missing in wilderness areas and in response, a search and rescue (SAR) operation is launched to locate, stabilize, and extract those missing. Actually locating the subject is often the most difficult of these processes. This study attempts to improve upon search operations by analyzing lost person behavior at the “local” level. If a search manager knew what a lost subject was most likely to do when lost, then they could plan the search accordingly and return them to safety much quicker. Additionally, if National Park officials knew who was becoming lost, and when and where this occurred, steps could be taken to prevent these people from becoming lost in the first place.

Eleven years (2000-2010) of Search and Rescue case incident reports from Yosemite National Park (2,308 in total) were examined and 213 searches were retained for analysis. It was determined that approximately 62% of incidents involve missing hikers. Nearly two thirds of the searches were for one subject and about two-thirds of these involved males. The mean age of missing persons was 36 years old. Most people were reported missing in July, on Saturday, and between the hours of 2 and 3 p.m. Almost half of people reported as missing were actually lost while others were merely separated from their party, or overdue. Contributing factors include losing the trail accidentally, failure to communicate the intended plan, and miscalculating the time or distance of the planned route, among others.

Within a Geographic Information System (GIS) the Initial Planning Point (IPP), the point at which the person was last seen or known to be, and the found location was georeferenced for each incident using the point radius method. This allowed for a Getis-Ord Gi* analysis to be conducted of both the IPPs and found locations and “hot spots” were identified for each. The GIS also provided an environment for analyzing lost person behavior. Within Yosemite National Park lost hikers most often utilized route travelling in order to reorient themselves. Additionally, descriptive lost person behavior statistics for hikers were calculated, including: horizontal distance from the IPP to the found location, vertical elevation change from the IPP to the found location, dispersion angle from intended destination to the found location, and the track offset of the found location. These “local” results were then compared to “international” statistics presented by the International Search and Rescue Incident Database (ISRID) using a chi-square goodness of fit test. It was found that the ISRID data provided for horizontal distance from the IPP and track offset were not suitable for use in Yosemite while the data pertaining to vertical elevation change from the IPP and the dispersion angle could potentially be utilized for search planning.

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I would like to thank Yosemite National Park (YNP), Yosemite Search and Rescue (YOSAR), the YNP Division of Resource Management and Science for research permissions, and the YNP Division of Visitor Protection for access to Search and Rescue case incident reports. More specifically, I would like to thank Keith Lober and Dov Bock for the opportunity to live and work in YNP for a summer. I want to thank John Dill for sharing with me his wisdom and experience in the field of search and rescue. I would also like to show my gratitude towards Werner and Marry Braun for allowing me to work in their office and for providing me with much needed breaks by taking me climbing. I also want to thank Joy Marschall, Wren Haaland, Greg and Diane Ambrose, and Raj Bolla for tirelessly scanning years of case incident reports. Without their help, the full scope of this study would not have been possible.

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“…while the individual man is an insoluble puzzle, in the aggregate he becomes a mathematical certainty. You can, for example, never foretell what any one man will do, but you can say with precision what an average number will be up to. Individuals vary, but percentages remain constant…”

- Sherlock Holmes

1. Introduction

1.1. Introduction

People seek recreation in non urbanized environments for a variety of reasons. Some seek adventure and excitement while others look for a reprieve from the chaos of everyday life. Occasionally though, whether by lack of preparation or unforeseen circumstances, people can get disoriented and become lost or become immobilized by injury or medical problems. If they do not arrive at their destination when expected, they will be reported missing. Once this happens, and authorities determine that there is an exigency, a search operation is launched to find them and return them to safety.

Search operations range in complexity from simple searches, involving just a few people on foot, to large-scale operations involving hundreds of individuals, search helicopters, and scent-tracking dogs. No matter the extent of the operation, the goal is always the same, to find the missing subject and return them to safety in the shortest amount of time possible. It is important to locate the lost individual quickly because the longer the person is exposed to the elements, the more likely they are to become severely injured or die (Adams 2007, Koester 2008).

A common search operation workflow can be described as follows. When a report of a lost person is made, authorities conduct initial interviews with those making the report. Officials then determine the urgency of the situation (search urgency) based on current weather conditions and the experience level and demographics of the lost person (Dill 2010). Trail blocks are then established in order to contain the lost person and a hasty search is performed at the Initial Planning Point, or IPP. The IPP can be defined as the point that is initially used to plan the search for a missing person. This point can be either the original Point Last Seen (PLS), the location the subject was last seen by an eyewitness, or the original Last Known Point (LKP), a location at which a significant clue places the missing subject.

If the lost person is not found within the first few hours, search planning specialists are contacted to conduct a more in depth investigation. Search perimeters are delineated and search segments, “area[s] that can be searched by a field team as part of a single unit,” are established (Koester 2008). Specialty teams such as scent tracking dogs, helicopters, and professional trackers are often utilized in addition to hiking ground units. The operation will continue to escalate until the subject is either found or until a situation is presented in which it is necessary to scale down the search or discontinue it all together. This is not uncommon, as most searchers are unpaid volunteers and at some point a decision is made that the benefits of searching (likelihood of detecting a viable person in need of help) do not outweigh the cost in terms of time, money, and/or risk of injury to searchers.

A geographic information system (GIS), “a computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information” (Bolstad 2008), can be used to improve the speed and efficiency of a search and rescue operation (Durkee and Glynn-Linaris 2012). A GIS can be used to draw search segments, calculate slope and aspect of a potential search area from a Digital Elevation Model (DEM), and analyze aerial imagery in order to interpret land cover and potential hazards. Resources used for the search can be readily managed with a GIS. Additionally, the search itself can be managed with global positioning system (GPS) tracks plotted to show where search teams have been and highlight areas that may need to be revisited. The use of GIS in Wilderness Search and Rescue (WiSAR) has only recently been formalized (Theodore 2009; Ferguson 2008) and new uses are continually emerging.

This research extends the use of GIS in search and rescue beyond simple tactical operations and into a more in depth search planning process, by using spatially explicit techniques to examine historic search incidents within Yosemite National Park. This is a novel research approach to search and rescue that has not been reported elsewhere. The information gained from this site specific retrospective study will provide valuable geographic knowledge to develop Preventative Search and Rescue programs and inform search planners in Yosemite. The study will also explore missing person behavior/outcome within the park and compare it to missing person behavior collected at the "international" level which will benefit SAR teams beyond Yosemite per se.

"Lost person behavior" has been a theoretical tool utilized by search managers since the 1970's, but it is now beginning to work its way into GIS processes that are used to plan searches for people lost in wilderness areas. The concept of lost person behavior is simple: if the search manager knew based on statistics what people were most likely to do after becoming disoriented, then he or she could conduct the search accordingly. Although it is difficult to ascertain exactly what a single person will do once lost, it is believed that their behavior can be inferred based upon their mental status (e.g. autistic, dementia, despondent), age, and their primary activity. As Heth and Cornell state, "Different patterns of travel may characterize persons who become lost while participating in different outdoor activities" (Heth and Cornell 1998). For instance, hikers tend to stay on trails while hunters wander off-trail, often through thick forest, in search of game.

Oftentimes, the data used to model lost person behavior comes from *Lost Person Behavior: A Search and Rescue Guide on Where to Look-For Land, Air and Water* written by Robert Koester, a researcher and search and rescue incident commander. This book is the result of years of data collection compiled in the International Search and Rescue Incident Database (ISRID). The ISRID project began in 2002 and had two main goals: “model previous lost person statistics in order to best predict where the current lost subject will be located, and predict the lost person’s likely survivability” (Koester 2008). *Lost Person Behavior* provides statistical tables with the intent that they be used as a guide to predict lost person behavior. These tables include information on horizontal distance from the initial planning point (IPP) in miles or kilometers (Figure 1.1), vertical elevation change from the IPP in feet (Figure 1.2), track offset for found location (Figure 1.3), dispersion angle from intended destination in degrees (Figure 1.4), survivability percent based on time, as well as a few other statistics. The data in these tables are derived from 16,863 individual cases collected up until the year 2007 with a majority of cases coming from the United States, New Zealand, Canada, and the United Kingdom. What is unique about this project is that Koester has separated the cases by ecoregion to account for behavioral differences based on the environment.

The ISRID statistics could be invaluable to a search manager; however Koester cautions that these data are no substitute for detailed local knowledge, and he suggests that data be collected at the “local” level to determine how lost persons are most likely to behave and where they are most likely to be found (Koester 2008). Due to limited resources and poor record keeping, this task may be nearly impossible to complete in some jurisdictions. Search managers must then rely on the next best thing – the ISRID database.

The information contained in the ISRID may be used to identify areas in which to search for a lost person and can help create a probability of area map allowing agencies to focus their efforts in areas where they are most likely to find the missing subject, in turn decreasing the time it takes to locate that person. This concept has been put into practice as a number of search teams have begun to rely on the ISRID statistics to create their initial probability of area maps for actual searches. The process is being further refined as GIS specialists develop scripts and models within Esri's ArcGIS 10 and 10.1 to calculate areas of high probability (Ferguson 2008; Theodore 2009; Sarow 2010; Laing and Lord-Castillo 2010). Not fully understood though, is the accuracy and effectiveness of these "International" statistics at the "local" level.

1.2. Goals and Objectives

Many studies have investigated medical illness and injury in wilderness environments from an epidemiological standpoint (Forrester and Holstege 2009; Wild 2008; Hung and Townes 2007) while others have addressed lost person behavior at the local level (Hill 2001; Koester and Twardy 2006; Perkins et al. 2004, 2005), but these studies have been primarily statistical in nature and lacked spatially explicit analyses. The goal of this research was to utilize a GIS to conduct an analysis of lost person incidents within Yosemite National Park to determine who is most likely to become lost, when they become lost, where they become lost, where they are eventually found, and why they became lost in the first place. In addition, lost hiker behavioral profiles were created based on the horizontal distance from the IPP to the found location in kilometers, the vertical elevation change from the IPP to the found location in feet, the dispersion angle in degrees, and the track offset in meters of the found location. If it is possible to determine statistically how a person is most likely to move after becoming lost or stranded (due to injury/medical issues) in Yosemite National Park, then their movement from the IPP can be modeled in future incidents in order to predict areas where they are most likely to be found.

The success of using global lost person behavior statistics for producing probability areas for the found location on a local level has not been previously quantified. Therefore, once the "local" data on lost person behavior were collected from Yosemite, it was compared to that of the ISRID "international" data, and I tested hypotheses regarding the quantitative success of this process for Yosemite National Park.

To summarize, this research had six clearly defined objectives:

1. Identify all ground based search incidents in Yosemite National Park from the years 2000 to 2010.
2. Georeference the IPP and found location for each incident using the point radius georeferencing method.
3. Produce descriptive statistics for the incidents so as to determine who becomes lost, when they become lost, where they become lost, where they are found, and why they become lost.

4. Analyze the lost person behavior of hikers in Yosemite by calculating the horizontal distance from the IPP in Kilometers, vertical elevation change from the IPP in feet, the dispersion angle in degrees, and the track offset in meters of the find location.
5. Compare the previously mentioned lost person behavior variables from the Yosemite dataset (objective number four) with those of the ISRID to determine if they are significantly different.
6. Provide a framework for which to study lost person behavior and the spatio-temporal aspects of search and rescue at future localities, in turn contributing to not only the field of Search and Rescue, but to the field of GIScience as a whole.

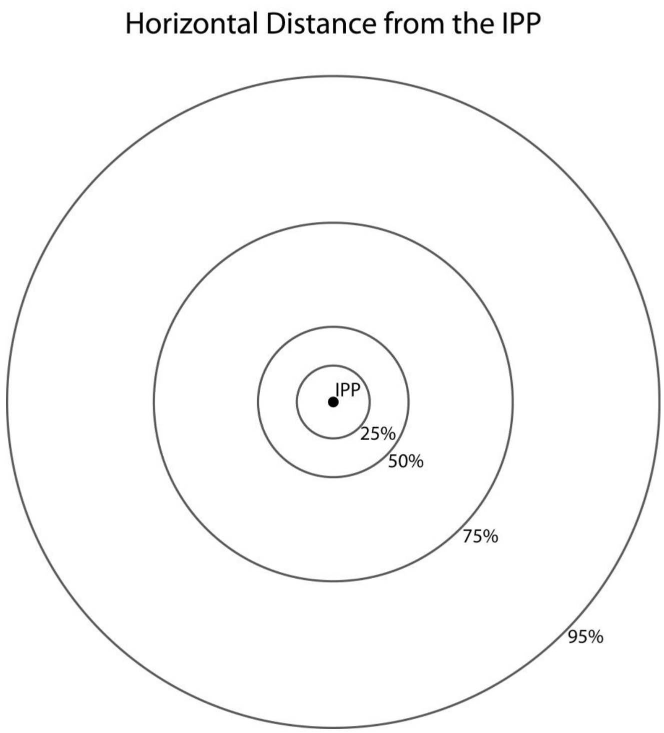
1.3. Hypotheses

Yosemite National Park is unique geographically and presents many challenges for lost persons. It is therefore hypothesized that lost person behavior for hikers will differ significantly from that which is recorded by the ISRID in a number of ways.

1. If the terrain in Yosemite has higher impedance than most environments included in the ISRID, then it is expect that the horizontal distance traveled from the IPP to the found location in kilometers by the subject will be shorter than that which is reported by the ISRID.
2. If most of the popular hikes begin in Yosemite Valley and travel upward gaining in elevation, then the vertical change in elevation from the IPP to the found location will be mostly uphill.

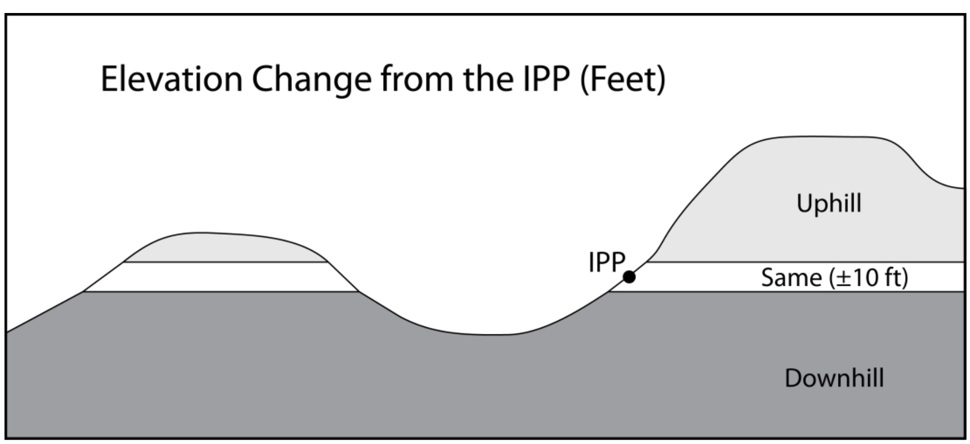
3. If the terrain does not allow for trails to go directly from one location to another in a straight line, then the dispersion angle will be much greater in Yosemite than reported in the ISRID.
4. If there are many trails, roads, and streams that cut through Yosemite, and it is likely that once a person becomes lost they will not be too far from one of these linear features, then the track offset in meters will be much shorter than reported in the ISRID.

Figure 1.1:



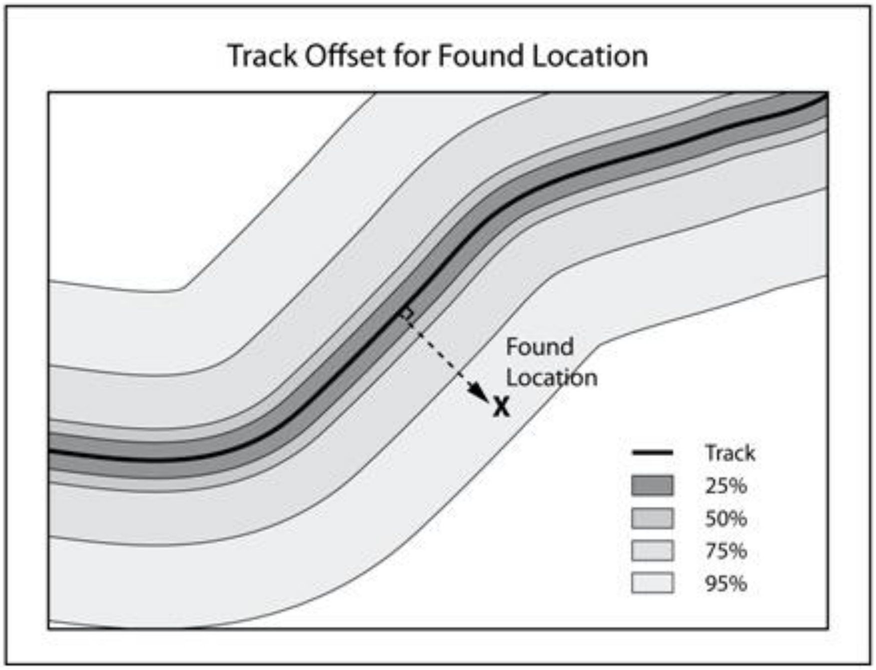
Rings based on Euclidean distance (crow's flight distance) are often plotted from the Initial Planning Point (IPP). These distances correspond to the lower quartile, median, upper quartile, and 95th percentile of distance (measured in either miles or kilometers) travelled by lost subjects collected by the ISRID.

Figure 1.2:



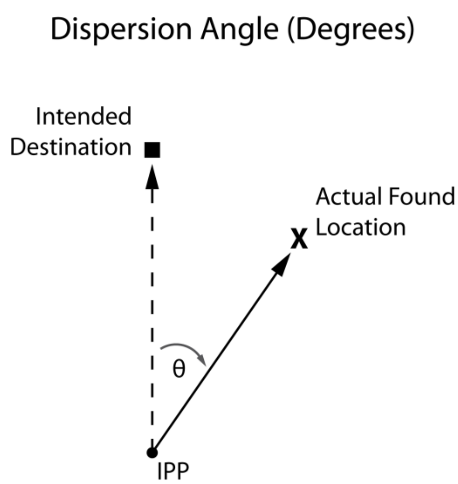
Elevation change is calculated as the difference between the Initial Planning Point (IPP) and the found location. This statistic ignores the total elevation change experienced by the lost person as they moved through the terrain.

Figure 1.3:



Track offset "describes the shortest perpendicular distance from an intended track or route to where the lost person was found" (Koester 2008). The lower quartile, median, upper quartile, and 95^{th} percentile distances for track offset collected by the ISRID are occasionally plotted from a track to determine search segments.

Figure 1.4:



The dispersion angle is the angle (θ) between the intended destination (or direction) and the actual found location. To calculate this distance the Initial Planning Point, intended destination (or direction), and the actual found location must all be known.

2. Literature Review

2.1. Psychology of Lost Persons

As previously stated, being lost in the strictest sense of the definition means that a person is, “unable to identify or orient their present location with respect to known locations, and has no effective means or method for orienting themselves” (Hill 1999). It is common for people to navigate through familiar surroundings in which they rely on their personal experiences and memory to remain oriented. As they venture into unfamiliar territory, they must begin to rely on wayfinding clues, such as road or trail signs, in order to get where they are going. They may not know their precise location on a map, but they know “the way” (Hill 1999). This is particularly true for men who tend to utilize Euclidean strategies (distances and cardinal directions) in order to navigate where as women prefer to navigate by landmarks (Dabbs et al. 1997 and Ward et al 1986). Once a person no longer “knows the way” and they are unable to re-orient themselves, then they are lost (Crampton 1988).

