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Landscapes of Danger: A Geospatial Analysis of Perceived and Realistic Risk in Bryce Canyon National Park

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Landscapes of Danger:
A Geospatial Analysis of Perceived and Realistic Risk in Bryce Canyon National Park

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This thesis is approved for recommendation to the Graduate Council.

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Abstract

The quantification of risk has inspired a wide breath of literature from the physical sciences, social sciences, and interdisciplinary disciplines like geography. Many attempts to estimate risk via natural hazards either focus on quantifying realistic risk or perceived risk of lay persons, with very little overlap between these paradigms. Due to this, a considerable knowledge gap exists within perceived risk and natural hazards research. This study aims to provide a comprehensive, risk estimation and assessment strategy through a multi-hazard risk assessment of Bryce Canyon National Park (BRCA). This case study analyzed knowledge of risk among visitors with perception surveys and Likert-based scales, in addition to identifying high risk areas of the park through Geographic Information Systems (gis). With a sample size of 254, a systematic stratified sampling method was implemented at specific sites in the park chosen for their distinctive viewsheds, accessibility, and popularity. To identify risky areas, two fuzzy logic models were built: one to identify areas susceptible to rockfall and another to identify areas susceptible to landslides/slumps. Overall, respondents reported feeling largely unconcerned when ranking their perception of various risks within the park ($\mu = 2.1$, $\sigma = .78$), however, perception gaps and demographic influences were revealed on individual event types. When asked to identify dangerous areas of the park, participants tended to select locations in the main amphitheater – the most highly trafficked area of the park – even though the fuzzy logic models showed a wider range of locations were susceptible to mass wasting events.

Keywords: Risk, risk assessment, risk perception, Bryce Canyon National Park, geohazard, fuzzy logic

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

On May 23, 2006 at 5:00 pm the weathering and erosional processes that shape badland topographies led to a rockfall that rocked the Wall Street section of the Navajo Loop Trail in Bryce Canyon National Park (BRCA). This rockfall brought down approximately 500 tons of rock covering an area of 60 feet long, 15 feet deep, and 15 feet wide (NPS, 2006). No visitors were harmed, however, the park received just over 800,000 visitors in 2006. Since then visitation numbers have jumped to an average of 2.5 million, meaning significantly more tourists would be at risk of injury or death if another rockfall of this magnitude occurred.

In September 2019, a tour bus overturned and flipped on State Highway 12, just 3.5 miles west of the BRCA entrance. Four tourists were killed, 15 were initially in critical condition, and 11 sustained minor injuries (Davoran, 2019). Although this was the first traffic accident in or near BRCA that received media coverage, traffic accidents are common in national parks due to distractions from wildlife and scenic views (NPS, 2020a). This will become especially prominent as visitation continues to rise between and within Utah's *Mighty 5* (Sundeen, 2020).

Since 1928, four visitors have been killed by lightning strikes in BRCA, with more surviving critical injuries by standing too close to the plateau rim during a thunderstorm (NPS, 2020b). In October 2019, a visitor was rescued by Search and Rescue (SAR) personnel after losing their footing on a social trail and becoming stuck (KSL TV, 2019). Dehydration, heat stroke, and altitude sickness due to BRCA's high elevation and arid environment are all hazards the NPS warns visitors about their various publications and newsletters (NPS, 2006). Proper footwear and prior knowledge of trail conditions is also recommended, along with awareness regarding extreme weather, staying on trails, and hydrating properly (NPS, 2016b).

Tourists, who are often in unfamiliar environments and without strong social networks, are vulnerable populations that are often overlooked in risk management planning (Bird, 2010). Tourists in a rugged and remote setting such as BRCA – where the closest hospital is a small, 41 bed institution 34 minutes away from the park entrance – are especially at risk. Depending on the circumstances of the rescue operation, it could take several hours before victims are able to receive proper medical treatment.

Like many NPS units, BRCA has bulletin boards at bus stops, overlooks, campgrounds, and the visitor center listing hazards visitors face within the park, preventative steps to mitigate risk, and managing the consequences if the unavoidable happens. There is an entire page on their website devoted to safety information and their newspaper, called "*The Hoodoo*", has a section listing the most frequent hazards within the park along with preventative measures. However, only 23% of park visitors read bulletin boards. While 89% of visitors indicated they used the park brochure/map and 60% used the park newspaper, it's unlikely that every visitor – or even most – who used these three services read the sections pertaining to safety (Holmes et al., 2009).

Due to the limited reach of brochures, newspapers, and bulletin boards, many national parks have enlisted volunteers who serve as preventative search and rescue personnel (PSAR) following Grand Canyon National Park's (GRCA) success in implementing a PSAR program in 1997. BRCA has a similar staff of volunteers, who stand at trailheads and hike trails to assist hikers with minor medical situations, point out safety issues, and educate visitors on trail length and proper preparation. There is no publicly available data which describes the effect this has had on the number of SAR cases in BRCA, however, the effects of PSAR programs have been documented by the GRCA (NPS, 2017).

While these preventative measures may mitigate some of the risk visitors face, the preceding discussion proves that accidents still happen. While BRCA staff conducted a visitor survey in 2009 with a small section on knowledge of risks, this section was not comprehensive, did not compare the results to measures of realistic risk, and had no spatial component (Holmes et al., 2009). Furthermore, the field of risk and risk assessment often divides risk perception studies and realistic risk assessments into two distinct research categories. By separating these inquiries risk assessments of both types are missing part of the picture which could be remedied by a broader methodological context.

BRCA is a prime landscape for this endeavor due to its remoteness, attraction as one of Utah's *Mighty 5* National Parks, and susceptibility to both environmental (i.e. rockfalls, lightning strikes, etc.) and human-environmental (i.e. dehydration, heat stroke, altitude sickness, etc.) hazards. The thrust of this research is to identify and understand the hazards prevalent in BRCA, in addition to exploring how these risks intersect with visitor risk perceptions. Results of this study will not only bridge a methodological gap between two distinct yet similar fields, but also aid NPS staff in understanding areas of spatial risk and demographics susceptible to risk perception gaps.

Chapter 2: Study Site

Bryce Canyon National Park (BRCA) is situated on the eastern escarpment of the Paunsaugunt Plateau in southwestern Utah. BRCA and the plateau primarily sit in a soft rock landscape, with summer weather patterns dominated by intense, afternoon storms (Bowers, 1990). This combination of geology and climate is responsible for forming one of BRCA's most prominent features: hoodoos, or tall spires of sedimentary rock (Figure 2.1). However, the same environment that makes BRCA ideal for hoodoo formation also makes this landscape susceptible to several types of geologic hazards (Gregory, 1940).

Figure 2.1: View of Thor's Hammer – one of BRCA's most iconic hoodoos – on a sunny, clear spring day (Photo: Wikipedia commons).

When considering the high volume of visitors (~2.5 million per year) BRCA receives each year, park staff face the problem of implementing effective mitigation efforts to provide a safe experience for tourists. This chapter provides a critical geologic, climatological, and cultural

background of the area – three factors that are critical to understanding the intersection of geologic hazards and risk perceptions within BRCA.

2.1 Setting and Topography

BRCA resides within the High Plateaus subregion of the Colorado Plateau, which represents a transitional zone between the Colorado Plateau and the Basin and Range Province to the West (Figure 2.2; NPS, 2011). BRCA is approximately 129 kilometers (km) East of Cedar City, UT with Tropic, UT as the closest town 26 km east of the park entrance. The northern section of the park is within Garfield County, while the southern section is within Kane County.

Figure 2.2: Regional map of Utah, with Bryce Canyon NP represented by the large gray diamond. (Cartography by Tia Francis).

Although BRCA is formally named as a canyon, this is a misnomer as the park was formed from headward erosion rather than downcutting from a perennial river. Due to this, the escarpment of Bryce Canyon is characterized by 14 bowl-shaped watersheds, instead of the typical v-shape from downcutting through resistant strata (Bowers, 1990). For this reason, the erosional features of BRCA are often referred to as an amphitheater rather than a canyon.

The top of the Paunsaugunt Plateau is 33 km long and 16.5 km wide, with a slightly northward tilt that causes the northern end of the plateau to be considerably lower than the southern end in elevation (NPS, 2011). While Rainbow Point – the highest point in the park – sits at an elevation of 2,778 meters (m), Fairyland Overlook – the northernmost overlook within the park – is at an elevation of 2,368 m. The lowest point is at 2,006 m in elevation near Tropic and the eastern boundary of the park, within the Paria River Valley. The topography of the park is made more complex by the sheer cliffs of the Claron Formation, which can be as tall as 90 m in places. Furthermore, slopes can be as steep as 88°, with elevations dropping 300 m from the rim of the canyon to the canyon bottom with more than 800 m of horizontal distance. (Wenker, 2004; NPS, 2011).

2.2 Geology

BRCA's geologic history began approximately 95 million years ago during the Late Cretaceous when sediments deposited into flood plains and near-shore coastal swamps eventually lithified into the Dakota Formation (Bowers, 1990). The Dakota Formation is the oldest formation visible in BRCA and the youngest visible formation 113 km Southwest in Zion National Park, another monument in the Grand Staircase super-sequence (Figure 2.3; Bowers, 1990).
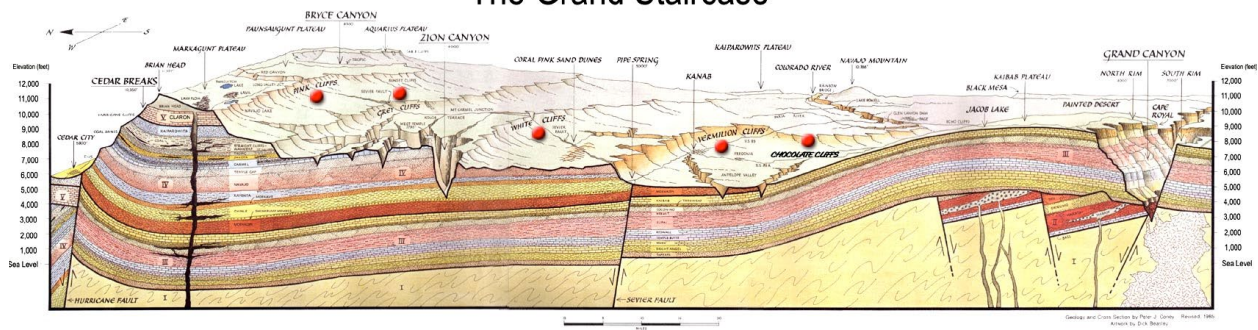
Figure 2.3: Popular depiction of the Grand Staircase Super Formation with Cross section by Peter Coney and artwork by Dick Beasley (1985). (Photo: National Park Service).

Following this, the area's sedimentary record continues for approximately 40 million years throughout the Cretaceous Period with the Tropic Shale, Straight Cliffs Formation, Wahweep Formation, and the Kaiparowits Formation, listed in ascending order (Figure 2.4; Bowers, 1990). These formations are largely concealed by younger strata along the eastern escarpment but are exposed in the eastern section of the park. Older, Jurassic formations are exposed along the Paunsaugunt Fault Zone, however, many of these geologic formations fall outside the boundaries of the park.
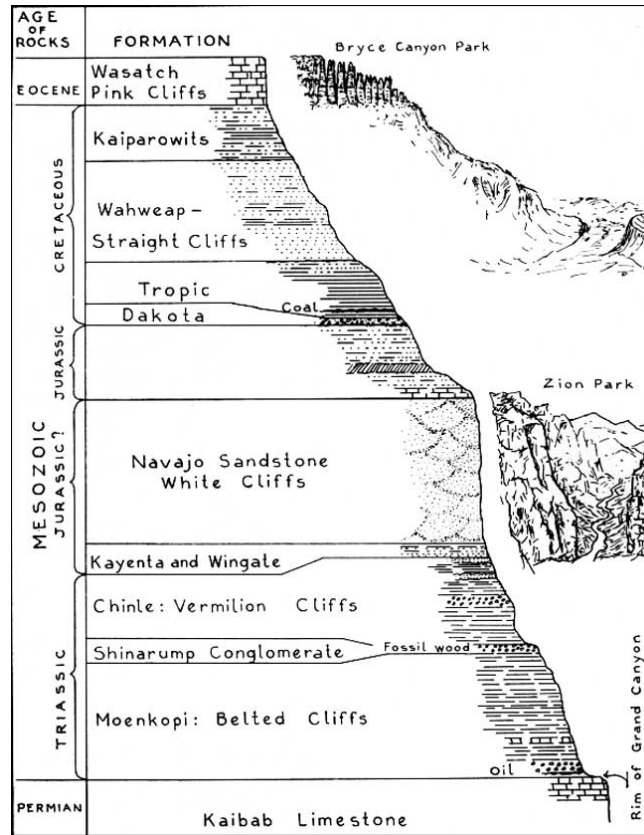
Figure 2.4: Stratigraphic column representing the geologic formations of BRCA within the context of the stratigraphy visible at Zion National Park and Grand Canyon National Park (Gregory, 1940).