Crampton (1988) describes a continuum of being lost with two distinct degrees of lostness. The first, and arguably the most serious, is defined as “unknown lost”. This occurs when a person believes that they know where they are when in fact they do not. This could happen to a hiker if they come to divergent trails and take one but misidentify the one they are actually on. The hiker may continue on in a denial process fitting the terrain to their expectations, rejecting any discrepancies. Eventually, they will realize the mistake that they made, and only then can they take action to correct their errors. They then move into the second category of lostness – “known lost”(Crampton 1988).

The realization that one is lost invokes a highly emotional state. Fear causes the sympathetic nervous system to activate, initiating the release of adrenaline into the blood stream, an increased heart rate, and dilated pupils among other physiological responses. This state of high arousal causes one's thoughts to scatter and "reduce[s] the number of environmental cues a person can perceive" (Hill 1999), specifically sights and sounds with which the victim has become familiar (Kelley 1973). A feeling of claustrophobia may set in and a person may get the urge to run so that they can find the "right place" causing the person to become even more lost (Syrotuck 1999). Some have even been known to hallucinate and have visions or dreams. This heightened state, generally referred to as "woods shock," can be detrimental to a lost person's overall wellbeing (Hill 1999).

Yerkes and Dodson (1908) described the relationship between the level of arousal and performance effectiveness as an inverted U-shape. If a person is under-aroused, as in lethargic, then their performance is poor. For optimal mental functioning, a moderate level of arousal is desired, but as the arousal level increases beyond that, performance again decreases. Consequently, the hyper state of arousal experienced while lost can cause people to have severe difficulty in reorienting themselves, fail to make a shelter or fire, discard equipment and clothing, and feel a distinct sense of abandonment (Syrotuck 1999).

The psychological effect of being lost can also be quite traumatic. Individuals begin to realize certain fears. They fear being alone, the darkness, and animals as well as the threat of suffering and death (Syrotuck 1999). Presumably, many of these factors impact a person who is injured or has medical issues in a similar manner, especially in a wilderness environment.

Lost people generally have two goals: try to find their way or try to be found (Cornell and Heth 1999). Secondary goals such as finding water or shelter may also play an import role in their decision making process, but reorientation is the paramount goal. Kenneth Hill (1999) describes ten different strategies people employ to reorient themselves (note that these definitions were used in the present research for describing reorientation strategies of those lost in Yosemite National Park):

> **Random Traveling**: “Totally confused, and usually experiencing high emotional arousal, the lost person moves around randomly, following the path of least resistance, with no apparent purpose other than to find something or some place that looks familiar (p. 7).”
>
> **Route Traveling**: “The lost person decides to travel on some trail, path, drainage, or other travel aid. The route is unknown to these persons, and they are uncertain regarding the direction they’re headed, but they hope that eventually they will come upon something familiar (p. 7).”
>
> **Direction Traveling**: “Certain that safety lies in one particular direction, the lost person moves cross-country, often ignoring trails and paths leading the “wrong” direction (p. 8).”
>
> **Route Sampling**: “The person uses an intersection of trails as a base, traveling some distance down each trail in search of something familiar (p. 8).”

Direction Sampling: “Similar to route sampling, except that the lost person does not have the advantage provided by an intersection of trails. Rather, these persons select some identifiable landmark as a base, such as a large tree or outcropping (p. 8).”

View Enhancing: “…the lost person attempts to gain a position of height to view landmarks in the distance. These persons attempt to enhance their view by climbing a hill, ridge or tree (p. 8).”

Backtracking: “After getting turned around, the person reverses the track and attempts to follow the exact route back out of the woods (p. 9).”

Using Folk Wisdom: “…miscellaneous category refers to the attempt to reorient by using any of the numerous adages on how to find your way safely out of the woods (p. 9)…” An example includes the saying, “All streams lead to civilization (p.9)”.

Staying Put: “staying where you are when lost…[when] the lost persons can reasonably expect a search to be organized on their behalf in the very near future (p. 9).”

Doing Nothing: Not making an active decision to stay put, but rather just sitting down and doing nothing at all to reorient themselves (Hill 2008).

It is important to note that a lost person may attempt several of the above strategies when attempting to reorient himself.

2.2. The Study of Search and Rescue (SAR) and Lost Person Behavior

The formal study of search and rescue as a discipline grew out of military operations conducted during World War II (Frost 1999). The mathematical theory of how to search for missing, lost, and hidden objects was used to search for enemy submarines as well as to recover lost allied ships and downed pilots (Frost 1999). This search theory became a branch of the applied science known formally as operations research, and Bernard Koopman, a mathematician for the U.S. Navy, conducted the initial work in this field (Frost 1999, Koester 2008). Koopman was the first to define probability of density (Pden) and apply it to search and rescue. Probability of density is equal to the probability of area (POA), or the probability that the search object is in the defined search area, divided by the size of the area itself (Koester 2008). This can be demonstrated with the equation p_1 / A_1. Both probability of density (Pden) and probability of area (POA) are common concepts within wilderness search and rescue today.

The first true analysis of lost person statistics did not occur until the early 1970s (Koester 2008). Dennis Kelley, a volunteer for the Montrose Search and Rescue team, analyzed 380 of his team's cases and reported on statistics such as age, search outcome, mortality cause, injury cause, and reason for becoming lost. He published his results in the first ground search and rescue management book called *Mountain Search for the Lost Victim* (Kelley 1973). His work, however, is not well known and was not widely incorporated into search and rescue operations (Koester 2008).

William Syrotuck made the first real impact on the search and rescue community by analyzing search and rescue statistics. He published *An Introduction to Land Search:*

Probabilities and Calculations in 1975 and, a year later, the better known *Analysis of Lost Person Behavior: An Aid to Search Planning* (Syrotuck 1975, 1976). Syrotuck (1976) analyzed 229 cases, mostly from the states of Washington and New York. He separated the data into six categories: small children (ages one to six), children (ages six to twelve), and adults further characterized as hunters, hikers, miscellaneous adult persons, and elderly persons (Syrotuck 1976). He then created probability distance rings (often called “crows flight” distance”) from the Point Last Seen (PLS) to the found location for each of the six categories for both flat and hilly/mountainous terrain. The sample size for Syrotuck’s research was small, but his probability rings became well known and have been summarized in several major search management textbooks (Koester 2008).

Ken Hill, a professor of psychology and a search manager in Nova Scotia, has not only studied the physiological responses of those who become lost (Hill 1999), but has authored numerous articles on lost person behavior including cases involving persons with dementia or mental retardation (Hill 1991, 1998, 2001). He has also summarized reports of lost deer hunters in Nova Scotia and found that elderly outdoor enthusiasts traveled much farther when lost than cognitively impaired wanderers from supervised care (Hill 1999).

Ed Cornell and Donald Heth also have made considerable contributions to the field of lost person behavior by writing about lost children (Cornell and Heth 1996; Cornell et al. 1996), and they have summarized statistics on lost persons from wilderness areas in Alberta, Canada (Heth and Cornell 1998). In this latter study, they tabulated crow’s-flight distance traveled and dispersion of travel for different categories of wilderness users. Notable findings include the fact that back country users, people in more remote, undeveloped, and risky areas, were found farther from their origin than were their front country counterparts (those who stayed close to vehicle parking lots with groomed trails and frequent signage), yet their dispersion was not reliably different. However, “For back country users, large distances between the point last seen and point found were moderately associated with small angles of dispersion” (Heth and Cornell 1998, p. 235). This means that “persons found farther from the point last seen are generally closer to the bearing to their intended destination” (Heth and Cornell 1998, p. 235). Their methodology for calculating dispersion angle was utilized in this current study.

Others have emulated these early studies in lost person behavior in order to gather a more localized data set to be used during search operations. Notable regional level studies include those from the United Kingdom (Perkins et al. 2004, 2005, and 2011) and Australia (Twardy et al. 2006).

The most comprehensive analysis of lost person behavior to date comes from Robert Koester. In 1992 Koester began to study lost person behavior by examining searches involving persons with Alzheimer’s disease. He introduced the concepts of track offset and was the first to separate data by ecoregions (Koester 2008). As was previously mentioned, he later became the lead investigator for the International Search and Rescue Incident Database. The hierarchy that he established for categorizing lost persons (i.e. mental status, age, and then activity) for the ISRID was utilized in this present study.

2.3. GIS in Search and Rescue

A GIS provides an ideal environment for which to bring together data from various sources, visualize that data and then query and analyze it to assist in making operational decisions (Ferguson 2008). One of the earliest examples of this is the United States Coast Guard’s (USCG) development of GIS models to assign probability of area (the probability that a region, segment, or other geographically defined area contains the search object) in maritime searches based on a vessel’s launch point, planned route, and intended destination (ASA 2012). These first models have evolved into a sophisticated GIS-based computer program called the SAR Optimal Planning System (SAROPS). This program combines route data along with environmental data, such as real time wind and ocean current information, and calculates a grid overlay that displays the probability of finding the lost vessel within each grid cell.

Although they are not as sophisticated as SAROPS, there are numerous examples of GIS based programs designed specifically for use in land based SAR operations. One of the first was a software package developed by Heth and Cornell (2006) that combined statistics from lost adult hikers on alpine wilderness trails with basic GIS processes. That same year, Ciolli et al. (2006), set forth a methodology to take physiological and environmental variables into account to determine the distance a person can physically travel given a certain amount of time. In their model, they consider terrain slope, vegetation density, terrain unevenness, and the time of day, as well as the lost person’s height, age, sex, physical condition, and weariness as time passes in their model. Paul Doherty, the GIS specialist for Yosemite National Park Search and Rescue has conducted similar work in which he uses slope, aspect, elevation, vegetation, and existing roads to create a model for time to traverse the landscape from the incident location (Doherty 2009).

Lin and Goodrich (2009) proposed a Bayesian model to automatically generate a probability distribution map from publicly available terrain feature data including topology, vegetation, and elevation data. A separate model introduced a "computational agent-based model of lost person wayfinding that is capable of describing the unique relationship between an individual lost person and a specific environment" (McDaniel 2010). Win CASIE III, a computer program designed to help assign probability of area (Win CASIE III 2012), and Incident Commander Pro, software which "combines maps with search management process and forms" (SAR Technology Inc. 2012), are yet even more examples of software programs to aid during searches.

Recently, GIS specialists have begun to develop tools within ArcGIS to aid in identifying the areas with the highest probability of area for search incidents based solely on the ISRID data published in Koester's *Lost Person* Behavior. One instance of this played out over a discussion forum posted to the *Using GIS in SAR for Emergency Responders* Google Group. The two main discussants – Richard Laing the Ridge Meadows Search and Rescue Team Manager based out of Maple Ridge, British Columbia, Canada, and Brett Lord-Castillo, an Information Systems Designer/GIS Programmer for the St. Louis County Police Department created a script to automatically produce buffer rings and dispersion angles for a given IPP (Laing and Lord-Castillo 2010). Their tool set was then posted to the Google Group for members to download. Perhaps the most significant progress in GIS tool development comes from Liz Sarow at ESRI. In "Determining Probability of Area for Search and Rescue using

Spatial Analysis in ArcGIS 10”, where she demonstrated how the ISRID statistics which contain a spatial component can be built into a tool set to calculate probability of area using raster analysis.

The newest GIS tool developed to aid in searches for lost people is known as MapSAR. MapSAR shows great promise, and its developers, a group of search and rescue professionals and GIS users from across the United States, were presented with the prestigious Foundation Award for Excellence in Public Safety GIS from the National Alliance for Public Safety GIS Foundation (Doherty 2011). It is essentially a set of data management tools and templates to be used within ArcGIS 10 that allows search managers to store and visualize data from a search incident. It also permits the user to create search assignments, manage clues, load GPS tracks, and create search buffers. Once a search is complete, it also provides a way to archive the search so that the data can easily be accessed in the event of a similar incident in the future (Durkee 2011). The program has the potential to incorporate more advanced spatial analyses, such as lost person behavior, but that is yet to be fully developed.

3. Study Area

3.1. Overview of Study Area

Before a true analysis of lost person behavior can be made, it is imperative to have a clear and comprehensive understanding of the study area. Yosemite National Park is unlike any other place on earth. It has its own distinct geology, climate, and history, all of which work together to create a unique environment for people to interact with. To understand what people do, and why they do it, one must first understand the environment, hazards, and underlying processes that influence their decisions. For a more in-depth description of the study area including geology, geomorphology, climate, weather, hydrology, vegetation, fauna, history, park visitation, and potential hazards see Appendix A.

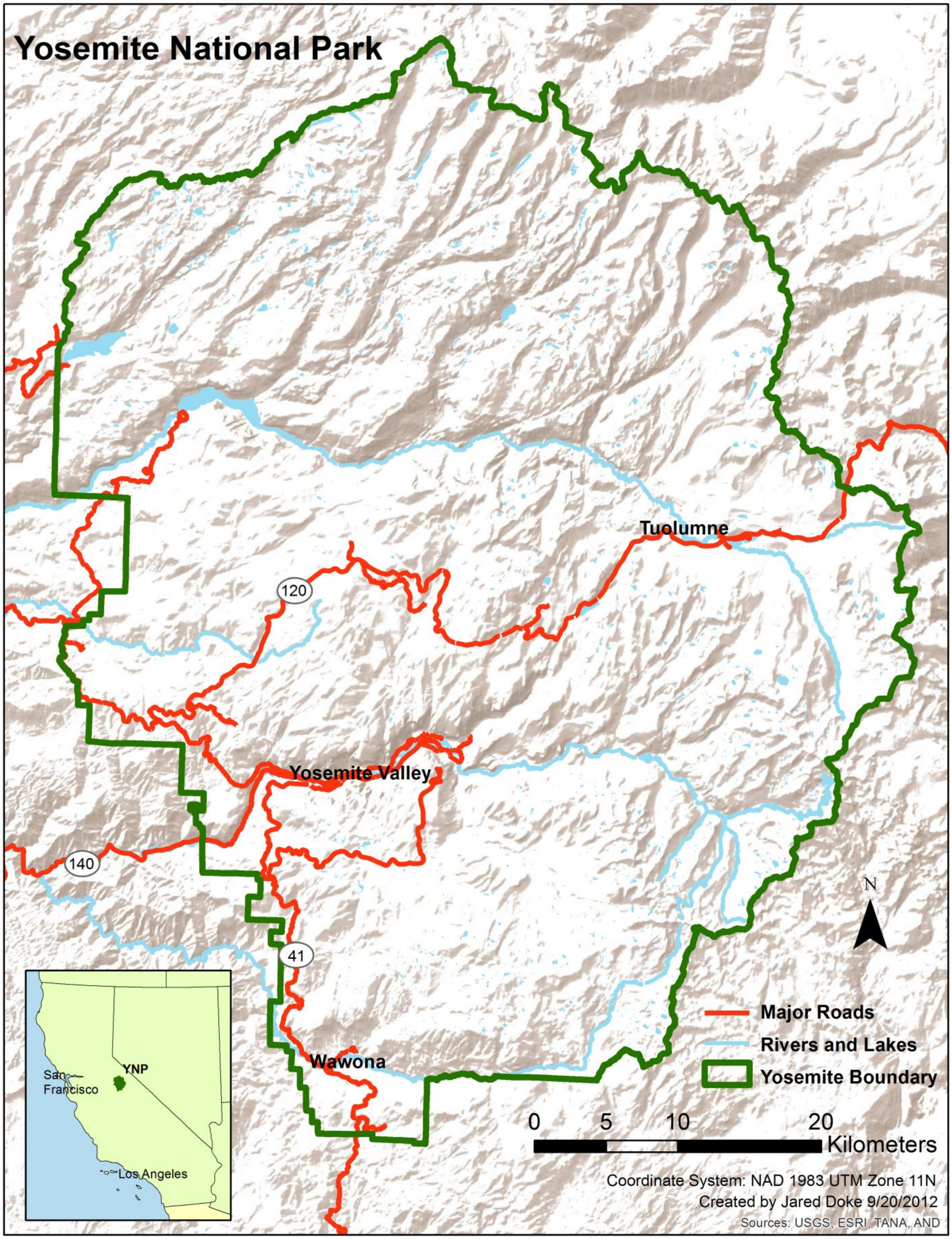
Yosemite National Park encompasses nearly 1,169 square miles and is located on the western slope of the Sierra Nevada mountain range in central California. To the west is the San Joaquin Valley and to the east is the Great Basin. It is fairly accessible as it lies 150 miles east of San Francisco and about 300 miles north of Los Angeles (Figure 3.1). There are about 214 miles of paved roads serviced by five separate entrance stations. The park also has 800 miles of trails, including the Pacific Crest Trail and the John Muir Trail, within the park. Overnight visitors may stay in one of the park's 1,504 total campsites or 1,377 lodging units (National Park Service 2011).

The park's physical landscape is a product of glaciation, and includes granite cliffs, deep narrow canyons, and a U-shaped valley that has become the focal point of the park. Elevation within the park ranges from about 2,000 ft. to 13,123 ft, and more than 95% of the park, or roughly 1,101 square miles, is designated as wilderness (National Park Service 2011).

Yosemite is characterized by a Mediterranean climate with long hot summers and mild winters. Precipitation can vary from 36 inches at 4000 ft to 50 inches at 8,600 ft. This climate, coupled with the variations in elevation, creates five major vegetation zones: chaparral/oak woodland, lower montane, upper montane, subalpine, and alpine. These vegetation zones are the home of roughly 300 species of vertebrate animals including the black bear, which often comes into conflict with park visitors and must be considered during search and rescue mission planning, both as a factor in lost person behavior and as a risk to searchers (Yosemite NPS 2006).

Yosemite National Park was created on October 1, 1890 and was named a World Heritage Site in 1989 (Yosemite NPS 2006). It now hosts more than 3.5 million visitors each year. People travel to Yosemite year-round to photograph the scenic beauty, ski the Nordic trails, and see some of the tallest waterfalls in the world. With so many visitors, it is inevitable that some of them will become disoriented, separated from their groups, or lost in the vast wilderness. As a result, the park service responds to numerous missing person reports each year. Most of these cases are resolved within the first twenty-four hours, but some can last much longer (Theodore 2009)

Figure 3.1:


Yosemite National Park
Tuolumne
120
Yosemite Valley
140
41
Wawona
San Francisco
YNP
Los Angeles
N
Major Roads
Rivers and Lakes
Yosemite Boundary
0 5 10 20
Kilometers
Coordinate System: NAD 1983 UTM Zone 11N
Created by Jared Doke 9/20/2012
Sources: USGS, ESRI, TANA, AND

4. Methodology

4.1. Data Gathering and Georeferencing

The data obtained for this analysis were derived from Yosemite National Park's Search and Rescue Case Incident reports for the years 2000 to 2010. Access to these reports was granted by the National Park Service Division of Visitor Protection (Permit 1024-0236). During this eleven year span, Yosemite National Park responded to 2,308 total SAR Incidents. This includes both genuine searches for lost people as well as rescues in which the actual location of the individual was known. Of these SAR incidents, 2201 incident reports were available for review. Out of these reports, 393 true search incidents were identified. Table 4.1 identifies the number of incidents by year.

Table 4.1 Number of Search Incidents Analyzed by Year

Year	Total SARs	Number of Incident Reports	Search Incidents	Retained for Analysis
2000	147	144	32	19
2001	140	139	21	11
2002	180	169	23	13
2003	214	187	30	16
2004	191	190	23	15
2005	231	200	47	24
2006	219	210	40	19
2007	241	236	46	25
2008	250	247	41	19
2009	244	243	57	33
2010	251	236	33	19
Total	2308*	2201	393	213

*The total number of SARs for each year was determined by the last SAR Number assigned in that year. It is possible that one or more SAR incident reports were missing at the end of the year.