Following the deposition of the Kaiparowits Formation, the Claron Formation was deposited during the Eocene, approximately 50 to 60 million years (see section 2.2.1; NPS, 2011). The Claron Formation forms the rim of the Paunsaugunt Plateau and is responsible for the park's most notable natural features, the hoodoos. There is an unconformity between the Claron Formation and the next strata within BRCA's geologic record, which wasn't deposited until the Oligocene or Miocene epochs (NPS, 2011). The Conglomerate at Boat Mesa is approximately 37 to 24 million years old, while the youngest visible strata in the park were deposited between the Miocene and Pleistocene as the Sevier River Formation. Both the Conglomerate at Boat Mesa and the Sevier River Formation are confined to small, specific localities within the northern section of the park (Figure 2.5).
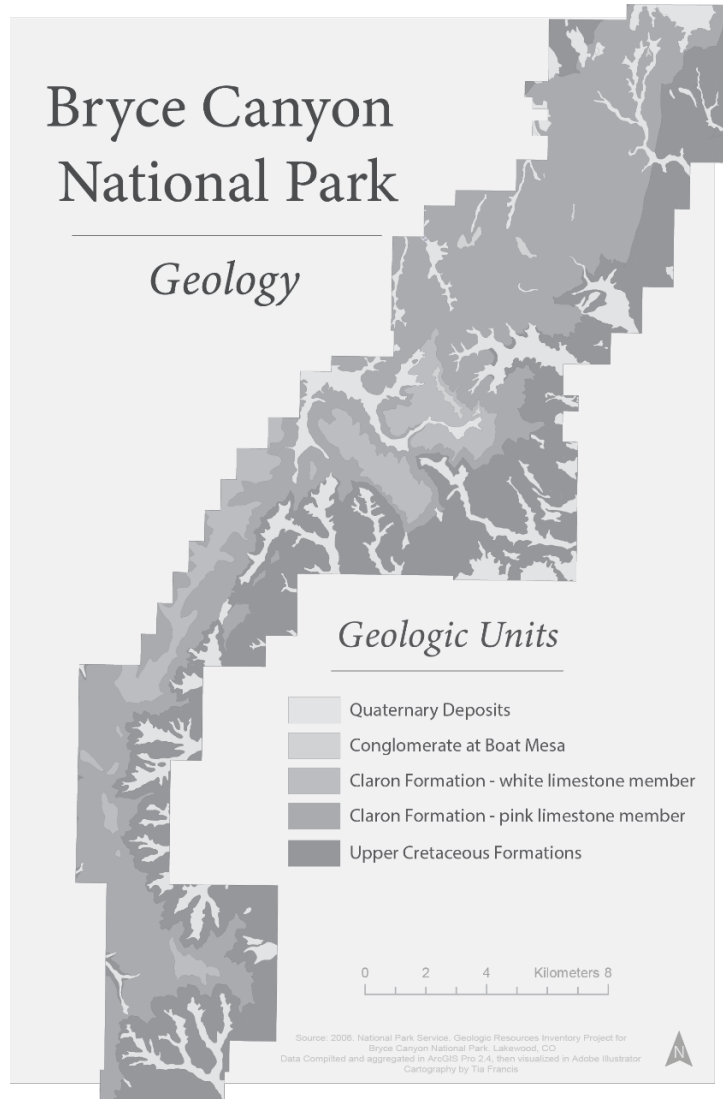
Figure 2.5: Geologic map of BRCA, showing geologic units grouped by age. Data compiled by the National Park Service Geologic Resources Inventory Project (2006). (Cartography by Tia Francis).

2.2.1 Claron Formation

The Claron Formation – also sometimes referred to as the Wasatch Formation or Pink Cliffs Formation – is a limestone formation interbedded with silt and sand. It is formed from lacustrine sediment deposits occurring approximately 50 to 60 million years ago and represents a transition from fluvial floodplains to shallow lakes (Bowers, 1990; NPS, 2011). This geologic formation is typically between 150-250 m thick and is informally split into two members: the

white and pink limestone members (Bowers, 1990). The white limestone member is primarily composed of carbonates, with varying percentages of silt and sand. This member is more homogenous than the pink limestone member, thus making it more resistant to weathering and suitable as a distinctive caprock. The pink limestone member is a less pure limestone with higher degrees of interbedded mudstone and varying amounts of calcium carbonate, the primary bonding agent for limestones (Bowers, 1990).

Due to the differences between and within the white and pink limestone members, the Claron Formation is quite susceptible to differential erosion, wherein interchanging layers of weaker and stronger limestone erode at different rates. Within the pink limestone member, mudstones and clay tend to erode quickly, while pure limestones and dolomite form protective caps and prominent ledges protecting the more fragile layers beneath. Within the Claron Formation generally, the white limestone member forms protective caprocks for the sheer cliffs of the pink limestone member (Bowers, 1990; Gregory, 1940).

As a result of the differing rates of weathering within the Claron Formation and the erosional forces that carved Bryce Canyon, the park can be split into three distinctive visual sections: the southern section, the middle section, and the northern section. Since the southern section of the park has been exposed to weathering and erosional forces for the longest, it is largely characterized by sheer vertical cliffs, relict hoodoos, and smooth, gullied outcrops. The Middle – and most popular – section of the park is characterized by extensive, mature hoodoos, steep stone walls, and scalloped embayments. The northern section of the park is only lightly weathered and eroded, with pink limestone fins and young, formative hoodoos dominating the viewshed (Figure 2.6).

Figure 2.6: panorama view from Yovimpa Point into the Paria River Valley, showing the gullied outcrops and relict hoodoos (Photo: Brian B. Roanhorse, obtained through the NPS)

2.2.2 Tectonics

Following the deposition of the Claron Formation, the story of BRCA is largely defined by a series of orogenies. During the Laramide Orogeny, compressional forces were powerful enough to form the 5° Bryce Canyon Anticline, which is responsible for the northward tilt of the plateau top. The eastern escarpment of the Paunsaugunt Plateau – and the establishment of Bryce Canyon as a National Park – is largely due to the normal, north-striking Paunsaugunt Fault (Figure 2.7; Bowers, 1990). The fault scarp can be difficult to visually identify since the main fault zone and the eastern edge of the plateau can be as distant as 4 km in some places due to erosion (Bowers, 1990). Nonetheless, uplift from this fault raised the Paunsaugunt Plateau from approximately sea level to 2,438 m in elevation, with as much as 457 m of displacement in some areas from this uplifting period (Scrattish, 1985).

Tectonic Overview

Bryce Canyon National Park
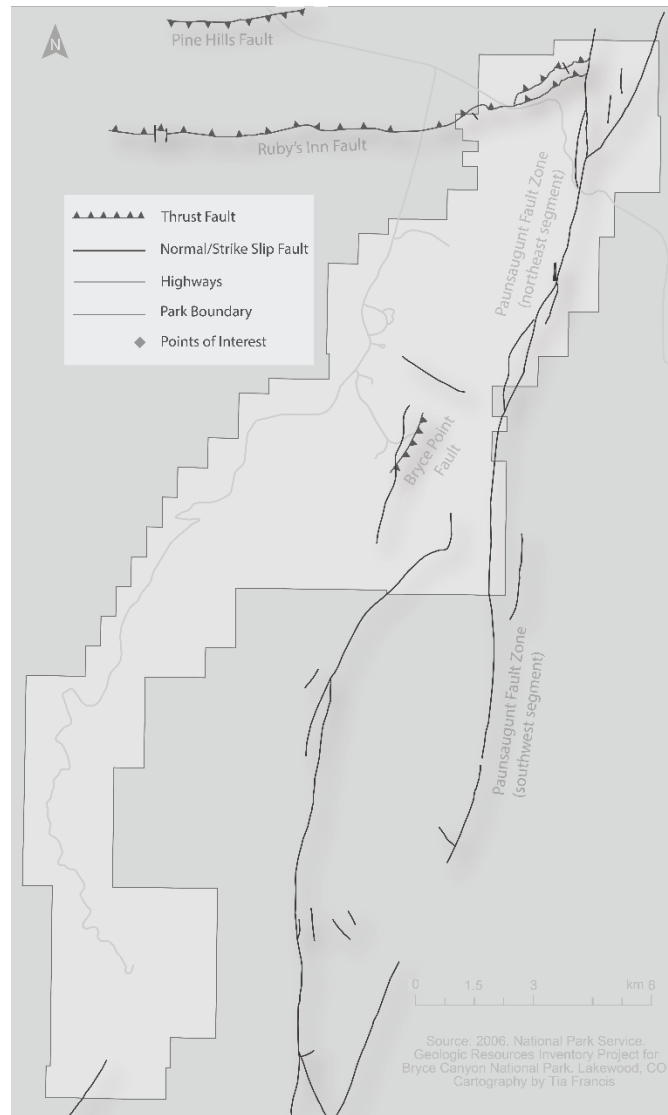
Figure 2.7: Tectonic Overview of BRCA. This map depicts the Ruby's Inn Thrust Fault and the normal, north-striking Paunsaugunt Fault Zone. Data obtained from the National Park Service Geologic Resources Inventory Project (2006). (Cartography by Tia Francis).