Each search incident was critically analyzed and must have met all of the following criteria in order to be retained for the current study:

1. The incident must have been a ground-based search incident. Searches for downed aircraft or searches involving bodies of water were not included.
2. The incident must have had a distinct PLS/LKP/IPP that can be georeferenced within the Yosemite National Park boundary.
3. The incident must have had a distinct found location that can be georeferenced within, or within walking distance of, the Yosemite National Park boundary.
4. An official SAR response must have been initiated by the National Park Service.

Two hundred thirteen search incidents met these criteria and were retained for analysis. Table 4.2 details the search incidents and their reason for exclusion by year.

Table 4.2 Reasons for Discarding Search Incidents

Year	Water or Air Search	"IPP" Outside Park	"Found" Outside Park	No Distinct IPP	No Distinct Found	Total Incidents Discarded	Total Incidents Retained	Total Search Incidents	% Retained
2000	1	1	1	3	7	13	19	32	59%
2001	0	1	0	5	4	10	11	21	52%
2002	0	2	2	5	1	10	13	23	57%
2003	1	4	2	4	3	14	16	30	53%
2004	0	1	0	3	4	8	15	23	65%
2005	4	4	2	9	4	23	24	47	51%
2006	1	5	2	8	5	21	19	40	48%
2007	3	6	1	4	7	21	25	46	54%
2008	1	9	0	4	8	22	19	41	46%
2009	2	6	1	7	8	24	33	57	58%
2010	3	5	0	3	3	14	19	33	58%
Total	16	44	11	55	54	180	213	393	54%

The reports retained were read in detail and a combination of incident related information (SAR Case Number, Search Times, etc.), lost subject demographics (ISRID Subject Category, Sex, Age, etc.), location information (Description of IPP, Description of Found Location, etc.), and search outcome were recorded. (Please see Appendix B for a full description of each field). The fields collected were adapted from the ISRID Platinum SAR Data Collection Form (ISRID Platinum Version 09-01 Draft 2009) and from an Access database created by Paul Doherty in the summer of 2010 for the Yosemite Search and Rescue Georeferencing Project (Doherty 2010).

From the collected incident data, I computed descriptive statistics to determine who (by age, sex, and subject category) became lost, when they became lost, and why they became lost. Each incident's PLS/LKP/IPP and found location were georeferenced using the Point-Radius Method and the *Guide to Best Practices for Georeferencing* (Chapman and Wieczorek 2006). In addition, the georeferencing error, or the uncertainty of the georeferenced location, was calculated for each georeferenced point using the MaNIS Georeferencing Calculator (Wieczorek 2008).

Within a GIS I used the georeferenced locations to determine the horizontal distance from the IPP to the found location in kilometers, the vertical elevation change from the IPP to the found location in feet, the dispersion angle in degrees, and the track offset in meters for each incident. The lower quartile, median, upper quartile, and 95th percentile were calculated for each of the previously mentioned lost person behavioral statistics for the hiker category. This category was the only one with a large enough sample to derive reliable statistics.

This observed behavior (the derived lost person behavior statistics from Yosemite) was then compared with the theoretical behavior of all lost hikers using a Chi-square Goodness of Fit Test (the lost person behavior statistics provided by the ISRID were treated as the population) with a significance of 0.05. The chi-squared statistic is based on the differences between the observed and expected frequencies and is as follows:

$$X^2 = \sum_{j=1}^{k} \frac{\left(O_j - E_j\right)^2}{E_j}$$

Where the data are divided into *k* bins, O_j is the number of observations in category *j* and E_j is the expected frequency in category *j* (Burt et al 2009). The calculations were performed using an open source Chi-square goodness of fit test calculator which can be found at http://www.quantpsy.org/chisq/chisq.htm (Preacher 2001).

To conduct the chi-square Goodness of Fit Test, a null hypothesis and an alternative hypothesis were constructed for each lost person statistic. The null hypothesis stated that the Yosemite distribution for the given variable was drawn from the population of all lost hikers. The alternative hypothesis stated that the Yosemite distribution for the given variable was drawn from some distribution other than the population of all lost hikers. If the probability value associated with chi-square was greater than the selected alpha, then I failed to reject the null hypothesis that stated there was no significant difference in the distributions. If however, chi-square was less than the selected alpha, then the null hypothesis was rejected: the Yosemite data were significantly different and the sample must have been drawn from some distribution other than the population of all lost hikers.

4.2. Spatial Statistics

Given the nature of lost person incidents, it is nearly impossible to determine the exact location that someone becomes lost. What can be done, however, is to map each incident's IPP. This gives a general sense of where people are getting lost or encountering difficulties that lead them to be reported as lost. For the analysis to be meaningful though, it must be conducted at an appropriate scale. As Doherty et al explain, if the average uncertainty radius of the georeferenced IPP's was 5 km, then a spatial analysis using a 1 km grid would not be appropriate (Doherty et al. 2011).

For this study, each incident's IPP was georeferenced using the Point-Radius Method. This method "describes a locality as a coordinate pair and a distance from that point (that is, a circle), the combination of which encompasses the full locality description and its associated uncertainties" (Wieczorek et al. 2004, p. 748). This technique is well documented and Weiczorek et al. provide a detailed six-step process to apply it. As part of this process, the radius of the uncertainty associated with that georeference was calculated using the MaNIS Georeferencing Calculator (Wieczorek 2008).

In order to spatially analyze the IPPs at the appropriate scale, several steps had to be taken. First, the 95th percentile value for the uncertainty radii of the entire dataset was calculated. This value was then used to create a grid that was overlaid onto the study area, Yosemite National Park. This process ensured that 95% of the uncertainty radii were smaller than the scale chosen for spatial analysis (Doherty et al. 2011). A spatial join was then performed to calculate the number of incidents that occurred in each square grid cell. In continuing to follow the methodology set forth by Doherty et al.

for the spatial analysis of historic search and rescue incidents, the Getis-Ord Gi* statistic was then calculated using this grid and the associated number of incidents. When performing the calculation within a GIS, the conceptualization of spatial relationship option that was chosen was inverse distance squared, which is used to model processes where “the closer two features are in space, the more likely they are to interact/influence each other” (Esri 2012). The Euclidean, or straight-line, distance method was also chosen in the calculation as opposed to the Manhattan distance method. The Getis-Ord Gi* statistic essentially determines if there are areas of significantly high or low frequencies and identifies these “hot and cold” spots (Getis and Ord 1992). The same procedure was utilized to examine the found locations for all incidents.

To compare and contrast the spatial distributions of the IPPs by season, a standard deviational ellipse was calculated using a GIS. The same procedure was used to analyze the spatial distributions of found locations by season. The standard deviational ellipse is created by separately calculating the standard distance in the x- and y- directions. As the ArcGIS Resource center states, “These two measures define the axes of an ellipse encompassing the distribution of features” (Esri 2012). This defines the distributions clearly and allows you to determine if the features are elongated and thus have a particular orientation (Esri 2012).

5. Results of the Yosemite Search Incidents

5.1. "Who" Becomes Lost

Of the two hundred thirteen search incidents retained for analysis, 137 (64%) consisted of a search for one subject (Table 5.1). The remaining 76 incidents (36%) were searches for groups of two to five people. Approximately two-thirds of the single subjects were male. Of the two person groups, 45% were mixed sex, 43% were male, and the remaining groups were all female. Almost two-thirds of the three person groups were all male, about 24% of the groups were mixed sex, and the remainder were all female. Searches for groups of four of five people were less common, but did occur.

The ages of lost subjects could be determined for 175 of the 213 incidents. The single lost persons ranged in age from one to 83 years old (n=126). The mean age was 36 years old while the median age was 35 years old. The mode age was 14 and 23, each occurring six times. The mean age of two person groups was slightly younger at 31 years old (n=39). Groups of three or more (n=10) had a mean age of 29 years old.

The people who became lost in Yosemite National Park were classified into twenty different lost person categories. Approximately 62% (n=133) of those lost could be classified as a hiker. This category includes both day hikers and multi-day backpackers. Nordic Skiers, Climbers, and Children aged 13-15 each made up about 6% of incidents respectively. The remainder of lost persons were categorized as shown in Table 5.2. It should be noted that detailed visitor data was not available to standardize the results by the age, sex, or category.

Table 5.1 Number of Subjects Per Incident by Sex (n=incidents)*

Number of Subjects	All Male n (%)	All Female n (%)	Mixed Sex n (%)	Unknown n (%)	Total n (%)
1	94 (68.6%)	43 (31.4%)	-	-	137 (64.3%)
2	23 (43.4%)	6 (11.3%)	24 (45.3%)	-	53 (24.9%)
3	11 (64.7%)	2 (11.8%)	4 (23.5%)	-	17 (8.0%)
4	-	-	3 (100%)	-	3 (1.4%)
5	1 (50%)	1 (50%)	-	-	2 (0.9%)
Unknown	-	-	-	1 (100%)	1 (0.5)
Total Incidents	129 (60.6%)	52 (24.4%)	31 (14.6%)	1 (0.5%)	213 (100%)

*Total percentages may not equal 100 due to rounding.

Table 5.2 Number of Lost Subjects by Category

Subject Category	n	%
Hiker	133	62.4%
Skier-Nordic	14	6.6%
Climber	13	6.1%
Child (13-15)	12	5.6%
Child (10-12)	7	3.3%
Child (7-9)	4	1.9%
Angler	3	1.4%
Despondent	3	1.4%
Runner	3	1.4%
Snowboarder	3	1.4%
Snowshoer	3	1.4%
Autistic	2	0.9%
Child (4-6)	2	0.9%
Mental Retardation	2	0.9%
Vehicle	2	0.9%
Worker	2	0.9%
Child (No Age Specified)	1	0.5%
Child (1-3)	1	0.5%
Dementia	1	0.5%
Mental Illness	1	0.5%
Substance Abuse	1	0.5%
Total	213	100.0%

5.2. "When" They Became Lost

Of the 213 incidents reviewed for this study, temporal data were included in 209 of them. Using the time in which a reported lost person(s) was last seen, it was shown that people are reported lost with more frequency between the months of May and September (Figure 5.1). However, when the data were standardized by the number of visitors per month (including both recreational and non-recreational visitors), February and March became the months with the most reported incidents with 0.85 and 0.94 incidents per 100,000 visitors respectively (Figure 5.2).

Furthermore, when the times that people are last seen are broken down by the day of the week, people tend to be last seen more frequently on the weekends (Figure 5.3). Approximately 53% of people are last seen on Friday, Saturday, or Sunday. When analyzed at even a finer scale, the time of day, people are reported to be last seen during the afternoon hours of 2:00 pm to 3:00 pm (Figure 5.4). It should be noted that visitor data was not available for standardization at these temporal scales.

Times from the case incident reports were precise enough to reveal the average total time missing (the time from when the subject was last seen until they were found) and the total search time (time from when the subject was first reported missing until the subject was found) for the extent of the study as well (Table 5.3). The median total time missing was nine hours (n=128) while the median search time was two hours (n=193).

Figure 5.1 Lost Person Incidents by Month (n=209)

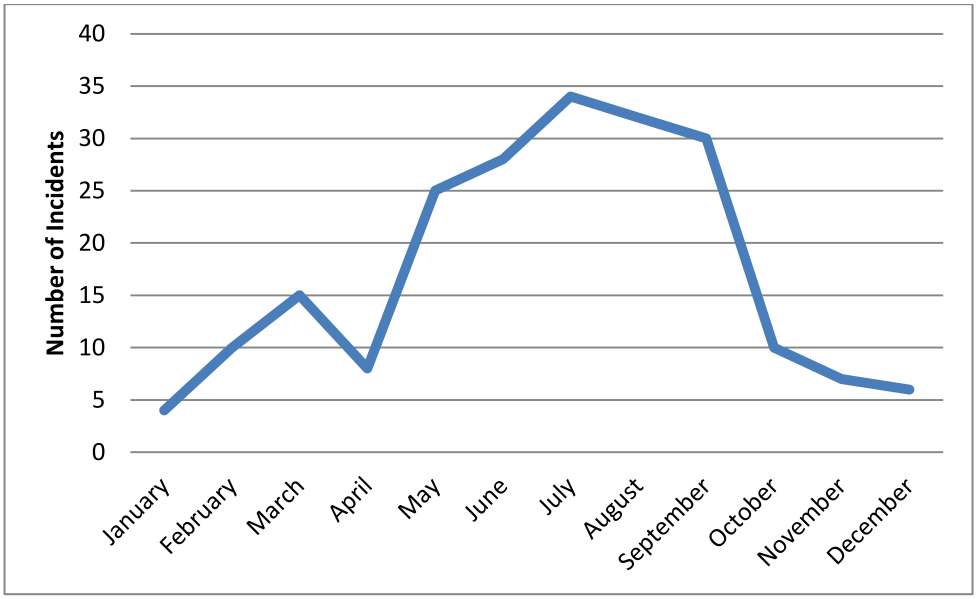


Figure 5.2 Lost Person Incidents Per 100,000 Visitors by Month (n=209)

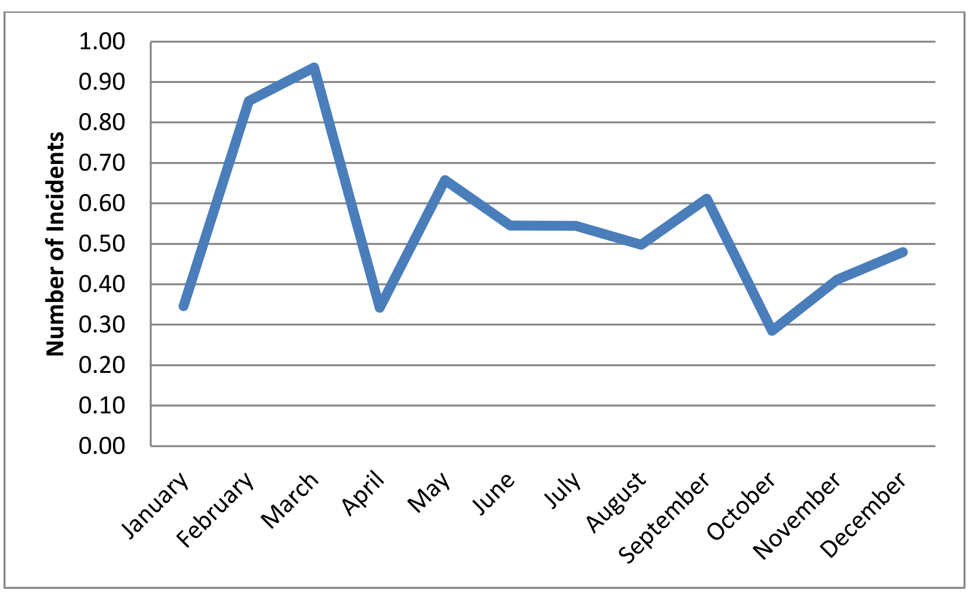


Figure 5.3 Lost Person Incidents by Day of Week (n=209)

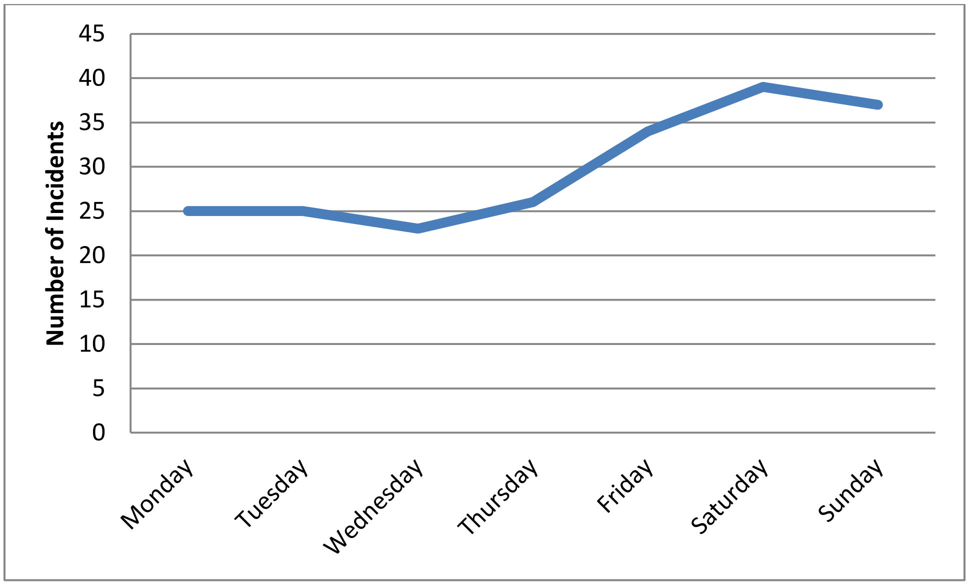


Figure 5.4 Lost Person Incidents by Hour of Day (n=136)

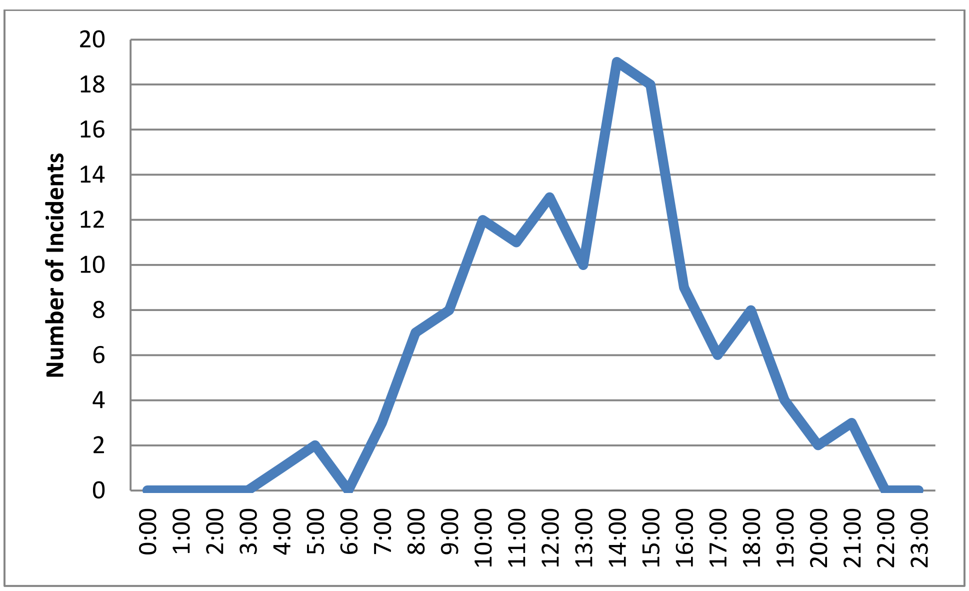


Table 5.3 Total Time Missing and Total Search Time for All Incidents

	Total Time Missing (Hours)	Total Search Time (Hours)
n	**128**	**193**
25%	3	1
50%	9	2
75%	22	10.5
95%	40.2	26.6
Mean	14.2	8.6

5.3. "Where" People Get Lost

For all search incidents (n=213), the mean uncertainty radius equaled 361 m while the median uncertainty radius equaled 63 m. The 95th percentile value for the uncertainty radii of the entire dataset was 1,719.98 m; therefore to ensure the analysis is conducted at the appropriate scale, a 1,720 m grid was created and overlaid onto the study area. Utilizing a confidence interval of 99 percent, the Getis-Ord Gi* analysis indicates that there are significant "hot spots" (Figure 5.5). Twenty grid cells have statistically significant Gi* z-scores (> 2.58 Standard Deviations) with a p-value less than 0.01. This means that there is a less than one percent chance that the pattern was created by random chance. These "hot spots" are centered over Yosemite Valley, the Yosemite Valley rim, Glacier Point, Sentinel Dome, and Badger Pass Ski area as well as a few trailheads.