Although the Paunsaugunt Fault Zone has had little to no notable seismic events within recorded history, 17 km to the west of BRCA borders is the fault scarp of the significantly more active Sevier Fault. From 1962 to 2016, this fault has been responsible for over 1,500 seismic events with epicenters within a 50 km buffer of BRCA (Figure 2.8). Six epicenters – including

one event with a local magnitude of 3.16 – have been within BRCA boundaries. The Sevier Fault Zone bounds of the western edge of the Paunsaugunt Plateau and is also normal and north-striking. In the northern section of the park, the Ruby's Inn Fault runs East-West and is the most prominent thrust fault in the park. The Ruby's Inn Fault developed as a result of the gravitational collapse of the Marysvale Volcanic Field 80 km northwest of BRCA. However, the only traces of the volcanic field within BRCA are small fragments of igneous conglomerates interbedded with sandstone in the Sevier River Formation, indicating that extensive erosion has since stripped the landscape (Bowers, 1990).
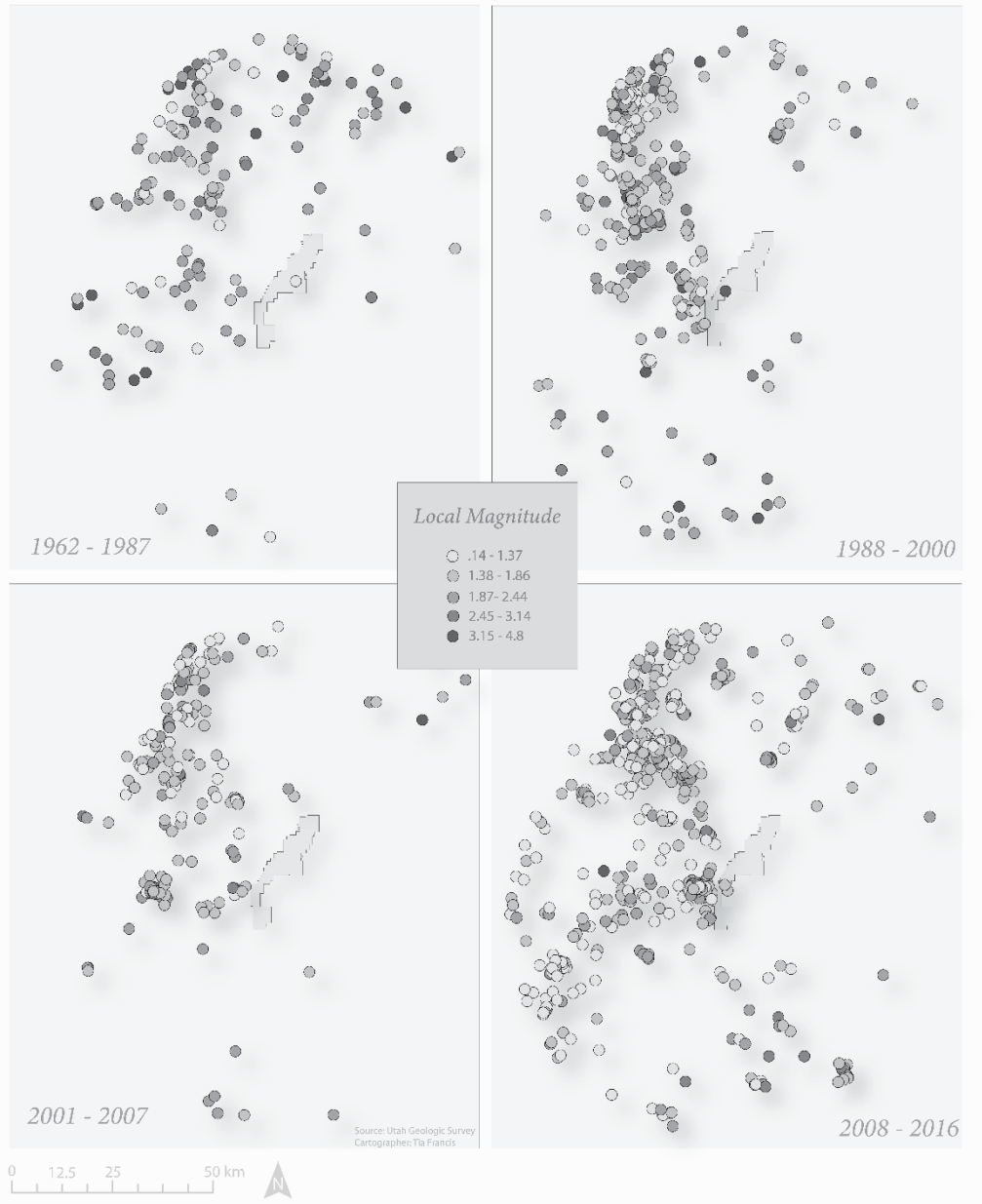
Figure 2.8: Map of seismic activity within 50km of BRCA boundaries from 1962 to 2016. Although the dataset includes records dating back to 1850, epicenter locations from 1850 to 1962 are inaccurate due to a reliance on witness records. Data obtained from Bowman & Arabasz, 2017. (Cartography by Tia Francis).

The expansional and compressional forces exerted on the Claron Formation during these

periods of tectonic activity are responsible for the vertical jointing in this formation. This

14

jointing, combined with the relatively weak bonding agents in the pink limestone member, makes the Claron Formation incredibly susceptible to weathering processes such as hydrolysis, frost wedging, and pressure gradients (Bowers, 1990). This susceptibility to weathering and erosion combined with climatic variables makes the Claron Formation incredibly prime for mass wasting phenomena (Figure 2.9).

Figure 2.9: 2006 rockfall in the Wall Street section of the Navajo Loop Trail. The rockfall was severe enough that the Navajo Loop Trail remained closed for over a year and the trail had to be rebuilt over debris and, in some cases, completely rerouted (Photo: National Park Service).

2.3 Hydrology

Due to the unique position of the High Plateaus subregion, BRCA represents a watershed boundary between the Basin and Range Province and the Colorado Plateau. While the plateau itself is drained by the East Fork of the Sevier River, the eastern escarpment of the park is drained by the Paria River (Figure 2.10; NPS, 2011).

The Paria River's headwaters are located within Tropic, UT city limits and flow south as a tributary of the Colorado River, with the two rivers joining near Lee's Ferry, Arizona. Bryce Canyon was formed due to headward erosion from the Paria River and its tributaries along the escarpment. This process began millions of years ago at the southern tip of the park near Rainbow and Yavimpa Points, with the headwaters of the river gradually eroding northwest to its current location. The Paria River's seasonal tributaries lie on incredibly steep gradients as a result of uplift from the Paunsaungunt Fault Zone (Bowers, 1990; NPS, 2011). When uplift occurs, adjacent streambeds often respond with steepening gradients to maintain equilibrium (NPS, 2011). As a result of this steepness, these tributaries become powerful agents of erosion, which in turn continue to steepen the streambed. In fact, tributaries draining the Claron Formation lose anywhere from 150-460 m of elevation in less than 1.6 km, causing the eastern escarpment of the plateau to recede by approximately 0.6 centimeters (cm) per year (NPS, 2011).
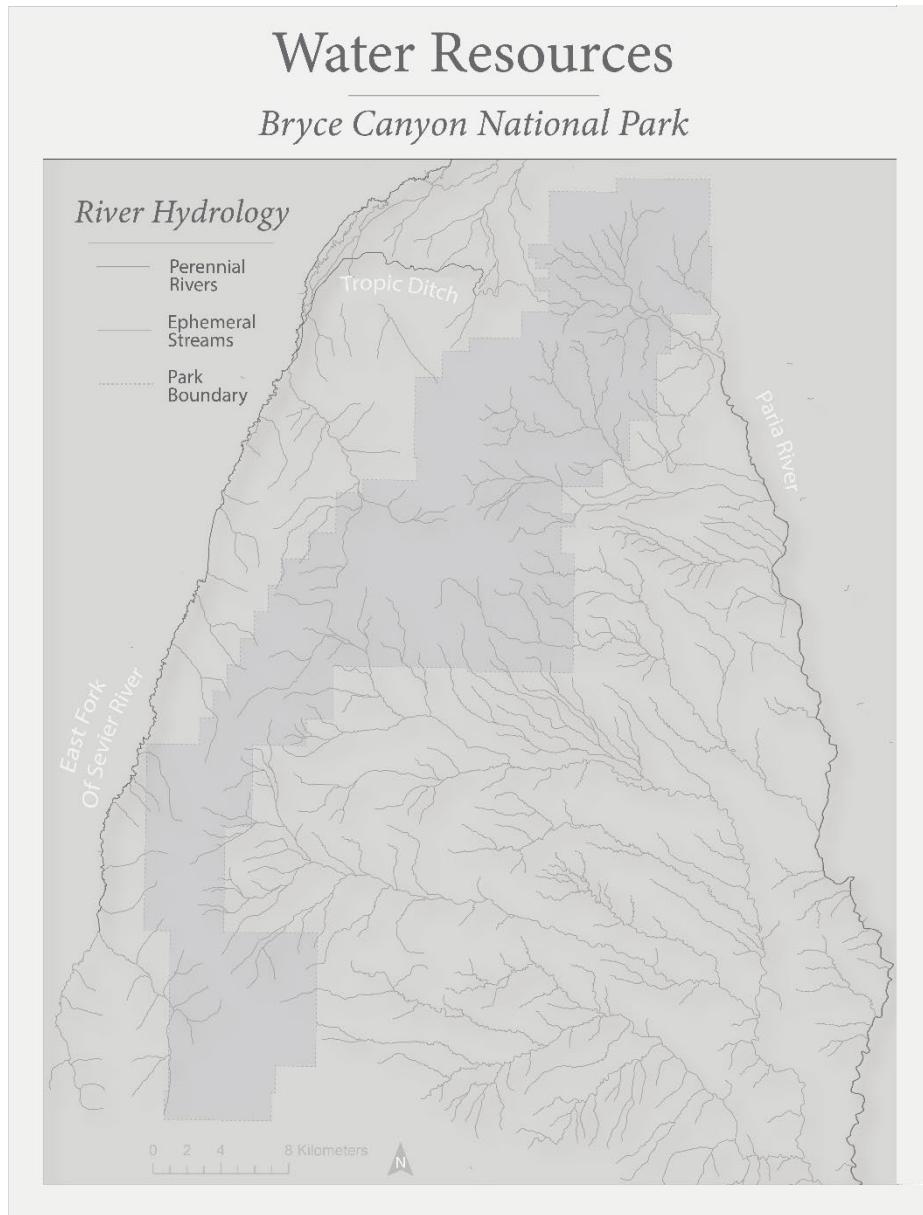
Figure 2.10: Hydrologic map of BRCA. This map does not depict all the channels within park boundaries, only those which drain to the Paria River or the East Fork of the Sevier River. These two rivers, along with the Tropic Ditch, are depicted in dark gray as perennial rivers. Data obtained from the Utah Automated Geographic Reference Center. (Cartography by Tia Francis).

Although the majority of the Paria River's tributaries are ephemeral, draining the

escarpment during intense, afternoon storms in July and August, Water Canyon is a notable

exception. Fed by the manmade Tropic Ditch from the East Fork of the Sevier River, it is a

perennial stream that runs through the northern section of the park and can be reached by the Mossy Overlook Trail (NPS, 2011).

The top of the Plateau is drained by the East Fork of the Sevier River, which finds its headwaters west of the park between the Markagunt and Paunsaugunt Plateaus (NPS, 2011). Its course runs through the center of the Paunsaugunt Plateau and its tributaries are considerably less steep than those of the Paria River. This creates a far more subdued topography on the plateau top and west of the escarpment, particularly when compared to the topography carved by the Paria River. After flowing through the Paunsaugunt Plateau, the river flows north for approximately 620 km before draining into the Sevier Lake bed in the Basin and Range province. Due to damming and heavy irrigation use, the last 48 km of the Sevier River is usually dry, and Sevier Lake is intermittent (NPS, 2011).

In addition to the perennial rivers and their largely ephemeral tributaries, the park is fed by several small springs along both the plateau top and the escarpment. Springs on the plateau top are usually fed by seasonally saturated alluvium, while the springs on and below the escarpment are fed by groundwater moving through fractures and bedding planes or more permeable layers, such as the Wahweep or Straight Cliffs Formations (NPS, 2011; Wenker, 2004). Due to this, the springs on the plateau tend to produce lower yields than those below it.

2.4 Climate

BRCA is commonly considered a prime example of badlands topography – or a landscape that has been heavily eroded by either fluvial or aeolian processes (Bowers, 1990). Within Bryce Canyon, the main erosional agent is rainfall from high magnitude and seasonally high frequency afternoon storms during the monsoon season (Figure 2.11). According to NPS records, thunderstorms can occur daily for over 50 percent of the days in July and August (NPS,

18

2018b). Between 1959 and 2011, annual average precipitation was 40 cm, with most of the

precipitation from August to October (NPS, 2011). However, meteorological data is collected at

the park headquarters, which is at 2,406 m in elevation (NPS, 2018b). Due to the elevation

variation found within the park, this average – and all other climatic averages – cannot be

extrapolated for the entire park (NPS, 2011). Tropic, which sits at an elevation similar to the

lowest sections of the park, only receives 30.7 cm of annual average precipitation. Meanwhile,

precipitation values are more than likely higher than 40 cm for the southern sections of the park,

which are about 300 m higher in elevation than the park headquarters (NPS, 2018b).