The locations in which people become lost, designated by an incident's IPP, vary temporally. Figure 5.6 illustrates the location of all IPPs for incidents by season which occurred between 2000 and 2010. Each point represents the IPP for an individual incident within the boundary of the park while the larger ellipse represents the Standard Deviational Ellipse for the respective incidents. Table 5.4 provides detailed data on the distribution of incidents by season and their corresponding Standard Deviational Ellipse.

Table 5.4 Data on the Spatial Distribution of IPPs by Season and their Standard Deviational Ellipses

Season	n	Ellipse Perimeter Length	Ellipse Area	X Center	Y Center	X Std Distance	Y Std Distance	Rotation[ǂ]
Winter	27	59,211	2.288×10^{8}	266,659	4,173,940	12,383	5,882	159
Spring	59	80,812	4.997×10^{8}	273,324	4,180,250	10,722	14,836	31
Summer	102	89,886	6.150×10^{8}	277,468	4,184,567	11,769	16,635	55
Fall	25	66,663	3.497×10^{8}	274,615	4,182,086	11,500	9,680	140

*All distances in meters

ǂ Rotation of the long axis is measured in degrees clockwise from North

Figure 5.5

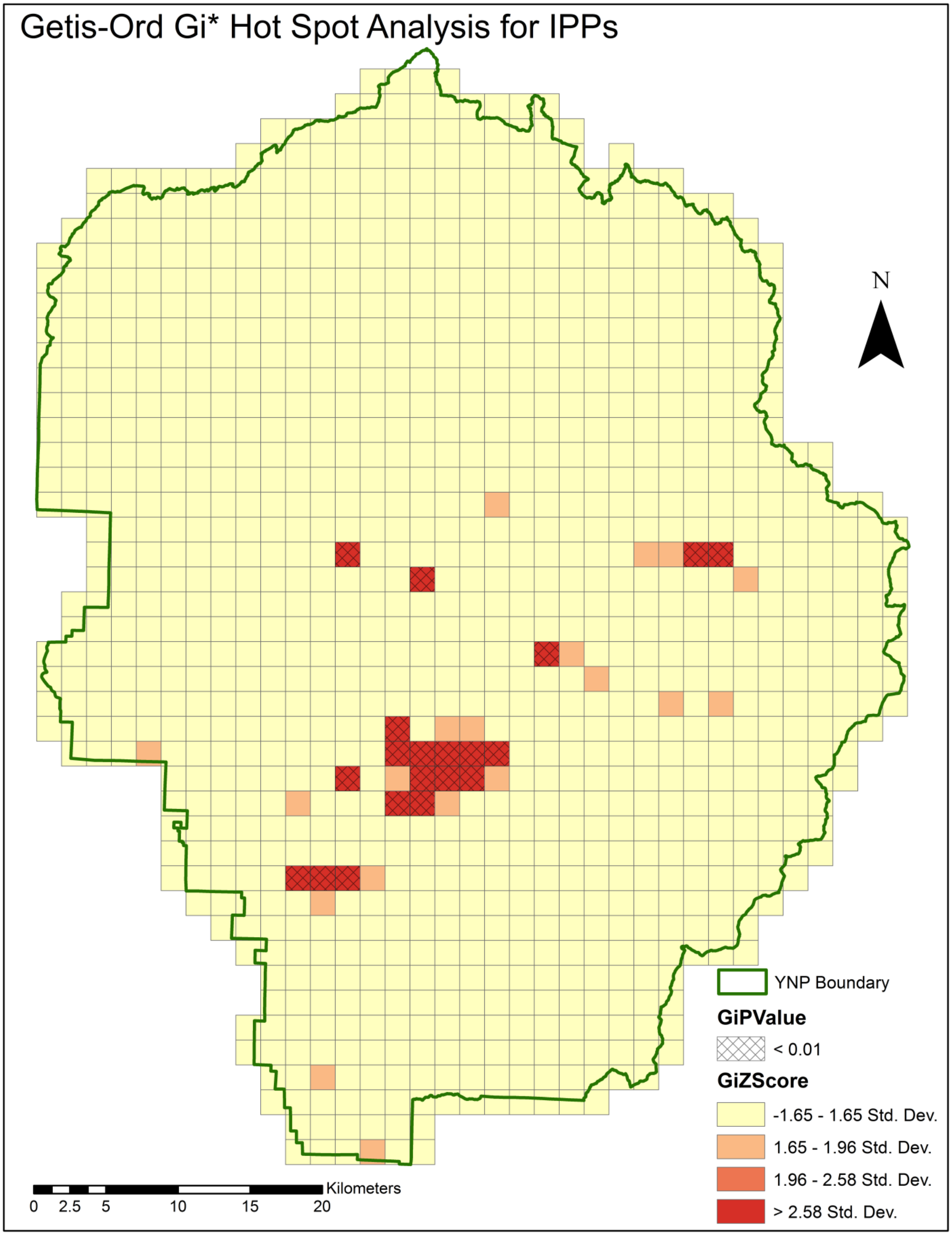
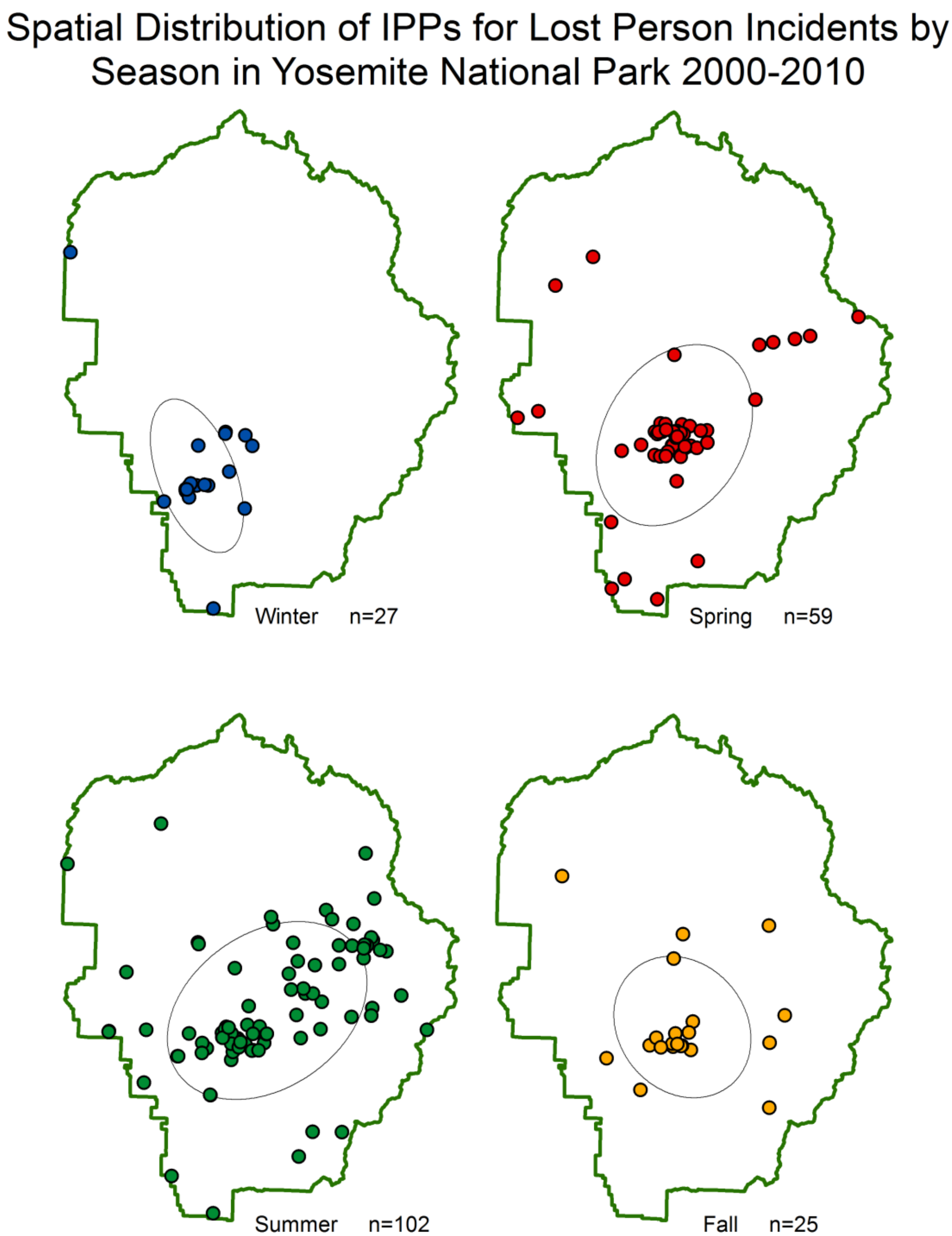

Getis-Ord Gi* Hot Spot Analysis for IPPs
N
YNP Boundary
GiPValue
< 0.01
GiZScore
-1.65 - 1.65 Std. Dev.
1.65 - 1.96 Std. Dev.
1.96 - 2.58 Std. Dev.
> 2.58 Std. Dev.
Kilometers
0 2.5 5 10 15 20

Figure 5.6


Spatial Distribution of IPPs for Lost Person Incidents by Season in Yosemite National Park 2000-2010
Winter n=27
Spring n=59
Summer n=102
Fall n=25

5.4. “Where” People are Found

There were a total of 218 found locations. This is the result of several groups of lost persons becoming separated and being found in separate locations (209 incidents had one found location, 3 incidents had 2 found locations, and one incident had 3 found locations). The mean georeferencing uncertainty radius for the found locations was 354 m while the median georeferencing uncertainty radius was 97 m. The 95th percentile value for the georeferencing uncertainty radii of the entire dataset was 1,651.19 m; therefore a 1652 m grid was created and laid onto the study area.

Utilizing a confidence interval of 99 percent, the Getis-Ord Gi* analysis indicates that there are significant “hot spots” for found locations (Figure 5.7). Seventeen grid cells have statistically significant Gi* z-scores (> 2.58 Standard Deviations) and a p-value less than 0.01. This means that there is a less than one percent chance that the pattern was created by random chance. The results are similar to those of the IPPs in that these “hot spots” are centered over Yosemite Valley, the Yosemite Valley rim, Tuolumne, and the Badger Pass Ski area. One unique “hot spot” that isn’t found in the IPP dataset, but is included in the found dataset is Glen Aulin High Sierra Camp.

The found locations, just as the locations for the IPPs, vary temporally (Figure 5.8). Table 5.5 provides detailed data on the distribution of incidents by season and their corresponding Standard Deviational Ellipses.

Figure 5.7

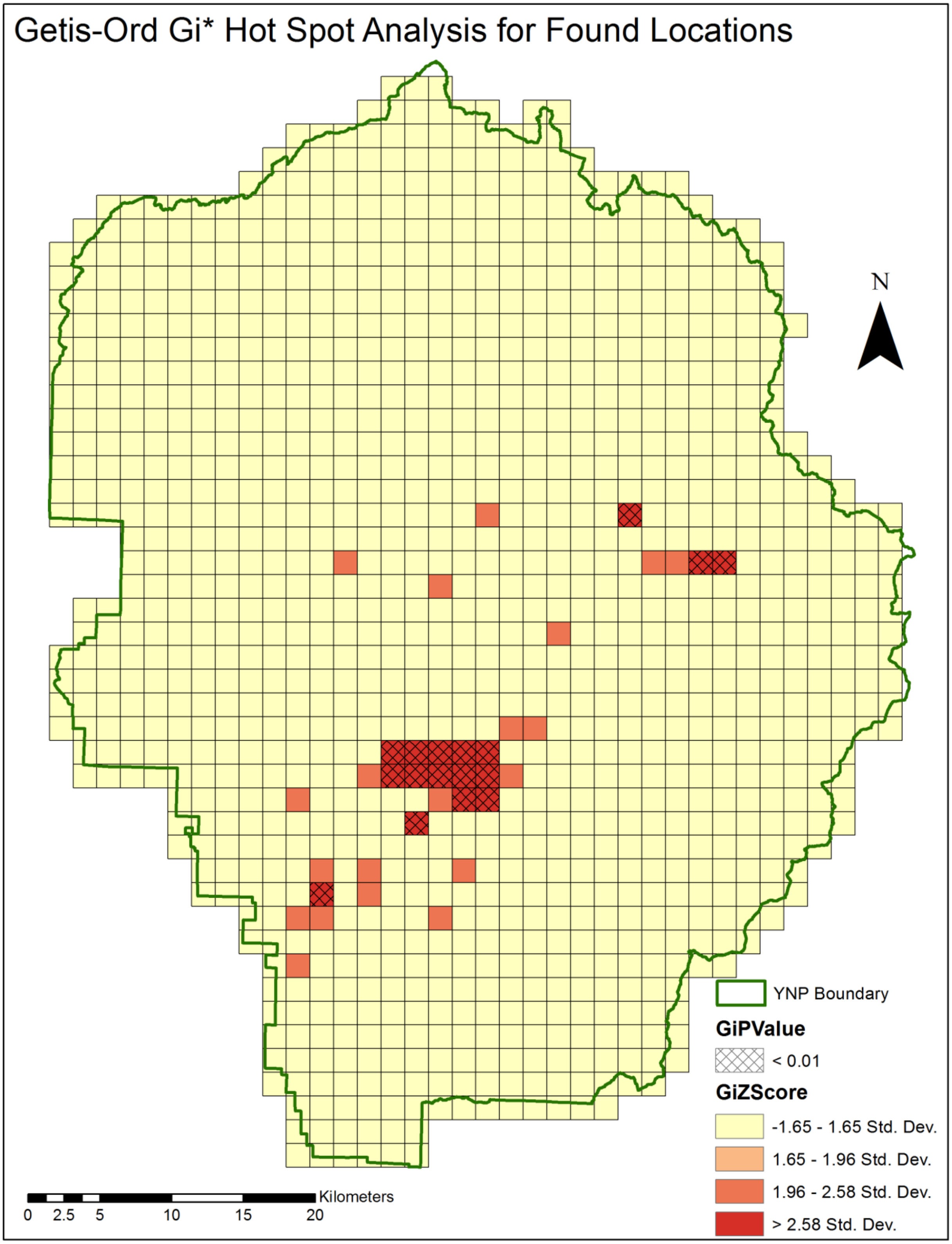

Getis-Ord Gi* Hot Spot Analysis for Found Locations
N
YNP Boundary
GiPValue
< 0.01
GiZScore
-1.65 - 1.65 Std. Dev.
1.65 - 1.96 Std. Dev.
1.96 - 2.58 Std. Dev.
> 2.58 Std. Dev.
Kilometers
0 2.5 5 10 15 20

Figure 5.8

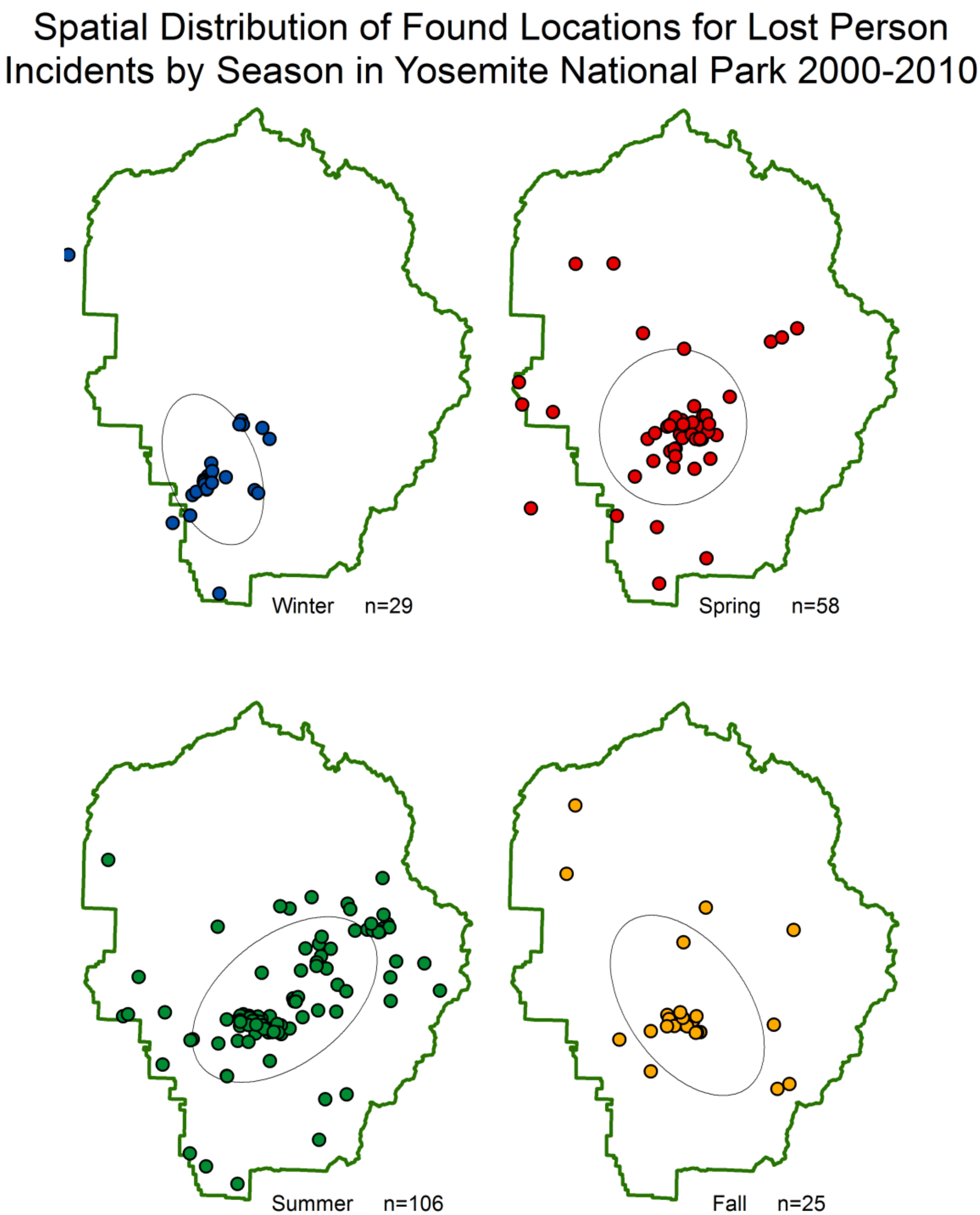

Spatial Distribution of Found Locations for Lost Person Incidents by Season in Yosemite National Park 2000-2010
Winter n=29
Spring n=58
Summer n=106
Fall n=25

Table 5.5 Data on the Spatial Distribution of Found Locations by Season and their Standard Deviational Ellipses

Season	n	Ellipse Perimeter Length	Ellipse Area	X Center	Y Center	X Std Distance	Y Std Distance	Rotation[ǂ]
Winter	29	61,558	2.703×10^{8}	266,376	4,173,656	12,194	7,056	159
Spring	58	74,075	4.358×10^{8}	271,587	4,180,361	11,356	12,216	21
Summer	106	84,209	5.109×10^{8}	277,601	4,183,605	9,829	16,546	52
Fall	25	80,517	4.658×10^{8}	273,890	4,182,746	15,858	9,350	144

*All distances in meters

[ǂ] Rotation of the long axis is measured in degrees clockwise from North

5.5. “Why” People Become Lost

Out of the 213 lost person incidents reviewed, only 97 cases (45.5%) involved persons who at some point were “lost”, or did not know where they were. This number in reality is probably much higher as people are often embarrassed to admit that they were lost. Of the remaining incidents, 58 (27%) involved separated parties, 42 (20%) involved overdue persons, 9 (4%) were found deceased, 6 (3%) were stranded, and 1 (0.5%) suffered from a medical condition and was unable to move.