Figure 2.11: Afternoon thunderstorm forming over Thor's Hammer on an otherwise sunny day.
(Photo: Brian B. Roanhorse, obtained from the National Park Service).

Winter precipitation is similarly unpredictable and influenced by elevation, with an

average rate of 220 cm at the park headquarters and an average snow depth that does not exceed

38 cm. In Tropic, UT average snow depth does not exceed 5 cm (NPS, 2018b). Snowfall is

largely limited to December through February, with many visitors using the winter months and

constant snow cover to cross-country ski along the rim trail. However, due to the combination of

elevation and a desert environment, weather patterns can be unpredictable at BRCA (NPS,

2018b). Unpredicted snowstorms at BRCA are not uncommon during the spring, with

snowstorms happening as late as June (Figure 2.12).

Figure 2.12: Six inches of snow on May 20, 2019 in the North Campground of Bryce Canyon. Figure in the background is the author's tent (Personal photo).

Average temperatures within the park are generally mild during the summer and quite cold during the winter, with July and January representing the hottest and coldest months, respectively. Average high temperatures in July at the park headquarters are 26.6° C, while average low temperatures in January are -12.5° C (NPS, 2018b). The record high for the park is 37° C in July, while the record low is -32° C in January (NPS, 2018b).

2.5 Hoodoo Formation

Due to the generally high elevation of the plateau and its high desert climate, BRCA has about 200 freeze-thaw days – or days when nighttime temperatures are below freezing and daytime temperatures are above freezing (NPS, 2018c). This freeze-thaw cycle creates the perfect conditions for frost wedging, a weathering process where water seeps into the joints and

bedding planes of rock strata during the day and then expands at night due to the below-freezing temperatures (Bowers, 1990). This expansion exerts a tremendous amount of pressure on the surrounding rock, leading to extensive weathering (NPS, 2018c).

Another weathering process seen within BRCA is called hydrolysis. Although water itself is neutral on the pH scale, rainwater often reacts with carbon dioxide in the atmosphere and dead organic matter on the ground, making it slightly acidic. Even clean rainwater typically has a pH of 5.6 (NPS, 2018c). When this slightly acidic rainwater falls seeps into limestone strata, it reacts with and dissolves the calcium carbonate cementing together limestone deposits, resulting in weathering (Thornberry-Ehrlich, 2005).

Figure 2.13: Depiction of the four stages of hoodoo development, from a dissected plateau top to the thin spires of rock. (Photo: National Park Service).

These weathering processes are especially prevalent within the weak strata of the Claron Formation, creating the hoodoos seen within the pink limestone member. Hoodoo formation begins with a un-dissected plateau top comprised of weak rock strata with extensive jointing and bedding planes (Figure 2.13; NPS, 2018c). Both hydrolysis and frost wedging use the joints and bedding planes as starting points and gradually widen these cracks until walls and then windows form. This process continues until individual hoodoos are formed, with resistant rock strata

forming strata and bulging layers of hoodoos, while the weaker layers are significantly thinner and susceptible to heavier weathering and erosion (NPS, 2018c).

2.6 Soils

Due to the combination of intense afternoon thunderstorms, rock strata susceptible to mass wasting, and steep, ephemeral channels, soils within BRCA are often clay-rich and poorly developed with little to no horizons and poor absorption capabilities (NPS, 2011). In line with this, the Badland-Rock outcrop Paunsaugunt complex is the most common soil unit within BRCA (NPS, 2011). This soil unit is found on eroded side slopes, drainages, and mesa tops along the breaks of the plateau (United States Department of Agriculture [USDA], 1990). It is primarily derived from sediment originating from sandstones and limestones. This soil complex is shallow, with high runoff and erosion rates. Its available water capacity is only 2.5 to 6 cm and its organic matter layer is 1 to 2 percent (USDA, 1990). Other commonly found soil units include a variety of gravelly loams found on slopes, with alluvium and colluvium-based soils comprising the plateau top (NPS, 2011).

2.7 Vegetation

Vegetation within BRCA is determined by a wide variety of parameters, including elevation, geology, slope, aspect, fire history, and soil drainage. Traditionally, vegetation communities within BRCA are broken into three different plant groups: pinyon-juniper woodland, submontane forest, and the montane forest belt (NPS, 2011). These plant communities are largely contained to elevation categories, with pinyon-juniper woodland being found at the lowest elevations and the montane forest belt at the highest.

The pinyon-juniper woodland community is associated with the breaks dissecting the eastern escarpment. These breaks are most accurately defined as areas where the pink limestone

member is the most prominent geologic feature, with steep slopes, rapid erosion and inhospitable climate making survival difficult for most vegetation (NPS, 2011).

The submontane forest is largely comprised of ponderosa pine woodland found on the upper slopes of the plateau and high plateau sagebrush in shallow, flat-bottomed valleys (NPS, 2011). This community supports some soil development, a significant shrub and grass understory, and is typically found on level to moderate slopes (NPS, 2011). Smaller ponderosa pine communities can be found in lower elevation alluvium deposits; however, these communities are at a considerably smaller-scale when compared to the main communities.

The montane forest is typically limited to the southern section of the park, as it thrives at elevations above 2,590 m (NPS, 2011). It includes stands of mixed conifers, with White-fir as the dominant canopy cover. Douglas-fir is also common within this community, with other mixed conifers found within specific microclimates. Ponderosa pine and Rocky Mountain juniper can be found on warm and dry slopes, while blue spruce can be found in deep ravines or steep, north-facing slopes (NPS, 2011). Montane forests do not support a significant understory but do support the development of spodosols.

2.8 History

2.8.1 Native American Occupation

Due to the park's position within a transitional zone between physiogeographic regions, BRCA was within the periphery of several different Native American cultural areas, including the Virgin Anasazi, Southern Paiutes, Parowan Fremont, and the San Rafael Fremont (Wenker, 2004). However, no architectural features indicating permanent habitation exist within park boundaries pre-European settlement, suggesting Native American groups used the plateau seasonally and for special-use ceremonies. The earliest recognized human occupation within the

vicinity of BRCA is dated to the Paleoindian Period, with archeological evidence of use within park boundaries beginning during the terminal Paleoindian/early Archaic Period transition (Wenker, 2004).

Materials from the Archaic Period are common on the Paunsaugunt Plateau, beginning with the transition between the Paleoindian and early Archaic Period (Wenker, 2004). This occurred between approximately 9500 B.P. and 6500 B.P. Archeological evidence from this period includes Great Basin Stemmed and Pinto Series points within the park, along with shelter sites within 160 km of the park boundaries (Wenker, 2004). The Middle Archaic Period (6500 to 4000 B.P.) saw Stemmed points replaced with Notched projectile points and increases in grinding slabs and other materials associated with plant seeds (Wenker, 2004). Although the Great Basin and western Colorado Plateau both saw a decrease in occupational use during this subperiod, the Paunsaugunt Plateau continued to be occupied. This is more than likely due to a transition towards an arid climate during this period, where high elevation plateaus may have had more precipitation than lower elevation settlements (Wenker, 2004).

The Late Archaic Period (4000 B.P. to 2000-1500 B.P.) saw an increased reliance on seed plants, as evidenced by an increase in storage facilities, grinding stones, and structures (Wenker, 2004). Some archeologists hypothesize that this period coincides with an increase of use within this area, however, it cannot be determined if this is due to a genuine increase or a transition to settlement patterns that leave a more prominent archeological record. At around 2000 B.P., the late Archaic period ended with the introduction of cultigens – or a new plant species or variety resulting from selective breeding – leading into the Late Prehistoric and Formative periods (Wenker, 2004).

During the Late Prehistoric and Formative Periods, the archeological record within BRCA becomes more robust, with both Fremont and Ancient Puebloan groups occupying the Paunsaugunt Plateau and the surrounding region. This period is largely defined by the use of the bows and arrow in the Great Basin, increased reliance on cultigens and sedentary lifestyles, and the development of culturally specific pottery (Wenker, 2004). The reliance on cultigens and pottery is group specific, with some Native American groups exhibiting a significant reliance (e.g. early Puebloan groups) while others incorporated these technologies into their existing hunting and gathering practices (e.g. Fremont groups; Wenker, 2004).

Fremont groups within the BRCA region can be split into two cultural groups: the Parowan Fremont to the west and the San Rafael Fremont to the east (Wenker, 2004). Thus, Bryce Canyon represented a diffusive division between these groups from around A.D. 200 to A.D. 1250. No Fremont sites have been identified within park boundaries, however possible structures, ceramics, and projectile points have been found in Dixie National Forest along the East Fork of the Sevier River (Wenker, 2004). Puebloan occupation of this area is largely associated with the Virgin Anasazi, beginning around A.D. 500 and declining by A.D. 1150, making them contemporary with the Fremont. Several ceramic sites are the largest indicators of Virgin Anasazi use, indicating that the Paunsaugunt Plateau was a special use site rather than a permanent occupational site (Figure 2.14; Wenker, 2004). Recent evidence suggests that the Virgin Anasazi and Fremont groups intermixed on the nearby Kaiparowits Plateau (NPS, 2016a).

Figure 2.14: Pottery sherds collected within BRCA. Top pieces are Virgin Anasazi, while bottom pieces are Southern Paiute Brown Ware. All four samples are from the Numic/Paiute Period. (Photo: Wenker, 2004).

Immediately following the decline of Fremont and Puebloan occupation, Paiute Native American groups began occupying the Paunsaugunt Plateau and the surrounding area from approximately A.D. 1200 (Wenker, 2004). As with Native American groups predating the Southern Paiutes, their use of the plateau was seasonal and supplemental to their highly mobile hunting and gathering practices. Paiute Native Americans are clustered within the Modern Numic-speaking people, which includes Paiute and Shoshonean groups (Wenker, 2004). BRCA was within the realm of the Southern Paiutes, with three specific bands concurrently using water sources on the Paunsaugunt Plateau. To the south were the Kaibab band, while the Kaiparowits band was to the east and the Panguitch band to the north and west (Wenker, 2004). The boundaries between these bands were porous and determined by ownership of water sources. Ownership of the Paunsaugunt Plateau itself is largely unknown. Some sources claim it fell within the territory of the Panguitch Paiutes, while one source claims it belonged to the Kaiparowits Paiutes and yet another source distinguished it as occupied by the Koosharem, a

group that was considered as somewhere in between Paiute and Ute (Wenker, 2004).

Nonetheless, many Southern Paiute artifacts have been found within BRCA (Wenker, 2004).

Such artifacts include brown ware ceramics, notched projectile points, and ax-marked ponderosa

pine trees. Additionally, accounts from early Mormon settlers place Paiute groups on and around

the Paunsaugunt Plateau as recently as the late nineteenth century (Figure 2.15; Wenker, 2004).

Figure 2.15: Undated and unattributed photograph of two Paiute Native Americans on the
Paunsaugunt Plateau (Photo: National Park Service).

2.8.2 Early Euro-American Occupation

Due to its high elevation, rugged topography, and unpredictable climate, BRCA was

avoided by Euro-Americans during the early to mid-19th century (Wenker, 2004). From the

1770s to the 1850s, early Euro-American presence in the Grand Staircase region was confined to

transitionary expeditions through uncharted territory. Such expeditions include the Escalante-

Dominguez and John Wesley Powell's expedition, along with solo travelers aiming for

California such as Jedidiah Smith and William Wolfskill. Expeditions that traversed the

Paunsaugunt Plateau began as government-funded geologic surveys in the 1870s. Lieutenant

George C. Wheeler and Captain Clarence Dutton led two such surveys in 1872 and 1875-1877,

respectively (Wenker, 2004). Although all of these expeditions were conducted with a regional

focus, they still provided invaluable data about the resources of the Paunsaugunt Plateau.

These surveys were contemporary with the first Mormon settlements within the vicinity

of BRCA. Although homesteading had been practiced in the region since the 1860s, formal

settlements weren't established until 1874 (Wenker, 2004). Between 1974 and 1892, six

communities were formed in the Paria River amphitheater. Of these six communities, three still

exist as of 2020: Tropic, Cannonville, and Henrieville (Wenker, 2004). As these communities

were established, residents began to seasonally use the Paunsaugunt Plateau for timber, water,

and foraging.

2.9 Economic Use

2.9.1 Early Use

Before the Pausaugunt Plateau was formally commercialized for its natural resources in

the early 20th century, early settlers used the plateau for two primary economic uses: logging and

livestock raising (Wenker, 2004). Logging was a relatively minor but impactful industry within

the area, especially as towns developed. Alternatively, livestock raising was a lucrative industry

in the region. Although the high elevation plateau provided little use during the winter season, its

summer season provided moderate relief from sparse, arid vegetation. By 1874, the Kanarra

Cattle Company established a headquarters at Blue Fly Creek, which is only 6.5 km from the

modern-day BRCA Visitor Center (Wenker, 2004). Sheep grazing, which quickly became the

preferred livestock in the Paria River Valley, was introduced to the plateau top in 1877. As the

Kanarra Cattle Company grew and monopolized the local economy, small-scale homesteaders

persisted in using available land on the plateau for summer grazing. In fact, homesteaders soon established stock trails to assist moving livestock from the river valley to the plateau between the winter and summer months (Wenker, 2004).

By the 1890s, logging operations provided a secondary economic industry and influenced land-use patterns within the emerging region (Wenker, 2004). Several small sawmills were established near canyon mouths within the amphitheater and on the plateau top along the East Fork of the Sevier River (Wenker, 2004). Logging operations remained a prominent economic sector until 1928 when the administration of BRCA was transferred to the NPS. Sheep grazing continued under NPS administration, but with a long-term administrative goal of eliminating grazing permits (Wenker, 2004).

2.9.2 Early Tourism

Similar to many of Utah's National Parks, BRCA was recognized for its unique natural beauty almost immediately. The land on the Paunsaugunt Plateau was quickly established as part of the Sevier National Forest – since renamed to the Dixie National Forest (Wenker, 2004). Following this, the USFS immediately built a road to provide access to the canyon rim, constructed trails, and ran tours to attract tourists to the area (Figure 2.16). These efforts were partially due to the Forest Supervisor's investment in attracting tourists to the area, resulting in published photographs, national publications, and articles about Bryce Canyon (Wenker, 2004).

Figure 2.16: Undated and unattributed photograph of a ranger-led campfire program. (Photo: National Park Service)

One of the first attempts to commercialize lodging in BRCA came with Ruby Syrett and his family in 1920, when they built a semi-permanent lodge and tent cabins near the rim. They named this lodge "Tourist's Rest", which received over 3,100 visitors in 1922 alone (Figure 2.17; Wenker, 2004). In 1923, when the canyon was formalized as a National Monument, Syrett moved his lodge to a parcel on his homesteading ranch and renamed it Ruby's Inn (Wenker, 2004). Ruby's Inn is still in operation and is currently owned by the descendants of Ruby Syrett. It is the main focal point of Bryce Canyon City and, due to Syrett's strategic donation of land during the construction of State Highway 63, sits at the entrance of BRCA (Wenker, 2004).

Figure 2.17: 1923 photograph of Tourist's Rest on the Paunsaugunt Plateau rim
(Photo: Ruby's Inn).

However, as BRCA increased in popularity, corporate forces also sought to profit from

the region's commercialization. Part of this increasing popularity can be attributed to the

accessibility afforded from automobile tours traveling from the Marysvale, Utah railroad station

to BRCA (Wenker, 2004). This piqued the interest of the Union Pacific Railroad (UPR), which

aspired to create a scenic tourist loop that included Zion NP, the North Rim of the Grand

Canyon, Cedar Breaks National Monument, and BRCA. This tourist loop was partially realized

in 1923, following negotiations with the state of Utah and the establishment of BRCA as a

National Monument (Wenker, 2004).

In 1923, UPR negotiated a twenty-five-year contract which allowed them to build a lodge

and other visitor services along a section of the rim owned by the state of Utah. The Bryce

Canyon Lodge was completed in 1925 and automobile tours began running the same year

(Wenker, 2004). By 1927, they added 73 cabins, several service structures, upgraded water and sewage facilities, and installed telephone lines (Wenker, 2004).

2.9.3 Establishing BRCA

BRCA was established as a National Monument four years after a bill had been introduced to congress to establish the area as Utah State National Park. This name was eventually modified, and the park was ultimately named after an early Mormon homesteader named Ebenezer Bryce. In 1880 Bryce remarked that the canyon would be "helluva of a place to lose a cow," (Wenker, 2004). Between 1923 and 1928 the monument remained under USFS jurisdiction. However, in 1928 when BRCA received formal recognition as a National Park, the parcel formally transitioned from USFS jurisdiction to NPS jurisdiction under the Zion National Park superintendent (Wenker, 2004). When BRCA was initially established it encompassed 2,833 hectares (ha), however, by 1931 it had expanded to include its current extent of 14,502 ha (Wenker, 2004). The NPS finished construction of the Rim Road – now called the Bryce Canyon Scenic Road – in 1934 and by 1956 BRCA gained its an independent administration and superintendent (Wenker, 2004).

2.10 Modern Day Bryce Canyon NP

Today BRCA receives over 2.5 million visitors per year, with visitation numbers increasing by over 192,000 visitors each year since 2010. In 2017, visitors spent over $256 million within the regional economy while visiting BRCA, supporting 3,119 jobs and representing $151 million in value-added. Additionally, there was $275 million in economic output from local gateway economies (NPS, 2018d).

There are a variety of amenities provided both within the park and within the near vicinity, including a visitor center, general store, and Bryce Canyon Lodge. The lodge and

general store are owned and run by Forever Resorts. In the winter, cross-country skiing and snowshoeing are popular activities. The summer season is BRCA's peak season when visitors can enjoy sight-seeing, day hiking, photography, and horseback riding (Holmes et al., 2009). Thirteen maintained trails within the park can be hiked within a day, with the shortest being 2.57 miles and the longest being 22.5 miles roundtrip. The Queen's Garden/Navajo Combination Loop Trail is the most popular trail within the park, providing views of the famous Thor's Hammer and Queen Victoria hoodoos.

The park also boasts annual events that attract visitors from all over, such as its Geology and Astronomy Festivals. Held in June and July, respectively, these events include activity booths, planned programs, and hikes with experts. The Annual Geology Festival has been held since 2007, while the Astronomy Festival has been held since 2001 and is supported by over 50 years of astronomy programs. In 2019, the park was formally certified as an international dark sky park. In addition to these festivals, the park also hosts an annual Christmas bird count in conjunction with the National Audubon Society's Christmas count.

Given the geologic wonders and spectacular viewsheds, it's no wonder that BRCA attracts millions of visitors per year from over 25 different countries (Holmes et al., 2009). This unique landscape is dominated by hoodoos and its spectacular combination of geology, climate, topography, and history truly make it a one-of-a-kind destination. However, park staff are often tasked with mediating the line between ensuring visitor safety and protecting valuable natural resources. Understanding how and where visitors face danger and how well visitors understand the dangers they face will only help staff mediate this line.

Chapter 3: Literature Review

The fields of risk and risk quantification have inspired and gathered attention from a wide variety of fields, including psychology, anthropology, geography, geology, statistics, and nuclear engineering. This is because many of the actions, behaviors, and decisions that are integrated into these fields carry a certain level of risk. For day-to-day actions, risk can include driving to work, often quantified through insurance actuaries. Risk can also include the probability of urban flooding in a low-income community, or the risk posed to communities by placing a nuclear reactor in one locality or another. Risk is integrated into the day-to-day tasks and choices of many people's lives whether they know it or not, allowing for the emergence of entire fields and sub-fields on quantifying these dangers. This concept is at the heart of research revolving around risk, no matter the discipline of choice. As a result of this, most risk studies revolve around four simple questions: Which risks are acceptable and why? How do people respond to risky events? Where are risky localities and why do people stay in these localities? Why do people act as they do in landscapes of perceived risk? – the thrust of this research.

3.1 Risk

Before a thorough discussion of risk quantification can be undertaken, a discussion of the working terminology as it relates to risk must be established. At the base of this discussion is the distinction between a risk and a hazard, terms which are often conflated in colloquial discussions. A hazard is a phenomenon that has the potential to incite loss and invoke consequences (Gallina et al., 2015). Loss can be quantified in terms of economic loss, social loss, or environmental loss and can include loss of property, life, infrastructure, or natural resources (Gallina et al., 2015). This list is not exhaustive, as any number of losses can be invoked by hazard occurrence. Hand in hand with the concept of loss is the concept of consequence. Legally,

a consequence is a negative outcome of a hazard that can be empirically quantified. Typically, but not always, consequences are quantified via monetary values (Gallina et al., 2015).

Alternatively, this work defines risk as the sum of four primary components: probability, consequences, presence of a hazard, and exposure (Gallina et al., 2015). A popular example used to demonstrate the different components of risk is that of a shark at a popular beach during the afternoon. Probability is the calculated likelihood of a hazardous event occurring, such as the likelihood of a shark being close enough to the beach to disrupt beachgoers. Consequences refer to the possible negative effects of a hazard occurrence, which can include the cost of medical care and physical impedances for a bitten swimmer or the resulting loss of tourism. The presence of a hazard would be the presence of the shark at the beach, while exposure is the act of becoming exposed to the hazard of the shark by entering the water. Finally, the hazard of a shark would become a risk after a swimmer enters the water with the shark, whether knowingly or unknowingly. In essence, a hazard is an event with negative consequences and risk is both the likelihood and consequences of a hazard occurring (Gallina et al., 2015).

Perceptions of risk are defined by how humans intuitively judge the risk of a hazard. Although the factors shaping perceptions of risk are not well understood, current models posit that three main categories of factors are responsible for determining perceptions: hazard characteristics, individual characteristics, and trust in communicating institutions (Wachinger et al., 2013; Sullivan-Wiley & Gianotti, 2017). Hazard characteristics include factors such as consequences and likelihood of occurrence, whereas individual characteristics include gender, age, and other demographic information. Factors such as knowledge, perceived levels of concern, and inclusivity alter trust in communicating institutions, which often include governmental agencies or University experts (Sullivan-Wiley & Gianotti, 2017).

Another important concept within risk studies is that of vulnerability. Vulnerability is the predisposition of an individual, community, or societal structure to the consequences of a hazard. For example, during heat waves, most fatalities occur in low-income communities due to their comparative lack of access to resources such as air conditioning or medical care. The concept of vulnerability is key to many geographic explorations of risk, as vulnerability often has a spatial component. For instance, using the heatwave example again, many urban low-income communities experience hotter temperatures due to a lack of green cover, thus exasperating the effects of severe heatwaves compared to higher-income communities with more green cover and outside of urban heat islands (Harlan et al., 2007).

3.1.1 Risk: Perceived vs. Real

Now that the working terminology has been established, most research that focuses on risk focuses on risk quantification. Risk can be represented quantitatively, qualitatively, or semi-quantitatively. Broadly, risk quantification within geography can be split into two frameworks: quantification of risk perceptions and quantification of realistic risk. However, it must be noted that all attempts to quantify risk are subjective, as risk in and of itself is a subjective concept created by humans to quantify and understand the danger they face from hazards (Slovic, 1992). Even assessments of realistic risk do not represent realistic risk, but rather a perception of realistic risk based on the assumptions, judgments, and inputs of a biased researcher (Slovic, 1992). While the rest of this paper will refer to the quantification of realistic risk as realistic risk or risk assessments, note that this is a common misnomer and misconception.