There were numerous contributing factors that played a role in why someone, or a group, was reported as missing. There may have also been several factors that played a role in a single incident (such as losing the trail and then being overcome by darkness), but only the most prominent one was recorded during data collection. The number one factor for becoming reported as lost was losing the trail accidentally (36 incidents), followed by a failure to communicate the intended plan (25 incidents), and miscalculating the time or distance of the planned route (20 incidents). A comprehensive list of contributing factors can be found in Table 5.6.

For the most part, the incidents had a favorable outcome. Of the 213 incidents, 144 (68%) resulted in the lost person/group being found uninjured and 48 (23%) incidents were resolved by self-rescue. Ten incidents concluded with the subject being found injured, 9 subjects were found deceased, and 2 were found with medical problems. Of those that were found deceased, injured, or ill, the three top conditions the subject suffered from was major trauma, an injury to the lower extremity, and exposure to cold (Table 5.7).

Table 5.6 Contributing Factors to People Being Reported as Lost*

Main Contributing Factor	n	%
Lost Trail Accidentally	36	16.9%
Failure to Communicate Plan Effectively	25	11.7%
Miscalculation of Time or Distance	20	9.4%
Darkness	15	7.0%
Left Trail Intentionally	12	5.6%
Insufficient Information/Error in Judgment	12	5.6%
Snow on Ground	11	5.2%
Wrong Trail Taken	10	4.7%
Fatigue/Physical Condition	9	4.2%
Steep Terrain	6	2.8%
Emotionally Upset	5	2.4%
Ground Level Fall	4	1.9%
Skied Wrong Trail	3	1.4%
Suicide	2	0.9%
Falling Snow	2	0.9%
Rain	2	0.9%
Insufficient Equipment/Clothing/Experience	2	0.9%
Ice/Snow	1	0.5%
Above Ground Level Fall	1	0.5%
Drugs	1	0.5%
Animals	1	0.5%
Unknown	33	15.5%
Total	213	100.0%

*Several factors may have contributed, but only the primary factor was recorded.

Table 5.7 Injuries and Medical Conditions Suffered by Lost Persons

Condition	n	%
None	192	90.1%
Major Trauma	7	3.3%
Lower Extremity Trauma	4	1.9%
Exposure (Cold)	3	1.4%
Medical Illness	2	0.9%
Dehydration	2	0.9%
Laceration	1	0.5%
Exhaustion	1	0.5%
Other	1	0.5%
Total	213	100.0%

5.6. “How” People Behave When Lost

For all lost person incidents, the case incident reports described how 74 lost persons attempted to reorient themselves after they determined that they were in fact lost. Table 5.8 shows the various strategies employed. Thirty-one people (42%) attempted some form of route travelling. This includes following trails, roads, streams, etc. with the intent of eventually reorienting themselves or encountering some sort of civilization. Nineteen people (26%) decided to stay put and wait for rescue, while twelve people (16%) backtracked in hopes of recognizing a familiar feature in the landscape and reorienting themselves.

The remaining analysis for lost person behavior will focus on the hiker category. This category comprised 133 of the 213 (62%) lost person incidents within Yosemite, however only 129 of the incidents were analyzed to determine behavioral profiles. Four incidents were withheld from behavioral analysis because the lost subject, at some point during the search, took advantage of motorized transportation by hitchhiking, taking a bus, or driving their own personal vehicle. These incidents created statistical outliers for the distance traveled before being found, as well as the other lost person statistics. While employing motorized transportation is a real possibility for a lost person, it drastically altered the results and consequently, may decrease the efficiency of using these statistics on future search incidents.

Since hikers made up most of the lost persons, the strategies used to reorient themselves after becoming lost are very similar to that of all lost people in Yosemite. Again, as Table 5.9 depicts, route traveling was the top strategy utilized by 21 people (38%) followed by staying put (15 people or 27%) and backtracking (9 people or 16%).

Other strategies included random travelling, view enhancing, route sampling, and direction traveling.

Table 5.8 Strategies Utilized by All Lost Persons to Reorient Themselves*

Lost Person Strategy	n	%
Route Traveling	31	41.9%
Staying Put	19	25.7%
Backtracking	12	16.2%
Random Traveling	4	5.4%
View Enhancing	3	4.1%
Route Sampling	2	2.7%
Direction Traveling	2	2.7%
Doing Nothing	1	1.4%
Total	74	100.0%

*Only able to determine information from 73 incidents involving 74 individuals (one group separated).

Table 5.9 Strategies Utilized by Hikers to Reorient Themselves*

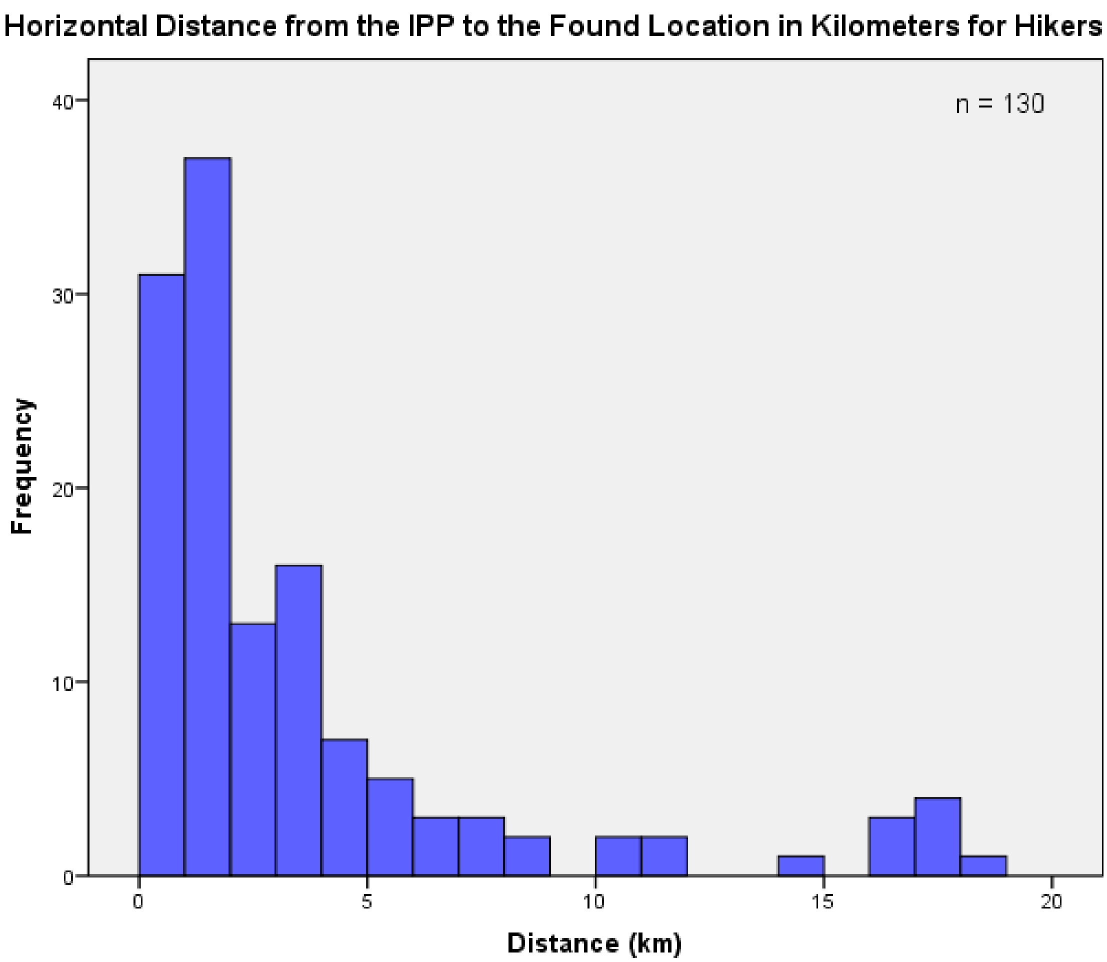
Lost Person Strategy	n	%
Route Traveling	21	37.5%
Staying Put	15	26.8%
Backtracking	9	16.1%
Random Traveling	4	7.1%
View Enhancing	3	5.4%
Route Sampling	2	3.6%
Direction Traveling	2	3.6%
Total	56	100.0%

*Only able to determine information from 55 lost hiker incidents involving 56 individual hikers (one group separated).

5.6.1. Horizontal Distance from the IPP for Hikers

There were 129 incidents involving lost hikers in Yosemite National Park that were retained for behavioral analysis. From these incidents, there were a total of 130 found locations (one incident involved a group of two that split up which resulted in two separate found locations). For these 130 occurrences the horizontal distance from each georeferenced IPP to its corresponding georeferenced found location was calculated. Figure 5.9 displays the distribution of these distances. The lower quartile, median, upper quartile, and 90th percentile of the dataset were 1.1 km, 1.8 km, 4 km, and 16.9 km respectively (Table 5.10 displays these calculations as well as their ISRID equivalents).

Figure 5.9



When the “local” Yosemite sample was compared to the “international” ISRID data (the population), the resulting Chi-square value was 15.354 (Table 5.11 shows the observed and expected frequencies used in the calculation). I found $P(X^2 > 15.354) \approx 0.004$; thus I rejected the null hypothesis. The Yosemite distribution for Horizontal Distance from the IPP to the found location was drawn from some distribution other than the population of all lost hikers. This means that the distances that hikers travel from the IPP to the found location in Yosemite was significantly different than the same corresponding distances that hikers travel at the global scale.

Table 5.10 Direct Comparison of Horizontal Distances traveled from the IPP to the Found Location in Kilometers for Hikers

	Yosemite (km)	ISRID (km)
n	**130**	**568**
25%	1.1	1.1
50%	1.8	3.1
75%	4.0	5.8
95%	16.9	18.3

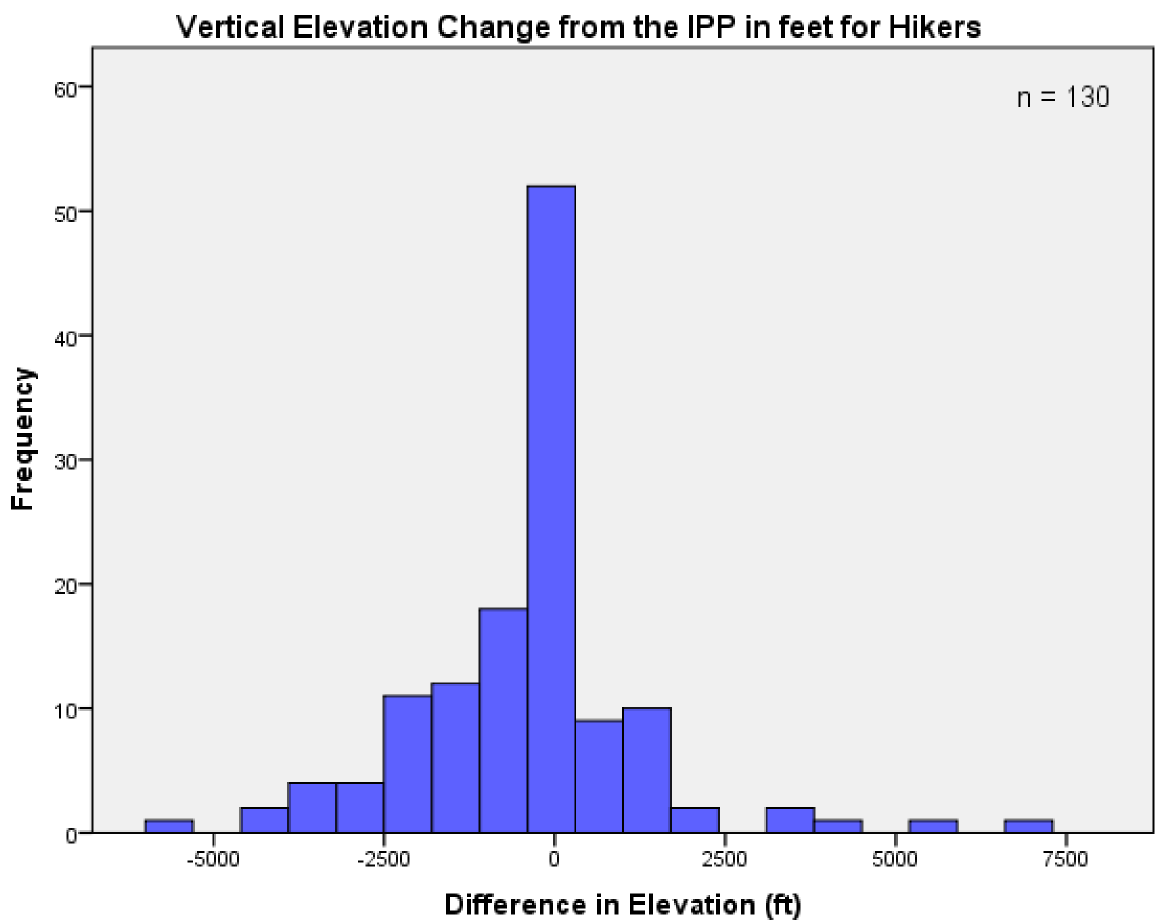
Table 5.11 Observed and Expected Horizontal Distance Frequencies

	Observed (O_j)	Expected (E_j)
n	**130**	**130**
0-25%	33	32.5
25-50%	49	32.5
50-75%	27	32.5
75-95%	20	26
95-100%	1	6.5

5.6.2. Vertical Elevation Change from the IPP for Hikers

Utilizing a 10 m DEM obtained from the National Park Service, the 130 occurrences were also analyzed to determine the difference in elevation between the georeferenced IPP and the georeferenced found locations. The distribution of changes in elevation can be seen in Figure 5.10. Approximately 31 % (n=40) of hikers traveled uphill from the IPP while 58% (n=75) traveled downhill and 12% (n=15) remained at the same elevation plus or minus 10 ft (Table 5.12 directly compares these data with the ISRID).

Figure 5.10



When these data were compared to the ISRID, the resulting Chi-square value was 2.489 (the observed and expected frequencies can be found in Table 5.13). I found $P(X^2 > 2.489) \approx 0.288$; thus I could not reject the null hypothesis. The Yosemite distribution for vertical elevation change in feet from the IPP to the found location was not significantly different than the same corresponding vertical distances that hikers travel at the global scale.

Table 5.12 Direct Comparison of Vertical Elevation Change from the IPP to Found Location in Feet for Hikers

	Yosemite (n=130)			ISRID (n=Unknown)		
	Uphill	Downhill	Same	Uphill	Downhill	Same
N	**40**	**75**	**15**			
%	30.8%	57.7%	11.5%	32%	52%	16%
25%	160	295		182	160	
50%	513	886		480	400	
75%	1479	2129		1175	1166	
95%	5819	3885		2634	2175	

Table 5.13 Observed and Expected Frequencies of Changes in Elevation

	Observed (O_j)	Expected (E_j)
n	**130**	**130**
Uphill	40	41.6
Downhill	75	67.6
Same	15	20.8

5.6.3. Dispersion Angle for Hikers

Eighty-one of the hiker incident reports contained information on the intended destination. This information, coupled with the IPP and found location, enabled the calculation of dispersion angle from where the person intended to go and where they were actually found. In fifteen of the incidents, the hiker returned to the IPP where they were eventually found by rescuers, so the dispersion angle could not be calculated for these cases. From the remaining 66 incidents, there were 67 found locations. Again this can be attributed to the fact that one group became separated leading to two distinct found locations. Of these 67 lost hikers, five had a dispersion angle of 0 meaning that these five people eventually arrived at their intended destination. Figure 5.11 illustrates the frequencies of the calculated dispersion angles. The lower quartile, median, upper quartile, and 95th percentile for these 67 occurrences were 7 degrees, 22 degrees, 56 degrees and 136 degrees respectively. Table 5.14 shows these data along with the data provided by the ISRID.

When I compared the dispersion angle in degrees from the found location to the intended destination for the Yosemite dataset to that of the ISRID, the resulting Chi-square value was 8.418 (the observed and expected frequencies can be found in Table 5.15). I found $P(X^2 > 8.418) \approx 0.077$; thus I could not reject the null hypothesis. The dispersion angle in degrees from the found location to the intended destination in Yosemite was not significantly different than the same corresponding dispersion angles that hikers experienced at the global scale.

Figure 5.11

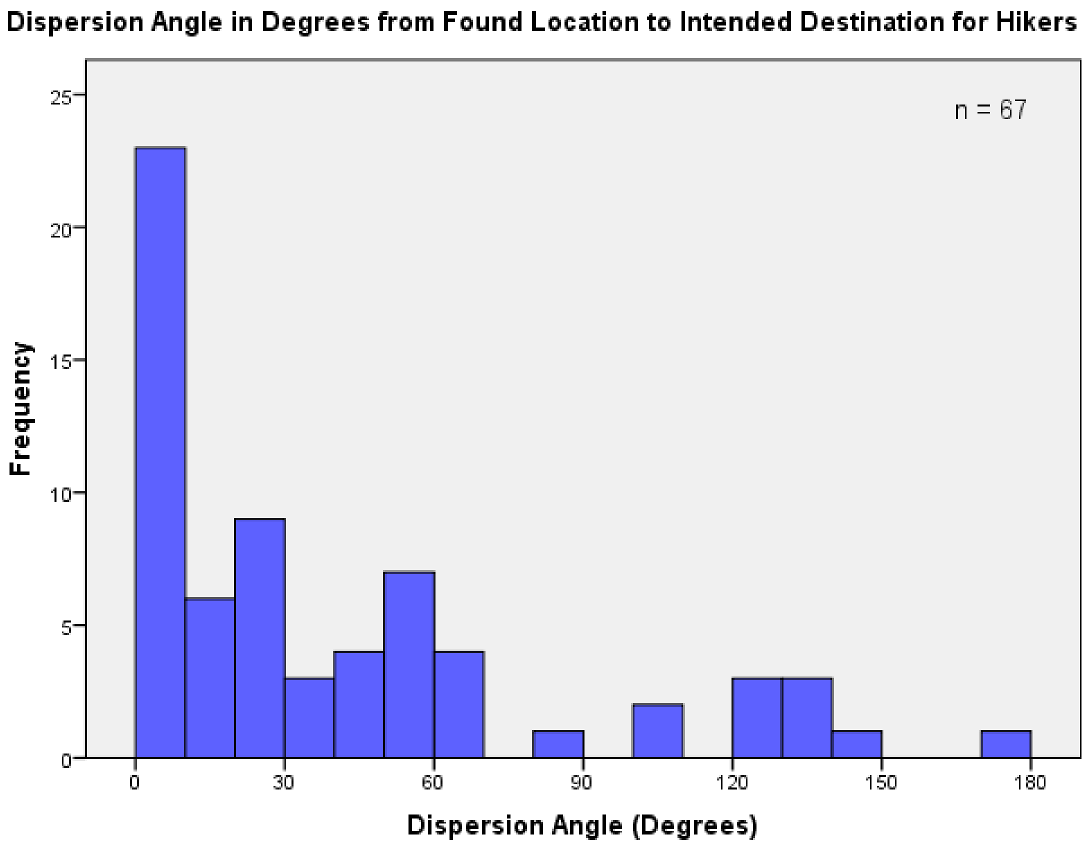


Table 5.14 Direct Comparison of Dispersion Angle in Degrees from Found Location to Intended Destination for Hikers

	Yosemite	ISRID
n	**67**	**134**
25%	7	2
50%	22	23
75%	56	64
95%	136	132

Table 5.15 Observed and Expected Frequencies for Dispersion Angle in Degrees

	Observed (O_j)	Expected (E_j)
n	**67**	**67**
0-25%	9	16.75
25-50%	25	16.75
50-75%	19	16.75
75-95%	11	13.4
95-100%	3	3.35

5.6.4. Track Offset for Hikers

The track offset, or distance from a road, trail, or linear hydrological feature, for the 130 found locations was also calculated. Forty-two percent (n=55) of the 130 found locations were directly on a linear feature. Of the 75 found locations not on a linear feature, the lower quartile, median, upper quartile, and 95th percentile distances from a linear feature were 20 m, 58 m, 94 m, and 411 m respectively. Figure 5.12 shows the distribution of the track offset distances while Table 5.16 shows the calculated descriptive statistics as well as the corresponding ISRID data.