Although both of the presented paradigms are interdisciplinary and draw from a wide variety of frameworks and disciplines, risk perception studies tend to be pursued by human geographers and focus on quantifying perceptions through Likert scales, interviews, and

observational work. Risk perception studies tend to draw on and build on the work presented by social scientists, such as psychologists, political scientists, and anthropologists. Additionally, they tend to focus on how spatial vulnerabilities, distributions, and demographics affect risk perceptions. Alternatively, realistic risk studies tend to be pursued by spatial scientists attempting to quantify risk and vulnerability using spatial models, indices, and numeric assessments. These spatial scientists tend to collaborate with soil scientists, biologists, geologists, and climate scientists as they attempt to model the risk associated with geologic hazards, severe weather events, and invasive species.

3.1.2 Perceptions of Risk

Although risk perceptions as a field did not emerge until the 1960s and 1970s, research on risk perceptions can be traced as far back as the 1940s. In 1945, geographer Gilbert White, often called the *"Father of Floodplain management"*, published a paper on how past experiences shape an individual's response to imminent flood risk. However, risk perceptions did not gain traction until the 1960s, when public opposition to advances in nuclear technologies became a hurdle for political agendas (Kellens et al., 2012). As a result of this, Chauncey Starr, an expert in nuclear energy, published a paper in 1969 on which risks are considered acceptable by society (Slovic, 1992). Two key assumptions within Starr's work were as follows: a) individuals always act rationally and within their best interests, and b) risks present within society must be considered acceptable by society. Criticisms against these two assumptions form the basis of the psychometric paradigm, which was developed in the 1970s by Paul Slovic, Baruch Fischoff, and Sarah Lichtenstein (Slovic, 1992; Figure 3.1). The psychometric paradigm can be best summarized as follows:

"…The psychometric paradigm encompasses a theoretical framework that assumed risk is subjectively defined by individuals who may be influenced by a wide array of psychological, social, institutional, and cultural factors."

(Slovic, 1992)
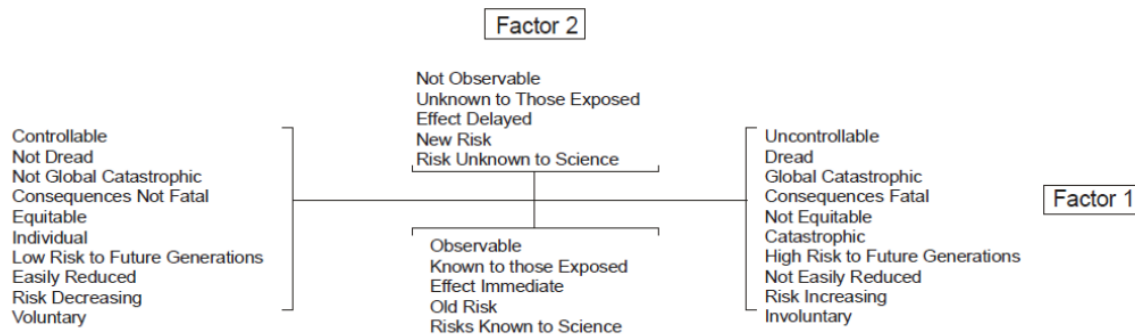
Figure 3.1: One of the most popular theoretical outputs from the psychometric paradigm is the Unknown Risk and Dread Risk theory, which assess how knowledge and controllability affect risk perceptions. (Slovic & Weber, 2002).

Slovic's career-long interest in risk perceptions eventually produced *The Perception of Risk* (2000), one of the most comprehensive guides to interdisciplinary risk perception research to date. It includes contributions from Fischoff and Lichtenstein, in addition to many other prominent psychologists, political scientists, and sociologists. Although there is a heavy bias towards psychological studies and frameworks, the book nonetheless covers anthropological, sociological, and interdisciplinary theories of risk perceptions (Slovic, 2000).

One of the many theories covered in *The Perception of Risk* is the *Cultural Theory of risk framework*, which assesses how cultural and societal predispositions affect an individual's perception of risk (Slovic, 2000). This framework came to formal fruition in the 1980s, when risk perception studies gained the attention of anthropologists, political scientists, and sociologists. This framework was first introduced by Mary Douglas in 1970, then formalized in 1982 in conjunction with political scientist Aaron Wildavsky (Slovic, 2000).

Douglas and Wildavsky's theory (1982) was based on two primary ideas: that hazard incidences are often viewed as a result of cultural transgressions and cultural types are some of the primary influencers of risk perceptions. Cultural types represent individual characteristics rather than overall cultural patterns and are modeled as a group/grid typology (Figure 3.2). This typology has four different types that affect risk perceptions, which include Fatalism, Hierarchy, Individualism, and Egalitarianism (Rippl, 2002). For example, hierarchy cultural types accept risks if the decisions revolving around those risks are endorsed by experts, while Egalitarianism cultural types reject risks that will adversely affect large numbers of the population. This framework has been applied to a variety of hazards, from small-scale taboos such as individual-scale illness to large-scale occurrences such as pollution and nuclear hazards (Tansey & O'Riordan, 1999).
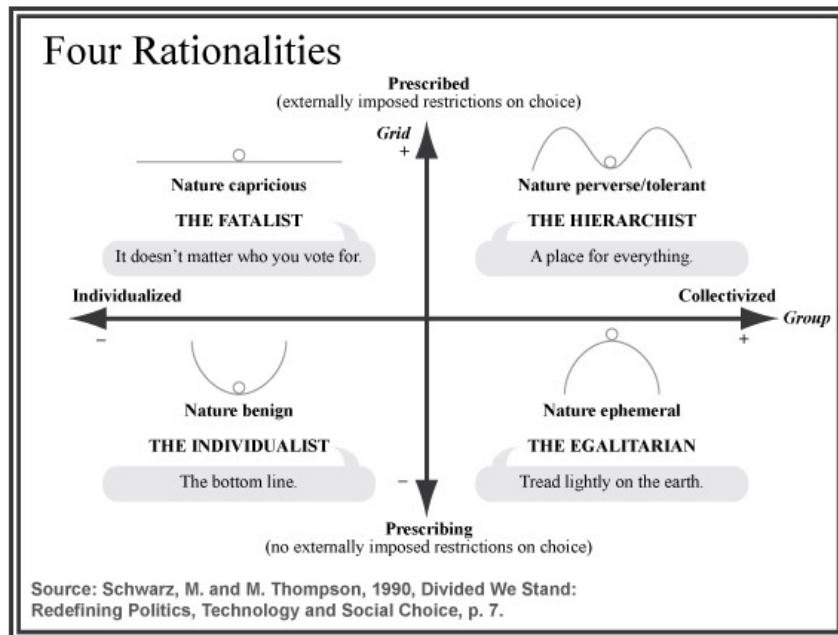
Figure 3.2: Diagram illustrating the group/grid typologies and their cultural worldviews, which directly impact their perceptions of risk.

Later works by Slovic and colleagues aim to remedy the gap between the psychometric paradigm and the Cultural Theory of risk through the cultural cognition of risk framework and

the social amplification of risk framework (Kahan et al., 2006; Slovic, 2000). Cultural cognition focuses on the tendency to assume risk perceptions that reflect and reinforce an individual's worldviews and attempts to address the gap between rational perceptions of risk and actual perceptions of risk (Kahan et al., 2006). Alternatively, the social amplification of risk framework draws from fields such as anthropology, public policy, and psychology to understand how the communication of hazardous events travels through society and is amplified. This framework is used to understand why some hazard events receive a wider response than others and how and why the ripple effect of risk communication is enacted (Slovic, 2000).

3.1.3 Risk Perceptions in Geography

Although geographical studies have significantly contributed to prior risk perception research, geography has not generated any field-specific frameworks or paradigms within the literature. This is partly for two reasons: a) geographical research of risk perception has different goals than those of psychology or anthropology, and b) risk perception research was largely integrated into the already existing paradigms of geographical thought.

As for the first point, psychological and anthropological risk perceptions studies tend to focus on how psychology and culture affect risk perceptions, whereas geographers tend to focus on these themes in the context of spatiality. Rather than asking whether the heuristic bias or a grid topology affect risk perceptions more, a geographer might ask how nationality affects the perceptions of climate change or how transient communities respond to disasters. Therefore, while the frameworks described above may influence and be integrated into geographic studies, they do not typically form the backbone of geographical research. As for the second point, geographical risk perception studies rely on integrating risk perceptions into the frameworks of critical geography. Thus, rather than creating new frameworks for handling risk – as

40

psychologists and anthropologists did – geographers took working geographical frameworks and fit them to risk perception research. Critical geography – often referred to as structural or radical geography depending on the source – encompasses a variety of theoretical subsets that attempt to tackle issues such as agency and societal inequalities (Peake & Sheppard, 2014). It was generated as a response to the model-centric framework of the spatial revolution and is often associated with Marxism. Popular subsets include feminist geography, postmodernist geography, and queer geography (Peet, 2000). Critical geography often intersects with risk perceptions by considering the perceptions of vulnerable populations constrained by socio-economic structures.

Due to this focus, risk perception research - especially as it relates to natural hazards - tends to focus on two main populations: communities relevant to the effects of climate change and communities in the global south that have prior experience with hazard occurrence. Several studies have focused on transient communities' perceptions and responses; however, these studies are sparse with most contributions stemming from one or two common authors. Communities vulnerable to the effects of climate change are a prominent focal point within geospatial risk perception research. This is because climate change will alter both the magnitude and frequency of many hazards, in addition to effecting exposure. In other words, the number of people exposed to hazardous environments will substantially increase (Gallina et al., 2015). Additionally, many studies highlight understanding risk perceptions as an important influencer for climate change mitigation policy, which integrates elements of political activism commonly seen within critical geography (Peet, 2000).

Studies that revolve around climate change as a factor often assess perceptions as a primary function of nation-state identities and secondary function of demographics, with an emphasis placed on the differences between countries that contribute to climate change and

countries that are vulnerable to its effects. Lee et al. (2015) analyzed risk perceptions regarding climate change among residents of 119 countries, investigating the role of socio-demographic characteristics, geography, and beliefs in shaping perceptions. Overall, this study found that educational attainment is the most important factor in shaping perceptions, while perception of local temperature change is a strong secondary influencer (Lee et al., 2015). Similar studies that use climate change as a focal point include risk perceptions of climate change in America (Leiserowitz, 2005), and the role of proximity and prior experience of climate change risk in Norway (Lujala et al., 2015).

Studies that focus on communities in the global south often revolve around interviewing community members that experienced the hazard of focus. Some of these studies include assessments of how various demographic information – such as gender or religion – may shape perceptions (Paradise, 2006). Furthermore, much of the literature tends to focus on residents of international communities in urban, populous cities in the Global South that have experienced past hazards. Example localities of such studies include the Philippines, Puerto Rico, Bolivia, Taiwan, and Uganda (Gaillard, 2008; Ho et al., 2008; Lopez-Marrero, 2010; Nathan, 2008; Paradise, 2006;). Interview questions often use proxies such as preparedness, concern of a repeated occurrence, initial response, or knowledge of relevant hazards as indicators of risk perceptions. Often, these studies only focus on assessing perceptions of one hazard, regardless of whether the community lies in a multi-hazard zone or not.

Finally, risk perception studies focusing on transient communities are sparse but critical, as these populations are typically vulnerable and either have little access to resources or do not know how to access available resources. These communities include homeless, nomadic indigenous, and tourist populations. Not only are these populations often overlooked in

mitigation plans, but they are often unable to access emergency information or resources and have loose social and economic networks (Drabek, 1999). These studies typically focus on assessing both risk perceptions and knowledge, often with the conclusion that transient communities tend to be unaware of the resources and evacuation plans available to them. Bird et al. (2009) assessed tourist and tourist guide knowledge of volcanic hazards and early warning systems in Iceland, finding that tourists had moderate to low knowledge of volcanic hazards and low knowledge of the early warning system, while tourist guides had high knowledge of volcanic hazards but low knowledge of the early warning system (Bird et al. 2009).

Drabek (1999) analyzed evacuation patterns of four different transient communities in the face of five different disasters. Communities included tourists, business travelers, migrant workers, and homeless persons (Drabek, 1999). As to be expected, Drabek found considerable differences between transient groups and residential groups and within the four transient groups. For example, almost one-fourth of all transient persons ignored the initial warnings and over one-third viewed mandatory evacuations as voluntary. Between the different transient groups, both initial warning sources and responses varied. This variation largely falls along axes of privilege, where business travelers and tourists had better access to economic and other structural resources than migrants or homeless persons. However, out of all the groups, migrants seemed to have the greatest access to social resources.

3.1.4 Realistic Risk

A distinct but related paradigm of risk involves the quantification of realistic risk. Attempts to model realistic risk – often called risk assessments – have been prominent in scientific studies since the 1970s and 1980s (Aven, 2016). Since then, the field has exponentially grown to include a variety of disciplines. This is evidenced by the sixteen specialty groups of

Society for Risk Assessment, which includes groups ranging from Security and Defense to Microbial Risk Analysis (Society for Risk Analysis, 2020). Similar to the subfield of risk perceptions, realistic risk assessment research draws from and is generated by a wide variety of academic disciplines, including nuclear energy, supply chain management, and finance (Aven, 2016). This is due to risk assessment's applicability to the many facets of societal systems and its two main goals: using risk assessments to manage the risk of specific activities (i.e. opening a business or constructing a building) or to generally assess and modify broader concepts of methods, models and frameworks to manage and govern risk (Aven, 2016). The key within both of these goals is the dissemination and use of risk assessment knowledge among non-experts such as government officials, policymakers and members of the public.

However, this goal of dissemination can be complicated by the variety of disciplines contributing to the subject, since different disciplines carry different terminology and different methodologies. Risk terminology influences the way risk is conceptualized and the tools used to quantify it, so understanding the differences in terminology between disciplines is critical. For example, risk, as defined earlier in this paper, focuses on the sum of probability, consequences, presence of a hazard, and exposure. Risk as it relates to nuclear energy and engineering, however, is defined by scenarios, consequences, and probabilities (Aven, 2016). Alternatively, risk within the field of supply chain management – a relatively new addition to risk assessment research – is defined as follows:

> "Supply chain risk is the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain developments of supply chain characteristics whose changes were caused by the occurrence of triggering-events"
> - Heckmann et al. (2015) as quoted by Aven (2016)

Between these definitions, common themes include quantifying consequences, probabilities, triggering events, and losses. However, the working definition for supply chain management

emphasizes loss as determined by efficiency, while nuclear and geospatial research defines loss in a broader sense determined by quantifiable consequences. As to be expected, geospatial research considers the intersection of risk with spatiality and vulnerability, a concept missing from the definitions used by supply chain managers and nuclear engineers.

3.1.5 Risk Modeling

Differences between working terminologies are compounded by methodological differences. However, key among these methodologies are contributions from statistics and geography. Statisticians tend to rely on complex decision-making and forecasting models to quantify risk, while geographers tend to incorporate less complex decision-making models with geospatial technologies such as satellite imagery and GIS. This difference in techniques can be attributed to different contextual constraints: while statistic-based techniques tend to quantify the probabilistic risks associated with insurance, stock markets, and business ventures, geography-based techniques tend to spatially quantify environmental risks such as geohazards, severe weather, and invasive species spread (Kalogirou & Chalkias, 2014). More complex geospatial models may integrate spatial statistics with geospatial technologies, such as heuristic models (discussed in further detail section 3.4.1). Although most risk assessors are not within the fields of geography or statistics, their methodologies more than likely draw from these methodological foundations.

Additionally, risk assessments often utilize similar workflows. This workflow accounts for the transition between experts and decision-makers, beginning with evidence collection, which contributes to the creation of a knowledge base (Figure 3.3). This knowledge base is a
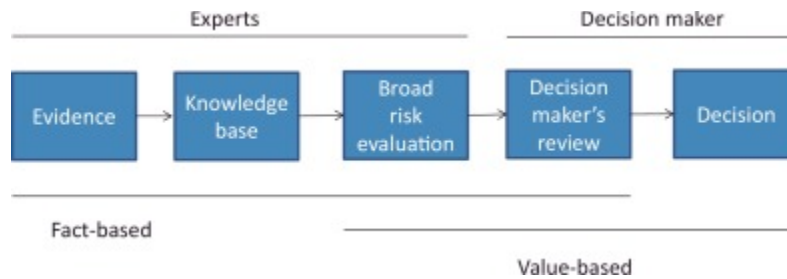
Figure 3.3: Diagram of the basic risk assessment workflow. (Aven, 2016).

collection of legitimate truth claims and beliefs, as provided by the collected evidence and previous studies. Using this knowledge base, relevant experts then perform a risk evaluation that provides various risks and uncertainties regarding the target hazard. This step must both integrate the values of decision-makers, while also balancing between scientific and practical burdens of proof (Aven, 2016). In other words, a risk evaluation must contain a healthy balance between assumptions and factuality. Once a risk evaluation has been created, this evaluation is then passed to appropriate decision-makers who review the outputs and make a decision (Aven, 2016).

3.1.6 Geospatial Modeling of Risk

Within the last five years, geospatial assessments of risk have become an increasingly popular framework. This increase in popularity is a direct result of advances in the capabilities of GIS, better resolution of satellite imagery, progress in remote sensing technologies, and the growing use of geospatial technologies outside of the geographical sciences (Kalogirou & Chalkias, 2014). Due to the environmental and spatial emphasis inherent with geospatial modeling, risk within this field is commonly categorized into one of three causal groups: *Environment-to-Human risks, Human-to-Environment risks*, and *Human-to-Environment-to-Human risks*. Environment-to-Human risks are naturally caused risks that significantly affect human populations, such as tsunamis or earthquakes. *Human-to-Environment risks* are risks that

humans pose to the environment with no short term effects imposed on human populations, such as pollution or habitat destruction. Finally, *Human-to-Environment-to-Human risks* encompass the negative environmental consequences of anthropogenic climate change, which subsequently jeopardize human populations (e.g. Increase in greenhouse gas emissions leads to climate change, which in turn affects the magnitude and frequency of severe weather events and thus jeopardizes vulnerable populations). Among these causal groups, Environment-to-Human and Human-to-Environment-to-Human risks are the most utilized frameworks due to the emphasis on natural hazards and climate change within the Earth Sciences (Kalogirou & Chalkias, 2014).

Despite methodological differences, almost all geospatial attempts to model risk use the same three-step workflow, which aligns with the same themes and goals of the previously discussed risk assessment workflow. This workflow is as follows: data integration, risk assessment tasks, and decision-making (Chen et al., 2003; Figure 3.4). Data integration involves collecting and compiling large amounts of data regarding hazard and risk factors and integrating these data sources into a GIS environment. Most risk assessments require a large amount of data from a variety of sources, with common examples including land use data from remote sensing applications, geologic data from previous geologic surveys, and population data from government Censuses (Chen et al., 2003). Determination of variables relevant to the selected hazard can be selected based on the literature or expert opinion.
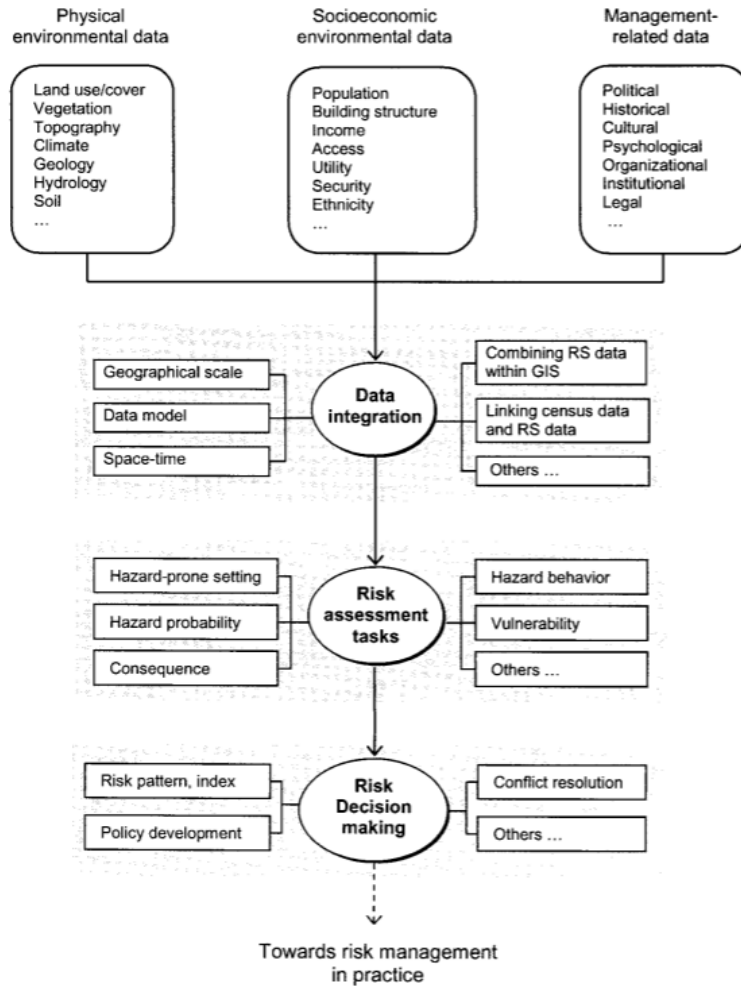
Figure 3.4: Basic workflow for a geospatial risk assessment using GIS (Chen et al., 2003).

Risk assessment tasks involve using the data collected from the data integration stage to assess the characteristics of a hazard, the vulnerability of a given population, and the interaction of these variables (Chen et al, 2003). Following the completion of risk assessment tasks, the decision-making process involves the use of integrative models to facilitate risk management decisions. These risk management decisions can involve static products such as risk assessment maps or can influence policy and decision-making, such as whether a prescribed burn should be scheduled for this week or next week (Chen et al, 2003; Figure 3.5). Often, this process involves

either the input or transfer of data to relevant policy or decision-makers, such as land managers or city planners.
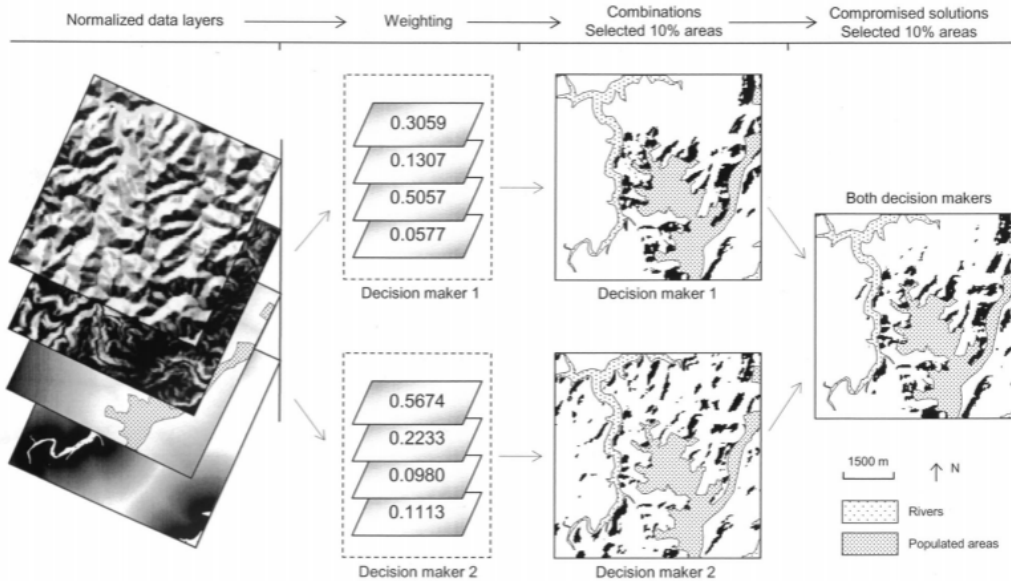
Figure 3.5: Case study operationalizing the proposed workflow in Figure 4.4 using an MCE-GIS methodology. The output is the far-right map, where black cells represent cells selected for a prescribed burn. Despite methodological differences, most GIS risk assessments produce similar outputs, where tasks output a raster map categorizing cells into chosen categories (i.e. high or low risk or selected for a prescribed burn or not, etc.; Chen et al., 2003).