When the track offset for hikers from the Yosemite dataset was compared to that of the ISRID, the resulting Chi-square value was 26.72 (Table 5.17 shows the observed and expected frequencies used in the calculation). I found $P(X^2 > 26.72) \approx 0.00002$; thus I rejected the null hypothesis. The distances that hikers were found from a linear feature, that is a road, trail, or hydrologic feature, in Yosemite was significantly different than the same corresponding distances that hikers were found from a linear feature in the global dataset. This means that in Yosemite, hikers were found much closer to a linear feature.

Figure 5.12

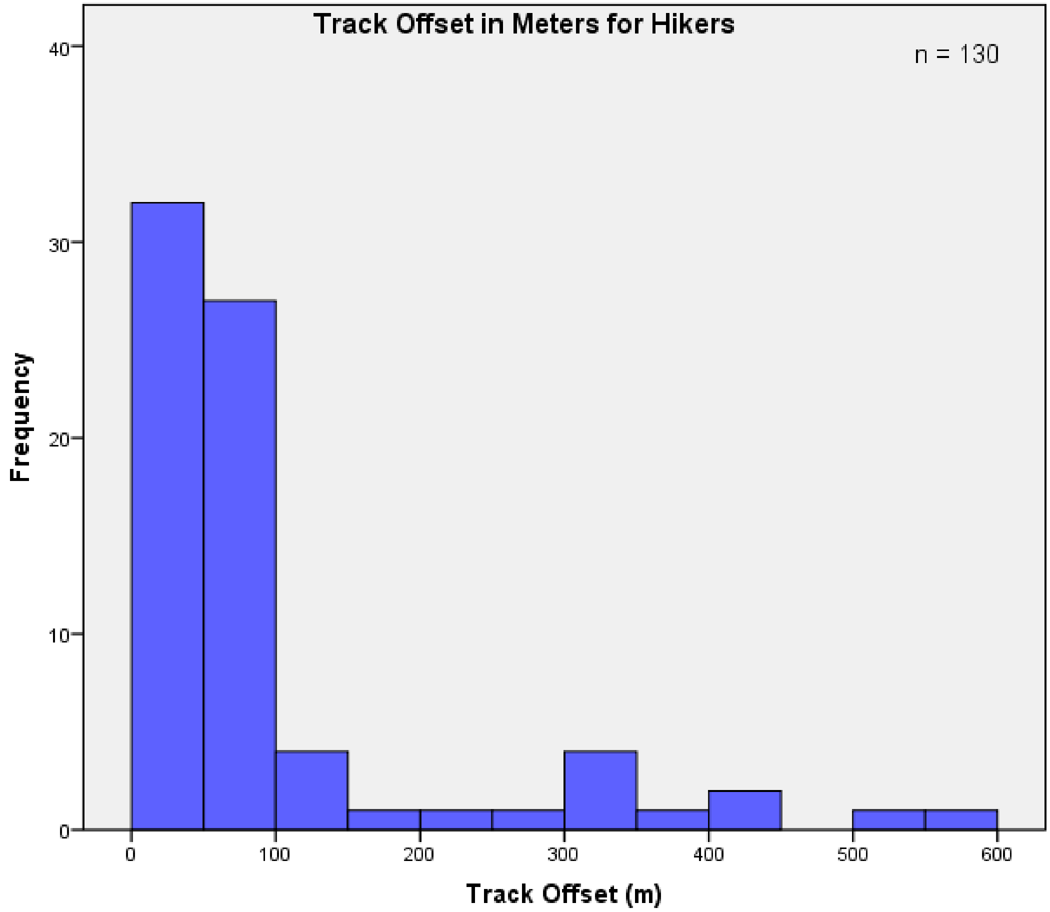


Table 5.16 Direct Comparison of Track Offset in meters for Hikers

	Yosemite (m)	ISRID (m)
n	**75**	**40**
25%	20	50
50%	58	100
75%	94	238
95%	411	424

Table 5.17 Observed and Expected Frequencies for Track Offset in Meters

	Observed (O_j)	Expected (E_j)
n	**75**	**75**
0-25%	33	18.75
25-50%	26	18.75
50-75%	6	18.75
75-95%	7	15
95-100%	3	3.75

6. Discussion

6.1. Explanation of Findings

The demographics of lost persons in Yosemite National Park closely resemble the findings of previous lost person studies conducted elsewhere. Kelley (1973), Perkins et al (2005), Twardy (2006), and Koester (2008) all found that the majority of subjects reported missing were single males. This study found that approximately 69% of single lost subjects within Yosemite were male. This is an interesting finding because a systematic, random sample of 563 visitor groups conducted by the Yosemite National Park Visitor Study from July 8-17, 2005 found that only 50% of all visitors were male (Littlejohn 2006). With respect to age, the median age of the Yosemite dataset was 35 which is similar to an Australian study that reported a median age of 36 years old (Twardy 2006). It was not surprising to find that the hiker category was the most prominent as Yosemite has over 800 miles of hiking trails and hiking is one of the main activities within the park.

Yosemite National Park is open year-round, therefore there is the potential for a person to become lost at any time of the year, yet, the months (May to September) that most people are reported as missing are somewhat predictable as they coincide with the months of highest park visitation (National Park Service Public Use Statistics Office 2011). The more people there are within the park, the more missing person reports there will be. However, when the frequency of lost persons was standardized for the number of visitors per month, February and March become the months with the most lost person incidents per 100,000 visitors. Inclement weather, such as heavy snow storms, can lead to dangerous conditions. This can have a major impact on the small number of visitors within the park. More research is needed determine why people are more likely to be reported as lost during the winter months, but the fact still remains that a majority of the incidents occur in the summer. This has implications for staffing for park officials and it follows that that since there more incidents, there needs to be more personnel to respond.

The days of week (Friday, Saturday, and Sunday) in which most people are reported missing also coincide with the days of highest park visitation (Pettebone et al. 2008). Again, the more people there are within the park, the more missing person reports there will be. It should be noted though that precise enough data was not available for the standardization of missing person incidents with the number of visitors per day.

The time of day that people are most likely to go missing is more difficult to explain. The temporal data gathered, along with qualitative examples from the SAR incident reports, indicate two possible reasons for people being reported as last seen during the afternoon hours. For one, people often begin their hikes early in the morning and continue on for most of the day. By mid-afternoon, they are exhausted and eager to reach their destination. This may cause them to unintentionally miss trail signs or veer off trail, or they may intentionally cut a trail in order to save time. This often leads to them becoming reported as lost or overdue. Second, people often wait until later in the day to go on hikes, and they think that they will be able to return before nightfall. Because of the terrain, people may not progress along the trails at their intended pace. In many cases, this leads people to become overtaken by darkness while on the trail slowing them down even more. Because of the darkness, they are either significantly delayed and are reported as overdue, or they become lost.

The spatial distribution of IPPs and found locations adhere to a similarly predictable pattern. The IPP “hot spots” are generally centered on the park’s busiest locations (e.g. Yosemite Valley) and strongly resemble “hotspots” of all search and rescue incidents in the park (a majority of these incidents are lower extremity traumas in which the location of the subject is known) (Doherty et al 2011). Because the median distance from IPP to the found location for hikers is less than 2 km, it would follow that the spatial distribution of found locations would closely resemble that of the IPPs.

When the dimension of time is incorporated, we see that the IPPs as well as the found locations vary temporally. A visual analysis of the IPPs and their standard deviational ellipses (Refer back to Figure 5.2), coupled with an understanding of the park’s physical and cultural geography, reveal certain patterns. In the winter, incidents are primarily confined to the valley and to the Badger Pass Ski Area. During the spring, more incidents occur, and after the Tioga Road opens in late May to early June (NPS 2011), their distribution begins to expand into the high country. However, most incidents are still confined to Yosemite Valley. As previously stated, peak visitation occurs during the summer months. Therefore most incidents take place during this time. The spatial distribution of incidents also becomes more widespread as the weather allows for travel into the back country. Then, during the fall, as the temperature begins to drop, so too does the number of visitors and hence the number of incidents. Fewer incidents occur in the back country, and again, most take place within Yosemite Valley.

It is not surprising, due to the median distance in which most lost persons travel, to find that the spatio-temporal distribution of found locations closely mimic that of the IPPs, yet it is important to note the patterns because this information has the potential to be implemented during a search operation.

The information derived from the above descriptive statistics can be invaluable to preventative search and rescue (PSAR) professionals. The goal of PSAR is to “help visitors avoid needing to be rescued by providing education about the hazards of hiking, and the time and equipment necessary to complete a planned hike” (Shier 2012). Yosemite has a newly established PSAR program and research such as this is helping to guide its development. With the right information, these initiatives can be more efficient and benefit more people. This is particularly important in times of tight budgets and thinly stretched resources.

With that being said, the findings of this study indicate that in order to reduce the number of lost persons, the park should post PSAR staff in Yosemite Valley and to a lesser extent Tuolumne Meadows, Sentinel Dome/Taft Point parking area, and Glacier Point during the busy summer months, specifically on the weekends and in the afternoon hours. More specifically, these PSAR stations should be near major trail heads due to the fact that most lost persons are hikers. In addition, park officials should consider setting up a PSAR station in the Badger Pass Ski area during the active winter ski season. As groups of people move past the PSAR stations, staff should attempt to speak with as many people as possible, but if they become inundated with visitors, they should make a concerted effort to talk to solo individuals, particularly males. They should also stress the importance of staying on trail, staying together as a group, and carrying a light source so that they do not become benighted. They may also want to point out that the terrain in Yosemite is very treacherous and the time that it takes to walk from one place to another may take much longer than anticipated.

6.2. Hypothesis Testing

One of the main objectives of this study was to determine if the “International” lost person statistics reported by the ISRID was suitable to be used in planning searches at the “local” level in Yosemite National Park, and several hypotheses were proposed.

It was hypothesized that the horizontal distance traveled from the IPP to the found location in kilometers by the lost person would be shorter for the Yosemite sample than what is reported by the ISRID. This hypothesis was found to be supported. Although the 25^{th} percentile was the same for both sets of data, the 50^{th} percentile, 75^{th} percentile, and 95^{th} percentile were much shorter in the Yosemite data than the ISRID when directly compared (refer back to Table 5.10). The Chi-squared Goodness of Fit Test confirms that the sample from Yosemite was significantly different from that of the ISRID. The ISRID data would overestimate the distance travelled by a lost hiker in Yosemite National Park (this may be attributed to the rough, steep terrain within Yosemite). This is important to note because if the ISRID data were used to plan a search in Yosemite, the search area may be greatly overestimated potentially leading to a longer search.

The second hypothesis was that the vertical change in elevation from the IPP to the found location would be mostly uphill due to the number of hikes that start in

Yosemite Valley and travel uphill. This was found to not be the case. In fact, a higher percentage of people travelled downhill in the Yosemite data set (58%) than in the ISRID (52%). There are potentially numerous reasons for this phenomenon. For one, the strategy employed by most people when lost was route travelling. Therefore, they may have followed a stream downhill in order to reach civilization, or they may have just chosen the path of least resistance and followed a trail downhill. Another reason for this is that people can become lost at any point during their journey. A person may have for instance been conducting a loop trail that began and ended in Yosemite Valley. They may have reached the farthest point and then begun their return heading back down toward the Valley when they became disoriented and lost. The point at which they were last seen would have been uphill from their final intended destination, and they would continue moving downhill in hopes of reaching where they eventually wanted to be. The chi-squared goodness of fit test confirmed that the sample from the Yosemite may have been taken from the population (that of the ISRID), therefore that the ISRID data on vertical elevation change may be used with some certainty when predicting the locations of lost hikers in Yosemite.

The third hypothesis was that the dispersion angle would be much greater for the Yosemite data than for the ISRID because the terrain does not allow for trails to go directly from one place to another within the park. Surprisingly, the dispersion angles were fairly similar between the two datasets (Table 5.12) and as previously stated the chi-squared goodness of fit test confirmed that the Yosemite data were not significantly different from the population (the ISRID). This means that the proposed predictive hypothesis may be rejected and the ISRID data on dispersion angle could be utilized in

Yosemite with some assurance. It seems that in Yosemite, lost hikers do not disperse more widely from their intended destination than they would elsewhere. More research in this area needs to be conducted to determine the exact reasoning behind this phenomenon, but perhaps it can be attributed to the topography and relatively narrow canyons in Yosemite which seems to restrict the dispersion of lost hikers.

The fourth and final hypothesis stated was that the track offset in meters for the found location would be much shorter than what was reported in the ISRID, because Yosemite has so many trails, roads, and streams, it would seem that a person could not get too far away from one of these features. There may be some support for this prediction as it was found that in a direct comparison between the Yosemite sample and the ISRID data, the distance for the 25^{th} percentile, 50^{th} percentile, 75^{th} percentile, and 95^{th} percentile were all shorter, even in some cases up to 40% shorter (Table 5.13). Again, in referring to the chi-squared goodness of fit test, the Yosemite sample was found to be significantly different from the population and could not have come from the ISRID. Therefore, the ISRID data on track offset should not be used alone without considering localized data in Yosemite when planning searches for lost hikers.

The Yosemite specific data for track offset has some direct implications for search managers when planning a search. Often, during the initial stages of a search, hasty search teams are sent up trails to look for missing subjects. The median track offset is approximately 60 m. Thus, if a team is sent up a trail, and they do nothing more than search 60m on either side of the trail effectively, then, in theory, they will find 50% of missing hikers.

6.3. Limitations of the Study

This study has two distinct limitations: the quality of the search and rescue case incident reports and the definition of “lost”. During the summer months when the park reaches its peak visitation, the NPS may be inundated with calls for help and available resources are sometimes stretched thin. The reports often become neglected and may be written several days after the incident was first initiated. The quality of the written report, specifically the locality information from which the incident will be georeferenced, may have been inadequate in some instances. In some cases, important data that was to be collected was absent, and when it was present, may not have been completely accurate. For this study, every effort was made to gather the most correct and detailed information available, and when that was not adequate, the incident was withheld from analysis.

Second, not all persons involved in this analysis were truly “lost”. Lost is narrowly defined by Hill as, “[being] unable to identify or orient their present location with respect to known locations, and have no effective means or method for orienting themselves” (Hill 1999). This definition does not accurately describe many of the subjects who were the focus of a search within Yosemite National Park. People could have either been separated from their party for an extended amount of time or merely overdue at their intended destination. At no time were these people “lost” according to the above definition, but they were reported as such by a concerned party. The term “missing” may more accurately describe these people, but that word too has its own preconceived notions. For this research, “lost” was defined as “being the subject of a land search, regardless of circumstances” (Hill 1999).

6.4. The Effects of Georeferencing Error

When georeferencing the IPP and found locations for incidents within Yosemite, great care was taken to produce the most accurate and precise location possible, but the fact remains that because of the way in which locations were reported by text within the reports, there is considerable georeferencing error. Essentially, the true location for each of these events could have occurred at any point within a circumscribed area defined by the uncertainty radius calculated by the MaNIS Georeferencing Calculator. To reiterate, the mean uncertainty radius of the IPPs equaled 361 m while the median uncertainty radius equaled 63 m, and the uncertainty radius of the found locations was 354 m while the median georeferencing uncertainty radius was 97 m.

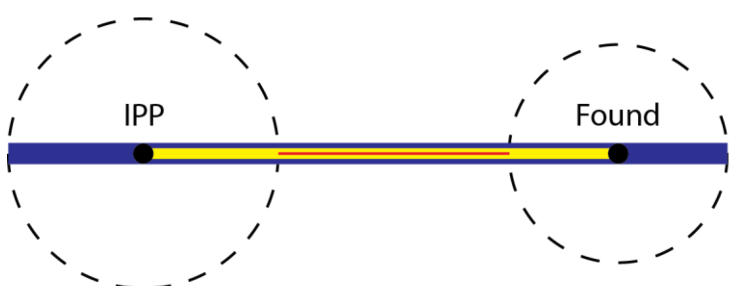
The georeferencing error has an effect on the analysis of lost person behavior in this study. For example, the distance travelled by a lost hiker from the IPP to the found location would vary if the actual IPP and found locations were in reality at different locations within the circumscribed georeferencing error circle. Figure 6.1 demonstrates the difference between the actual calculated distance and the hypothetical minimum and maximum possible distances between the two points. Table 6.1 shows how the 25th percentile, 50th percentile, 75th percentile, and 95th percentile would be altered if the minimum and maximum possible distances were accepted for all hiker incidents rather than the actual calculated distances.

If the theoretical minimum and maximum distances from the IPP to the found location for all hikers were compared to the ISRID dataset again using a chi-squared goodness of fit test, then the results are altered somewhat. The resulting Chi-square value for the theoretical minimum distance (n=130) is 41.577. I found $P(X^2 > 41.577) \approx$

$2x10^{-8}$. As with the actual calculated distance we reject the null hypothesis that the sample was taken from the population (ISRID) and accept the alternative hypothesis that the sample was taken from some distribution other than the population of all lost hikers. However, the Chi-square value for the theoretical maximum distance (n=130) is 7.292. I found the $P(X^2 > 7.292) \approx 0.121$. In this instance, I can accept the null hypothesis that the sample may have been taken from the population (ISRID), and therefore, the sample for the theoretical maximum distance between the IPP and the found locations in Yosemite is not significantly different from the population (ISRID).

The error associated with the georeferenced locations may cause this scenario to play out with the other variables as well. However, because the locations were georeferenced using the Guide to Best Practices for Georeferencing (Chapman and Wieczorek 2006), they represent the absolute best location for the incident points as they are both precise and accurate. This point merely illustrates the importance of accurately georeferenced data, and future studies of lost person behavior need to take uncertainty into account.

Figure 6.1



The yellow line represents the actual calculated distance between the IPP and the found location presented in the results. The dashed circle around the IPP and found location represents the georeferencing error. The red line denotes the theoretical minimum distance and the blue line is the theoretical maximum distance between the two points.

Table 6.1 Theoretical Minimum and Maximum Horizontal Distance in kilometers from the IPP to Found Location for Hikers

	Minimum Yose	Reported Yose	Maximum Yose	ISRID
n	130	130	130	568
25%	0.0	1.1	1.4	1.1
50%	1.2	1.8	2.9	3.1
75%	3.5	4.0	5.5	5.8
95%	14.5	16.9	19.0	18.3

6.5. Watershed Model

During the course of this research, it became apparent that there may be another useful way to evaluate lost person behavior. It is evident that the topography affects how people move through their environment, so instead of looking at how far they travel in a straight line from where they were last seen in order to predict where to look for them, perhaps it would be better to analyze the topographic features around them. One way in which to do this is by analyzing their movement between watersheds.

Figure 6.2 shows a spider diagram (a map with lines that join desired features used to visualize spatial patterns) linking the IPP for each missing hiker incident with its corresponding found location along with the Planning Watersheds for Yosemite National Park as defined by the California Interagency Watershed Map of 1999 (Calwater 2.2.1) (Watershed Specialist California Department of Forestry and Fire Protection 2010). It's important to note that the lines connecting the points are not actually the route of travel for lost hikers, but rather a visualization that joins the IPP with the found location. For all 129 hiker incidents (130 found locations), 63 people/groups (48%) were found within the same watershed in which they were reported last seen, and 15 of these were found at the IPP. Fifty (38%) people/groups were found in a watershed adjacent to the one in which they were reported last seen. Finally, 17 people/groups (13%) were found more than one watershed away from where they were last seen (Table 6.2). This means that 86% of lost hikers were found within one watershed of where they were last seen. Granted, this may still create a very large search area, but within a GIS this method may refine the planning process and assist in identifying higher probability search segments. This method of analyzing lost person behavior has the potential to revolutionize the way in which searches are conducted.

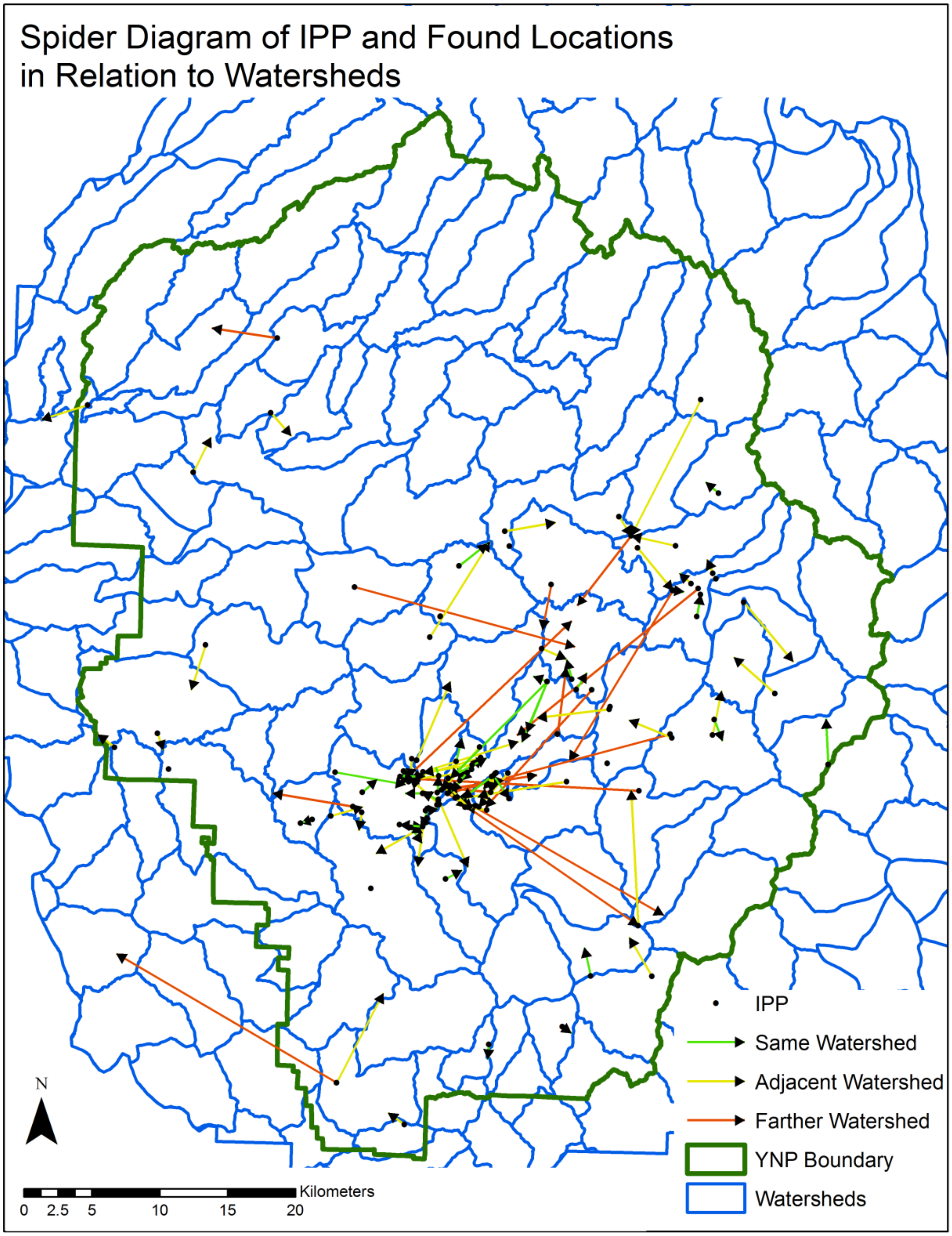
Table 6.2 IPP and Found Locations in Relation to Watersheds

	n	%
IPP and Found in Same Watershed*	63	48%
Found in Watershed Adjacent to IPP	50	38%
Found in Watershed Farther than Adjacent to IPP	17	13%
Sum	130 [ǂ]	100.00%

* 15 Found Locations were at the IPP

[ǂ] 130 found locations from 129 incidents (one group split up)

Figure 6.2


Spider Diagram of IPP and Found Locations
in Relation to Watersheds
N
Kilometers
0 2.5 5 10 15 20
IPP
Same Watershed
Adjacent Watershed
Farther Watershed
YNP Boundary
Watersheds

7. Conclusion

7.1. Conclusion

To the author's knowledge, this was the first comprehensive geographic analysis of historic wilderness search incidents in which GIS was utilized. Eleven years of Search and Rescue Case incident reports were reviewed from Yosemite National Park beginning in the year 2000, and all search incidents that met strict predetermined criteria were collected and evaluated. The IPP and found locations for each of these incidents were georeferenced using the point radius method by decoding geographic data that were buried in narrative text. Furthermore, incident and demographic information was parsed out and provided details of the events that occurred for each incident.

From this information, descriptive statistics were produced in order to determine who is getting lost, when they are getting lost, where they are getting lost, why they are getting lost, and where they are being found. These statistics were then evaluated in order to make recommendations on where and when to initiate PSAR operations. Now that park officials know where, and when, someone is most likely to become lost, they can approach the problem from an epidemiological standpoint and develop targeted preventative initiatives to keep a person from becoming lost in the first place (Ostfeld et al. 2005).

This study also looked at how people behaved once "lost". It was determined that in Yosemite, people typically attempt to follow a linear feature in order to reorient themselves or to become found. The 25^{th} percentile, Median, 75^{th} percentile, and 95^{th}

percentile were calculated and presented for several “lost person statistics” for the hiker category, including: the horizontal distance from the IPP to the found location in kilometers, the vertical elevation change in feet from the IPP to the found location, the dispersion angle in degrees, and the track offset in meters for the found location. Please refer back to sections 5.6.1 through 5.6.4 for tables presenting these findings.

The derived Yosemite specific statistics were then compared to the “international” lost person behavior statistics provided by ISRID to determine if lost person statistics at the “international” level are suitable for planning searches at the “local” level. It was found that the ISRID data provided for horizontal distance from the IPP and track offset were not suitable for use in Yosemite while the data pertaining to vertical elevation change from the IPP and the dispersion angle could potentially be utilized for search planning. Although the ISRID data are divided into eco-regions, the results of this study call into question their total effectiveness at the local level because two of the lost person behavior statistics evaluated, horizontal distance from the IPP and track offset, were found to be significantly different in Yosemite. Additional “local” lost person behavior studies need to be conducted elsewhere, and their results compared to those of the ISRID, before a definitive conclusion can be drawn about their overall effectiveness in search planning. If the data are significantly different in Yosemite, then the data may be different in other places as well.

The information gained from this study about lost person behavior within Yosemite can be used to assist search managers to coordinate search operations within the park in a more efficient and timely manner. In turn, this will potentially decrease the time it takes to return missing subjects to safety, minimize their chance of injury, and increase the odds of survival. Regardless of search outcomes, this research will provide tools that help search planners make decisions with accountability and confidence.

The wellbeing of the missing individual is not the only benefit of a more efficient search. The overall financial burden associated with search and rescue operations within Yosemite National Park may be reduced. Most search operations are staffed in one way or another by volunteers, but all operations in the park also involve paid personnel from law enforcement agencies and the National Park Service. Lengthy operations require hundreds to thousands of man-hours and some even involve the use of helicopter searches which can cost hundreds to thousands of dollars per hour (Wallach 1994). The National Park Service as a whole spends upwards of $3 million a year on rescues (Heggie and Heggie 2008), and this cost is eventually passed on to taxpayers (Wallach 1994). The high cost of search and rescue operations has led some politicians to propose charging those who are rescued for the cost of the operation (Repanshek 2008). By utilizing the Yosemite specific lost person behavior statistics, this cost may be reduced or avoided.

This study not only benefits search operations in Yosemite, but potentially those in other jurisdictions as well. It provides a structure through which to study lost person behavior at the local level. The methodology presented can be replicated with other search and rescue datasets to create additional "local" statistical profiles and, ultimately, provide more insight into lost person behavior.

The methodologies from this study not only contribute tactically, but also provide a theoretical framework that has the potential to contribute to the field of geographic information science as a whole. The search for a missing person is inherently a spatial problem, and once the critical factor of time is incorporated, it provides a unique opportunity to study spatio-temporal phenomenon. One very important question that remains to be examined is how the lost person moves from the IPP to the found location over time. This is an interesting facet of behavior that deserves further study, and the methodology provided here, including georeferencing the IPPs and found locations, lays the foundation. One way in which a future study like this may be conducted is by georeferencing not only the IPP and found location, but also all the locations described by a lost person in interviews after they were found. This data is occasionally included in case incident reports.

This study opens the door to other additional research as well. One of the most promising aspects of this report was the realization that watersheds may be used to predict the found locations for lost subjects. Watersheds are often used to draw search segments because ridges and streams provide natural borders for searchers in the field. Yet, to the author’s knowledge, there has never been a detailed study in which IPPs and found locations are used to analyze lost person behavior in relation to these watersheds. A more in depth analysis of watersheds and the way people move through them in Yosemite would be very beneficial, and, because the physical geography varies across the world, this same type of study should be recreated in other study areas.

Another aspect that needs more detailed review is that of the qualitative data provided in the case incident reports. Some of the case incident reports provide very meticulous transcripts from debriefings with lost subjects. These accounts describe where they first became lost as well as where they travelled and why. As previously mentioned, this information may be georeferenced in order to model their movement through the terrain. Additional information as to why they became lost is also included. Examples include poor trail signage near Sentinel Dome/Taft Point or deep snow covering the trail around the rim of Yosemite Valley in early spring.

Although there is still much work that needs to be done on lost person behavior in Yosemite National Park, this research provides a solid foundation. The findings presented here may help prevent individuals from being reported as missing and may ultimately save the lives of those who do eventually become lost.

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Appendix A – Detailed Description of Study Area

Geology and Geomorphology

The Sierra Nevada mountains are an asymmetric mountain range that run approximately 350 miles north-to-south and are anywhere from 50 to 80 miles wide (National Atlas of the United States 2011). The Sierra Nevada range is essentially the product of a huge block of the Earth's crust that broke free on the east along a bounding fault system and was uplifted and tilted westward about 25 million years ago(Huber 1987). This process created a long gentle western slope that raises an average of 200 feet per mile (Wahrhaftig 1962). In contrast, the eastern side is a steep escarpment that rises rapidly at nearly 1000 feet per mile culminating in a crest that is more than 13,000 feet in elevation (Wahrhaftig 1962, Huber 1987).

The area has a long and dynamic geologic history. The oldest rocks in Yosemite were created about 475 million years ago. Granite dominates the Yosemite area as well as throughout much of the Sierra Nevada. Granite is an intrusive igneous rock which formed deep within the Earth by the cooling and solidification of molten rock. It should be noted that the granite in the Sierra Nevada is not monolithic, but rather a composite of smaller bodies of granitic rock. These composites became exposed when the overlying metamorphic rock eroded away creating an area of low relief. Then, about 25 million years ago, as previously mentioned, this area was uplifted creating the present day Sierra Nevada (Huber 1987). As the area was lifted, the gradients of the streams which flowed into California's Central Valley increased causing the streams to cut deep into the granite.

About 10 million years ago, many of the canyons and valleys north of the Tuolumne River became buried by volcanic lava flows and mudflows. The streams renewed their downcutting, but many shifted their course laterally as they flowed toward the Central Valley (Huber 1987). This process established the present day Sierra Nevada drainage patterns and intervening divides as well as created the template for the landforms which would later be refined by glaciation (Huber 1987).

As the world began to cool 2-3 million years ago, glaciers began to develop throughout the Sierra Nevada, and Yosemite experienced at least three separate glacial periods. Glaciers have had a number of affects on the park, and the striking features that can be seen today are a product of them. Glaciers created cirques, arêtes, and horns along the higher divides. Glaciers cut striations into granite and gave it a glacial polish. Glaciers cut through the sinuous V-shaped valleys created by flowing water, straightening, deepening, and widening them to give them a distinct U-shaped appearance. Glaciers also created high hanging valleys within the park, which led to some of the highest and most dramatic water falls in the world. Hundreds of kettle lakes were also formed as glaciers receded (Huber 1987).

Climate and Weather

In the 1970s Robert Bailey, a US Forest Service geographer developed a system for classifying and mapping ecoregions in order to better assist federal agencies in managing natural resources (Bailey 1996). Bailey defined an ecoregion as “[a] major ecosystem, resulting from large-scale predictable patterns of solar radiation and moisture, which in turn affect the kinds of local ecosystems and animals and plants found there" (Bailey 1998, p. 145). This classification system was based on likenesses and differences which requires the consideration of the "physical factors that underlie ecosystem differentiation" (Bailey 1998). Several federal agencies including the USDA Forest Service, U.S. Geological Survey, and the U.S. Fish and Wildlife Service, as well as many private entities (including the ISRID), have adopted this multi-level detailed system of land classification based on the ecoregion concept (U.S. Forest Service 2011). For this reason, Bailey's ecoregion description was chosen to describe Yosemite's climate for this research.

Yosemite is characterized as M261 – Sierran Steppe –Mixed Forest—Coniferous Forest—Alpine Meadow Province (U.S. Forest Service 2011).The most general designation is the Ecosystem Domain designated by the 200 level number. This signifies a Humid Temperate Domain, located in the middle latitudes, and governed by both tropical and polar air masses (U.S. Forest Service 2011). Further segmentation is designated by the 60 level number. This specifies a Mediterranean Division with long hot summers and mild winters, which according to Bailey "…is a product of subsidence associated with the subtropical high. In the summer, the high moves poleward over these areas, bringing essentially desert weather. In the winter the anticyclonic circulation moves equatorward, allowing the westerlies to bring moisture into the area" (Bailey 1998, p. 81). The letter M represents "Mountains" with altitudinal zonation (for a more in depth look at the zones found within Yosemite see the section on Vegetation in Appendix A). This, along with the last number, 1, designates the specific province which as stated previously is the Sierran Steppe -- Mixed Forest -- Coniferous Forest -- Alpine Meadow Province. Here, temperatures average 35 to 52 degrees Fahrenheit, but fall with rising elevation (U.S. Forest Service 2011). The climatic conditions for this region are influenced by prevailing west winds, leading to much drier east slopes. The base of the west slope however does have a long dry summer season and may only receive 10 to 15 inches of precipitation a year. As elevations increase, so too does the amount of precipitation. At higher elevations, the dry summer season is shorter and annual precipitation of as much as 70 inches may be encountered, much of it falling in the form of snow. In fact, the precipitation that falls in the winter makes up 80 to 85 percent of the annual precipitation (U.S. Forest Service 2011).

Although the climate in Yosemite is quite predictable, the weather is not. Summer thunderstorms may hit unexpectedly, especially at higher elevations. One of the main dangers associated with these thunderstorms is lighting which may threaten hikers and climbers in open areas. Likewise, snowstorms may hit suddenly in the winter months dumping several inches of heavy, wet snow.

Hydrology

The lakes, streams, and rivers within Yosemite National Park play an important role, not only as an integral component in local ecology, but also as a source of drinking water for thousands of Californians. Yosemite's two principle rivers are the Merced River and the Tuolumne River, and the headwaters for both can be found within the park. The water from all of Yosemite's streams and tributaries will eventually end up in one of these two rivers. In order to preserve their free flowing conditions, the U.S. Congress declared both rivers as "Wild and Scenic Rivers" in the 1980s (National Park Service 2011).

The Tuolumne River begins on the slopes of Mount Dana. This river, along with its tributaries, drains the northern half of the park. The Merced River originates on the slopes of Mount Lyell and the Clark Range and flows through Little Yosemite Valley, over the Nevada and Vernal Falls, and on into Yosemite Valley. This river drains the southern portion of the park, including the water from all of Yosemite Valley's majestic falls (National Park Service 2011).

Although precipitation is highest from November to March, stream flow remains relatively low during this time. It is not until late spring when the temperatures rise and the winter snow accumulation above 6,000 ft. begins to melt that the rivers begin to swell. During this time, the soils become saturated and rivers begin to overflow their banks, inundating meadows and wetland areas. This process brings rejuvenating nutrients, but can cause some issues as campgrounds and other areas become flooded. This time of annual rise in water levels is referred to as the "spring pulse" (National Park Service 2011). In early to mid June the rivers reach their "peak" flow and the waterfalls are at their grandest. Slowly the rivers begin to recede, and by fall, many of the Valley's waterfalls become only trickles. The winter snow eventually comes though and the process is repeated once more (National Park Service 2011).

Vegetation

The climate, coupled with the vertical zonation, and the influences of topography and soil type create five major vegetation zones: foothill-woodland, lower montane, upper montane, subalpine, and alpine (Yosemite National Park 2011).

The foothill-woodland zone begins at approximately 1,800 ft (549 m) and can be found on the park's western boundary near the El Portal Administration center and the Hetch Hetchy reservoir. This area is characterized by hot and dry summers with little to no snow in the winter. These conditions allow for several different plant species including, chamise, ceanothus, blue oak, interior live oak, gray pine, and manzanita, which predominates.

The lower montane starts at about 3,000 ft (900 m) and covers nearly 166,000 acres along the western side of the park. It can be seen in Yosemite Valley, Wawona, Hetch Hetchy, as well as along the Big Oak Flat Road. Like the foothill-woodland zone, this zone has hot, dry summers, but in contrast, the lower montane zone has cool moist winters where accumulation of several feet of snow in the winter is possible and it can stay on the ground for quite some time. This zone has a great floral diversity with numerous species of trees including California black oak, ponderosa pine, incense-cedar, and white fir. Yosemite's groves of giant sequoia are also found in this zone.

At about 6,000 ft (1,800 m) in elevation, the lower montane gives way to the upper montane. The upper mountane covers 216,000 acres and are found in areas north and south of Yosemite Valley. This zone has short, moist cool summers an cold wet winters with snow beginning to fall in November. Accumulation of up to six feet is possible and it may remain until June. Jeffrey pine and western juniper can be found here as well as pure stands of Red fir and lodgepole pine. From June to August, wildflowers bloom in the meadows.

The subalpine forest emerges at approximately 8,000 ft (2,450 m) and encompasses 297,000 acres. It can be found east of the Tuolumne Meadows area to

Tioga Pass. This zone has long, cold, and snowy winters, and snow accumulation of three to nine feet is typical. This cooler climate results in a short growing season. Western white pine and mountain hemlock can be found here, and subalpine meadows flower in July and August.

The final zone is classified as alpine, and it covers 54,362 acres areas above tree line, approximately 9,500 ft (2,900 m). This zone has short cool summers with long, cold, and snowy winters. Besides, the harsh climate, vegetation is hindered by expansive areas of exposed granite and talus slopes. However, several types of lichens, mosses, and succulents have found their niche here (Yosemite National Park 2011).

Fauna

Although Yosemite Naitonal Park is not specifically known for its wildlife, it is home to more than 400 species of vertebrate animals including fish, amphibians, reptiles, birds, and mammals. The large variety of species can be attributed to the diverse habitats found throughout the park. Visitors can often catch a glimpse of a mule deer, an acorn woodpecker, or the endangered Sierra Nevada bighorn sheep. There are also several species of non-native fish that have been introduced into the park, most notable trout, which attract fishermen (Yosemite National Park 2011).

There are three main species of concern to visitors that must be considered during search and rescue mission planning, both as a factor in lost person behavior and as a risk to searchers: black bear, mountain lion, and rattlesnake (Yosemite National Park 2011).

Wildlife biologists estimate that there are currently between 300 and 500 black bears within Yosemite National Park, and despite advanced bear management programs, there is still a problem with human-black bear conflict (Madison 2008). This conflict usually arises when the bears wander into front country areas, lured by the scent of garbage or human food. Every year bears rummage though tent cabins and break into locked vehicles in search of food. Attacks on humans are rare, and the National Park Service claims that no one has been killed by a bear within the park, but the threat is still very real. Visitors are encouraged to keep a safe distance from bears and are forced to adhere to strict food storage regulations by utilizing food storage lockers and “bear canisters” while hiking in the back country (Yosemite National Park 2011)

Of lesser worry is the potential threat posed by mountain lions and rattle snakes. A study conducted in 2003 by scientists at Yosemite found that mountain lions “occasionally pass through developed areas but seldom linger” (Yosemite National Park 2011). In addition, mountain lions in the park showed no aggressive behavior towards visitors. However, officials still caution visitors and warn them to keep children close.

The Northern Pacific rattlesnake is the only rattlesnake found within the park. It is venomous and has been known to bite visitors. The official Yosemite National Park website states though, that “no one has ever died from a bite in Yosemite (“except for one questionable account in 1931”) (Yosemite National Park 2011).

History

Carbon-14 dating places the first occupancy in what would later become Yosemite National Park between 3,000 and 4,000 years ago, but little is known about these first inhabitants. Then about 2,000 years ago a tribe known as the Sierra Miwoks began seasonal occupancy of the region as they attempted to escape the summer heat of the central valley. The foothills and valleys were an ideal location for these early peoples and they were able to capitalize on the area's abundant resources including game, fish, plant foods, and water (Greene 1987). It should be noted that White historical accounts refer to these people as the Yosemite Indians (ibid).

The first historical account of the area stems from an expedition lead by Joseph Rutherford Walker to explore and map the area between the Rocky Mountains and the Pacific coast in the mid 1830s. One of the members of this party, Zenas Leonard, published an account of their journey through the Sierra Mountains in 1839, and in it he describes the "Big Trees" and impressive scenery. It is unclear however if they actually discovered what later would be known as Yosemite Valley. That "discovery" is credited to the Mariposa Battalion lead by James D. Savage in March 1851 when they pursued a band of American Indians in order to retaliate for raids on a the Fresno River post southwest of Yosemite. After gazing upon the magnificent valley, Dr. Lafayette Houghton Bunnell, a battalion surgeon, suggested that the valley be called "Yosemity" after the native inhabitants. The spelling was changed to end in an "e" in an official report of the expedition and from that point forward became the adopted spelling. (Greene 1987).

In 1855 the first tourist party of Yosemite Valley was organized by James M. Hutchings. During this trip, Hutchings and his party chronicled the spectacular natural elements and painted images of several of the valley's iconic features. His accounts became popularized in the press and spread quickly to the east coast. Tourists began to pour into the area. As they did so, there became a realization that there was a need to conserve natural environments, not just for the preservation the resources, but for the enjoyment of citizens (Greene 1987).

On June 30, 1864 the U.S. Congress passed the Yosemite Grant, and it was signed by President Abraham Lincoln. This act transferred Yosemite Valley and the Mariposa Grove to the State of California and it became "reserved from settlement". The area was to be managed by the Governor of California along with eight commissioners. Galen Clark, who was an advocate for the preservation of the Yosemite Valley and former hotel operator in Wawona (south of Yosemite Valley), became the representative of these commissioners and was appointed the "State Guardian" (Yosemite National Park 2011).

The passing of the Yosemite Grant was an important moment in American history as this was the first instance in which a central government preserved an area strictly for the enjoyment of people and for the protection of scenic values. It was also the beginning of not only the California State Park System, but of state park systems nationwide. This is also the credited as being the birth of the National Park idea (Greene 1987).

In 1889, John Muir, a naturalist, conservationist, and author, began to campaign for Yosemite to become a National Park in response to concerns about overgrazing. He became successful, and on October 1, 1890 Yosemite National Park was created. Then in 1906, the Yosemite Grant was returned to the Federal Government by the State of California and the land became incorporated into the National Park. From the time it was first established, Yosemite National Park was protected by the 24th Infantry and the 9th Calvary, composed of African American Soldiers known as Buffalo Soldiers. Then, in 1916 the United States National Park Service was formed and it took over the role of protecting the park (Greene 1987 and National Park Service 2011).

Throughout the 1900s the development of roads, construction of hotels, and the rise of automobile traffic lead to an increase in visitation. The works of the famous photographer Ansel Adams also popularized the area, drawing numerous visitors who came to see the dramatic features captured in his black and white photographs. Yosemite National Park was eventually named a World Heritage Site in 1989 (Yosemite NPS 2006). Today the National Park Service tries to balance protecting Yosemite and its resources with the enjoyment of its visitors.

Park Visitation

Yosemite National park is open to the public twenty-four hours a day, 365 days a year and although there are no reservations required for entry, there is a twenty dollar fee per vehicle. Since the inception of the park, there has been a general increase in the number of visitors to the park, and in 2010, Yosemite National Park was host to 3.9 million recreational visitors (NPS Public Use Statistics Office 2011), with most of them arriving during the summer months. This currently ranks Yosemite as the third most visited national park, behind only the Great Smoky Mountains and the Grand Canyon (Bly 2011).

The National Park Service (NPS) Visitor Services Project (VSP), part of the Park Studies Unit (PSU) at the University of Idaho has conducted several studies in the park to determine visitor demographics and visitor use (Blotkamp 2010, Le 2008, and Littlejohn 2006). These studies also examine the differences between the summer and winter use. The following generalizations come from a study conducted July 8-14, 2009 (Blotkamp 2010) and one conducted February 2-10, 2008 (Le 2008).

Most visitors to the park arrive in groups, only a small percent are solo subjects (5% of people in summer and only 8% of people in winter). Visitors range in age from 1 to over 90 years of age, however, more than a third of visitors are between 41 and 60 years of age (37% in summer and 35% in winter), and almost 20% are 15 years or younger (19% in summer and 17% in winter). An overwhelming percentage of visitors classified themselves as white (88% in both summer and winter) followed by Asian (11% in summer and 10% in winter). English was the language most likely used by visitors for both speaking and reading (>90% in both studies).

A majority of visitors to Yosemite are from the United States (75% in summer and 91% in winter) and of those most are from California (62% in summer and 89% in winter). Only a small percentage of visitors were considered residents of the area, defined as living within 50 miles of one of the entrance stations, (3% in summer and 10% in winter). Of the international visitors, the majority are from European and Asian countries. In summer, 87% of visitors surveyed said that they were visiting the park for their first time in 12 months; 53% visited for the first time in twelve months during the winter. The summer months were also more likely to see first time ever visitors (57% as compared to 26% of winter visitors).

More than 90% of visitors obtained some type of information about the park prior to their trip. The most likely source of this information was the National Park Service website, information gained on previous visits, or information from friends/relatives/word of mouth. Summer visits were planned further in advance than winter visits. About 68% of people made the decision to visit Yosemite in the summer more than one month in advance, as compared to only 32% in winter. Trips planned less than seven days in advance accounted for only 18% of trips in the summer, yet 39% of trips planned in the winter were done so in less than seven days in advance. The average length of stay for visitors in the summer was 2.4 days. People tended to stay for a shorter period of time during the winter with an average of 1.3 days.

Yosemite National Park has numerous activities and nearly everyone can find something in which they like to do. Many people come to emulate Ansel Adams and photograph the scenic beauty, some hike on the park’s 800 miles of trails, while others only want to see some of the tallest waterfalls in the world. Yosemite also has various water activities, trout fishing, world class rock climbing, numerous picnicking spots, ranger-lead interpretive programs, and cultural and historical sites. When surveyed, the activities most partaken in by visitors included viewing scenery, taking day hikes, and doing activities in Yosemite Valley such as shopping and dining. During the winter, 24% of respondents also reported that they skied (Blotkamp 2010 and Le 2008).

The areas most visited during summer include Yosemite Valley, Glacier Point, Tuolumne Meadows, Mariposa Grove, Wawona, and Tenaya Lake (Blotkamp 2010).

Due to snowfall and road closures, the areas visited in the winter are much different. During winter visitors are most likely to go to Yosemite Valley; Badger Pass and Glacier Point Road; and Mariposa, Tuolumne, and Merced Groves. It should be noted that less than 1% reported going to Tuolumne Meadows (Le 2008).

Areas of Interest

Within Yosemite there are several different areas that are popular with and easily accessible by visitors. These areas include Yosemite Valley, the Mariposa Grove, Wawona, Glacier Point, Badger Pass, Crane Flat, Tuolumne Meadows, and Hetch Hetchy.

Yosemite Valley is by far the most visited area in the park. The Valley is where visitors can see some of the tallest waterfalls in the world including Yosemite Falls and Bridalveil Fall. The Valley is also home to the picturesque Half Dome, the prominent El Capital, and several other large granite features, as well as meadows and wetlands. The Valley is also the start of many day hikes and the infamous John Muir Trail. Shopping, dining, and museums can be found here as well. A majority of the park's campsites and hotels are in the Valley too.

Mariposa Grove and Wawona are near Yosemite's South Entrance. The Mariposa Grove contains about 500 mature giant sequoias, some of which exceed 3,000 years old (NPS 2011). Two of the most famous sequoias are named the Grizzly Giant and the California Tunnel Tree, both of which are about a 0.8 mile hike from the parking lot (NPS 2011). The road leading to the Mariposa Grove is not maintained during the winter, so it is often closed to cars from November through April. It is however accessible to skiers and hikers. Wawona is about eight miles North West of Mariposa Grove and is the location of the historic Wawona Hotel and several other historic buildings. Wawona is accessible year round by car.

Glacier Point is an overlook with sweeping views of Yosemite Valley, Half Dome, and the High Sierra, and it is about thirty miles by road from the Valley (NPS 2011). The road to Glacier point is closed from November until early May to late June, depending on snowfall. During this time, Glacier Point is only accessible by cross-country skiing or snowshoeing. On the way to Glacier Point, along Glacier Point Road, lies Badger Pass, a cross country and downhill ski area. The road to Badger Pass is maintained from mid-December through March.

Crane Flat is located 16 miles west of Yosemite Valley at the intersection of Big Oak Flat Road and the Tioga Road (Highway 120). Crane Flat is an area of enjoyable forests and meadows with several camping sites. The Tuolumne and Merced Groves of Giant Sequoias are nearby and are easily accessible by foot. Crane Flat is accessible by car year round.

Tuolumne Meadows is located along the Tioga Road northeast of Yosemite Valley near the Tioga Pass entrance station. This area is an open sub-alpine meadow which the Tuolumne River winds its way through. Here visitors can camp, dine, and get information from the Tuolumne visitor's center. There are also several day hikes departing from the area, some of which ascend large granite domes overlooking the meadow. Due to heavy accumulating snows, the Tioga Road is closed from November through late May or early June, and this area is only accessible by cross-country skis or snowshoes.

Hetch Hetchy is regarded by the NPS as the "lesser known twin to Yosemite Valley" and it lies in the northwest corner of the park (NPS 2011). Like the Valley, Hetch Hetchy has dramatically exposed granite cliffs and two of North America's tallest waterfalls, but construction of the O'Shaughnessy dam was authorized by Congress in 1913 and the valley was flooded creating Hetch Hetchy Reservoir. This reservoir is now the source of drinking water for much of the San Francisco Bay Area. There are several less-used wilderness trails that begin at the reservoir and the road leading to Hetch Hetchy is open year-round during daylight hours. The road can however close periodically due to snow during the winter and early spring.

Hazards

As beautiful as Yosemite is, it can also be very dangerous. The Operations Branch of the Visitor and Resource Protection Division is tasked with keeping visitors and employees safe within Yosemite National Park. The Operations Branch manages the law enforcement rangers, emergency medical services, and search and rescue (Yosemite National Park 2004). During a search incident, Yosemite Search and Rescue, notoriously known as YOSAR, organizes under a command structure to locate, stabilize, and extricate the lost victim. YOSAR was established in the 1960's and its members are specialized in search techniques, emergency medicine, high angle rescue, swift water rescue, helicopter rescue, as well as several other rescue disciplines. YOSAR ranks among the best search and rescue teams in the world and is prepared for any emergency which may take place within the park (Friends of YOSAR 2011). With that being said, there are numerous hazards that threaten the average visitor, but if proper precautions are taken, these dangers may be mitigated. The following descriptions of hazards are not an all encompassing list but rather a representation of events that have happened to visitors in the past as evidenced by Yosemite search and rescue case incident reports.

As previously explained, the topography of Yosemite national park is unique, and with that comes a unique set of dangers. The nearly three thousand foot cliffs within the valley provide ideal “big wall” rock climbing conditions, but misfortune or inexperience can cause climbers to take falls of several hundred feet causing traumatic injury and death. Climbers have been known to become benighted on the rock face, trapped by sudden changes in weather, or even become “ledged out”, where they are unable to move up or down and are essentially confined to one small area. Hikers can also become “ledged out” if they leave the designated trail, whether accidentally due to poor trail conditions or purposefully attempting to take a shortcut. The rapid elevation gains experienced by climbers and hikers as they leave the valley have caused some to develop acute mountain sickness. Symptoms include, but are not limited to, headache, nausea, and weakness (Cox and Fulsaas 2003). The rockiness and unevenness of the trails cause many hikers to experience lower extremity injuries as well. In fact, a study conducted by Hung and Townes examined Yosemite search and rescue incident reports from 1990 to 1999 and found lower extremity injuries to be the most common injuries reported (Hung and Townes 2007). Another danger posed to climbers, and hikers as well, is that of rock fall. As granitic rock weathers, large sections of it slough off and fall unexpectedly. This can cause severe trauma to those in its path. From 1857-

2002, ten people were killed and at least 20 people were severely injured by rock falls in Yosemite Valley (Guzzetti 2003).

The weather poses hazards to visitors as well. The hot dry summers cause visitors to become dehydrated and experience heat illness; furthermore, dehydration, hypovolemia, and hunger were the most common non traumatic reasons for SAR incidents between 1990 and 1999 (Hung and Townes 2007). During the summer months, thunderstorms can roll in rather unexpectedly. This is especially dangerous for hikers who are ascending Half Dome. Heavy rains can wet the granite causing slippery conditions on the “cable route”. One such incident occurred during a July storm when a woman slipped and fell 800 feet to her death from the side of Half Dome (Cone 2011). Lightening can be very dangerous as well for those standing above tree line or on exposed rock outcroppings. Snow storms can also cause problems for visitors. Snow can overcome and trap hikers, snow shoe-ers, and cross-country skiers as well as obscure trail systems making navigation difficult, leading to lost person incidents.

The many streams, waterfalls, and lakes throughout Yosemite are sources of danger as well. The spring snowmelt causes the rivers to pulse and surge. This fast moving high volume of water can flood campsites, rip out roads and bridges, and inundate buildings (Bly 2011). When not at max flood stage, visitors enjoy spending time in and around water, but the powerful currents can still overturn rafts and overpower swimmers or people merely trying to cross streams. This often leads to swift water rescue incidents and drownings are not an uncommon occurrence. The picturesque waterfalls can also turn deadly when people playing in or around the water are swept over the falls. In the summer of 2011 three people fell to their deaths after they were swept over the 317 high foot Vernal Falls ("After waterfall deaths" 2011). Even much calmer water can pose a hazard. Giardia and other water-borne diseases can be found in Yosemite and have been known to affect people who drink untreated water from streams and lakes (Yosemite National Park 2011).

There are several other environmental hazards that have been touched on but should be reiterated. Black bears pose a significant risk to hikers and campers, and visitors in the park are urged to use proper food storage practices. Mountain lions inhabit the area as well, and although an attack is not likely, they do pose a serious threat to solo hikers and small children. Rattle snakes too are found within the park and have been known to strike people. Of less seriousness, but still of concern, is poison oak and ticks. Poison oak can cause inflammation and itching of the skin in exposed areas, while ticks are known to carry both Lyme disease and relapsing fever in the Yosemite area.

Appendix B – Description of Data Fields Collected

Field	Description
CaseNumber	Year + 4 digit case number (201000060)
SARNumber	Year + 3 digit SAR number (2010250)
IncidYear	Year incident occured
DateTimeLastSeen	Date subject was last seen alive
DateTimeInitiated	Date the SAR was initiated
DateTimeSubLocated	Date the subject was located
DateTImeIncidClosed	Date incident was closed
DayLastSeen	Day of week subject was last seen alive
ContactMethod	Way in which subject was reported missing
EcoRegionDomain	Eco-Region Domain as listed by Bailey
EcoRegionDivision	Bailey EcoRegion Division number including the M designator if a mountainous Divison from the list
IncidType	Type of Incident
NumberofSubjects	Number of Subjects involved
GroupDynamics	Describes if there was more than one subject and if the group stayed together or not
SubjectCategory	Subject Category as described by Koester
SubSex	Subject Sex
SubAge	Subject Age
IPPType	Type of Initial Planning Point
IPPClassification	Physical Feature that best represents IPP
IncidContribFactors	Factors contributing to subject being reported missing
IncidOutcome	Outcome of incident
Scenario	Reason for incident outcome
SubjMedInjType	Subject Injury
RescueMethod	How subject was rescued
LostPersonStrat	Stategy, as described by Kenneth Hill PhD, undertaken by lost subject to reorient themselves
IPP_GR_Locality	Locality Associated with the IPP Georeference
IPP_GR_Type	Georeference type for IPP
IPP_GR_Path	Path used to georeference IPP
IPP_GR_Notes	Notes for IPP georeference
Intended_Destination	Subject's intended Destination
FindFeature	Terrain feature that best describes where subject was found
Found_GR_Locality	Locality Associated with the Found Location
Found_GR_Type	Georeference Type for Found Location
Found_GR_Path	Path used to georeference Found Location
Found_GR_Notes	Notes for Found Location
Motorized_Transport	Subject used motorized transportation prior to being found (hitchhiking, bus, etc.)

Field	Description
Age1	Age of first member in a group
Age2	Age of second member in a group
Age3	Age of third member in a group
Age4	Age of fourth member in a group
Age5	Age of fifth member in a group
Incident_Notes	General Notes from Incident