Now that the basic workflow for a geospatial risk assessment has been established, the remainder of this review will focus on the risk assessment task. Risk assessment tasks encompass a wide variety of methodological frameworks that largely produce one of two outputs: inductive or deductive models (Chen et al, 2003). Inductive results include the spatial likelihood of a hazard occurring, while deductive results attempt to model some sort of behavior associated with hazard occurrence. For example, an inductive model might attempt to ascertain areas in a preserve that are at high risk for a bushfire starting, while a deductive model would model bushfire behavior in a specific locality once it has already ignited.

These two categories of risk assessment tasks can be further broken into a wide variety of methodological groups that span the breadth of statistical and geospatial-based methods. However, I will only focus on the methodological sub-groups relevant for geohazard risk assessments, which are typically divided into four types: *inventory, statistical, deterministic,* and *heuristic* (Metternicht et al., 2005). While inventory, statistical, and heuristic frameworks are inductive approaches, the deterministic framework is a deductive approach.

The inventory approach involves constructing inventory maps – or maps of previous hazard occurrences – and qualitatively assessing risk based on past incidences. The Utah Geologic Survey, which has worked extensively to document geohazard risk in Utah, has produced several state and region-specific inventory maps for sliding/slumping, rock falls, and earthquake epicenters (Utah Geologic Survey [UGS], n.d.). This approach can be useful for preliminary mass wasting hazard assessments by city and land managers in large scale study sites, however, it is rarely seen in novel literature due to its inability to forecast future hazards or predict spatially variant hazards (i.e. cyclones, forest fires, flash flooding, etc.). (Metternicht et al., 2005).

The logical extension of this approach is the statistical method – also termed the stochastic or probabilistic method depending on the source. This method involves predicting hazard occurrence by creating a database of past hazard events. The characteristics of these past events are then inventoried and described using a statistical model, allowing the model to predict future hazard sites and occurrences (Metternicht et al., 2005). Lan et al. (2004) used a statistical approach to predict landslide risk in Yunnan, China. Under their model, they used a landslide inventory digitized in GIS to quantify the relationships between landslide occurrence and affecting factors via the Certainty Factor model. Additional uses of this approach for geohazards

include predicting landslide occurrence in Kansas (Ohlmacher & Davis, 2003), Central Italy (Carrara et al., 1991), and Spain (Lorente et al., 2002; Jiménez-Perálvarez et al., 2010), along with predicting rockfall occurrence in Iran (Shirzadi et al., 2017) and Spain (Marquínez et al., 2003), and forecasting flood susceptibility in Jeddah City, Saudi Arabia (Youssef et al., 2015). The UGS has also used this method to predict landslide susceptibility by statistically evaluating the correlations between slope angles within specific geologic units against landslide occurrence.

However, as with any statistical classification model, this paradigm is *data hungry* and the quality of the model is dependent on the quality of the data. Within the statistical framework, most data are derived from a combination of field observations and satellite imagery, since satellite imagery alone is often not precise enough for such a large, high-quality training dataset. Additionally, the quality of field observations can vary between studies (Zhu et al., 2014). Another shortcoming to this method is the dichotomy between hazard presence and hazard absence. Using the example of landslides, landslides are commonly modeled by assessing the susceptibility of priming and triggering variables, or variables that make a location susceptible to a landslide (i.e. lithology, slope, etc.) and variables that trigger landslide occurrence (i.e. rainfall, distance from faults, etc.). Due to this, landslide absence may indicate a lack of triggering variables rather than a lack of priming variables, meaning that landslides could occur in the future with shifts in priming variables (Zhu et al., 2014).

Deterministic models, which are commonly used by geologists, hydrologists, and physicists, model the physical processes involved in hazard occurrence to determine vulnerable areas and hazard behavior (Metternicht et al, 2006). This framework often relies on mathematical and geophysical models to determine the conditions necessary for hazard susceptibility, with GIS and remote sensing data used as an ancillary data source (Metternicht et al, 2006). For example,

a deterministic framework might ascertain the amount of rainfall necessary for a specific hillslope within a specific geologic unit and at a specific slope angle to experience failure. Within rockfall analyses, this approach has been used to assess block-slope interactions, rebounding movements, sliding and rolling models, and the mitigating effect of trees on rockfall movement (Volkwein et al., 2011). Further examples of this framework within the literature include modeling rock fall likelihood and trajectory in Saudi Arabia (Youssef et al., 2014), assessing building practices in Albania as they relate to seismic risk (Muço et al., 2002), and forecasting flash flooding in South Africa (Poolman et al., 2014; Volkwein et al., 2011). This framework is suitable for large scale studies and lacking for regional and medium scale studies since it provides highly detailed results and can forecast the parameters necessary for hazard occurrence (Metternicht et al., 2006). Due to these advantages and disadvantages, some studies focusing on flooding and seismic risks have successfully bridged the gap between statistical and deterministic frameworks through combined methodologies (Rulli & Rosso, 2002; McGuire, 2001; Mazzorana et al., 2011).

The heuristic methodology integrates expert judgments into assessment models. This integration can be done either directly or indirectly, wherein direct methods have experts conduct fieldwork and then directly determine spatially vulnerable areas. The indirect method involves integrating expert opinion into the model, which can be achieved in several ways. Indirect methods can involve weighing the relevance of different parameters and the values within each parameter or can involve determining the mathematical relationship between parameters and hazard occurrence. Both methods then require combining data layers, resulting in a hazard zonation map. This method allows for a high level of integration with geospatial techniques, is most suitable for regional and medium scale studies, and does not make assumptions based on

52

hazard presence and absence. However, this method also raises questions of replicability and the subjectiveness of expert opinion. Various heuristic approaches have been used to model landslide susceptibility in China (Zhu et al., 2014) and Sikkim India (Anbalagan et al., 2015), generate multi-hazard risk maps in the Gulf of Aqaba, Egypt (Arnous & Green, 2011), assess flash flooding risk along the St. Katherine Road in Egypt (Youssef et al., 2011), and assess rockfall and landslide susceptibility in Iran (Daneshvar, 2014; Shizradi et al., 2017).

Out of the various heuristic-type methodologies available to researchers, fuzzy logic is popular due to its ability to model the inherent error of forecasting geohazard risk, produce a non-binary assessment, and capture complicated, non-linear relationships between parameters and hazard occurrence. Fuzzy logic does this as a function of modeling parameters in a continuous – or "fuzzy" – manner (Zhu et al., 2014). This is achieved through fuzzy sets, or the porous categorization of raw data values into overlapping groups of high, medium, and low suitability. A commonly used example to describe fuzzy sets is classifying the heights of high schoolers into groups of short, average, and tall. In a crisp set framework, students who are between 4'9" and 5'3" would be considered short, students who are between 5'4" and 5'6" average, and so on. However, in fuzzy sets, students who are below 4'10" would be absolutely short, while students between 5' and 5'1 3/4" would be possibly short, while heights between 5' and 5'3 ½" would be somewhere in between the short and medium classes (Figure 3.6). The key to fuzzy sets is that the categories are continuous and overlap, allowing the model to spatially account for uncertainty and produce a non-binary output (Environmental Systems Research Institute [ESRI], n.d.).
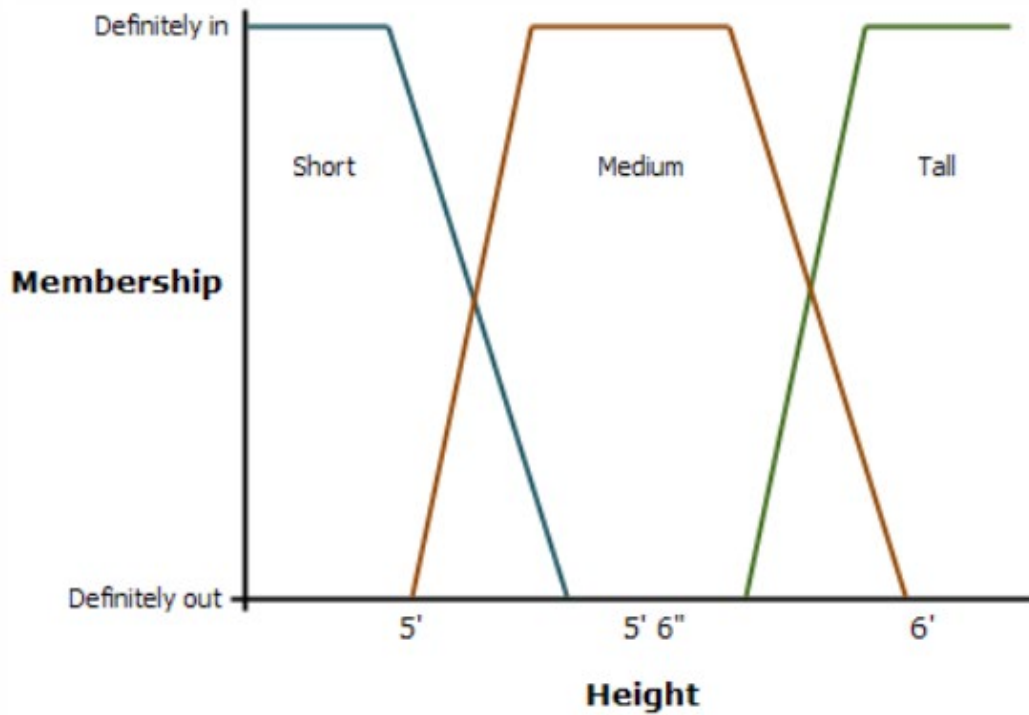
Figure 3.6: Depiction of fuzzy sets using the height example described above, where categories can overlap and account for error (ESRI, n.d.).

Expert knowledge is integrated by using expert opinion to set the relationship between parameters and hazard events, resulting in a dataset that ranges from 0 to 1. Using the example of flash flooding, basins with larger areas tend to be more susceptible to flash flooding, so a Z-shaped curve may be applied to this relationship (Youssef et al., 2011). In doing so, basins with larger areas are considered suitable for flash flooding and vice versa. The actual process of integrating expert opinion and transforming datasets is covered in greater detail in section 4.2.2.

Fuzzy logic is particularly popular for habitat suitability, but it has also been extensively utilized in landsliding/slumping assessments (Zhu et al., 2014). This model has not been utilized for a rockfall assessment; however other continuous, heuristic models have been used to forecast rockfall occurrence (Shizradi et al., 2017). Due to this, this research is novel in attempting to

apply fuzzy logic to rockfalls, a combination that – to my knowledge – has not been attempted before.

3.2 Current Research

The goals of the current research lie at the intersection of prior research between risk quantification, risk perception, and risk assessment. To comprehensively assess risk in BRCA and contribute to risk quantification literature, this project aims to methodologically bridge the gap and assess the dichotomy between risk perceptions and risk assessments. Although prior studies largely treat these fields as independent and unbridgeable aspects of risk inquiry, both perceptions and assessments encompass similar fields and goals. Research from both branches attempt to quantify subjective values of risk and use their research to aid relevant decision-makers in their risk mitigation efforts. If a proposed housing development on a floodplain is considered a risky place to live or develop by experts, does that zonation affect development if city planners and residents do not perceive that area as risky? Additionally, perceptions of risk directly affect decision-makers and expert opinion, since realistic risk is still based on the subjective decisions and measures of a researcher.

Thus, risk assessment and risk perception are two sides of the same coin which interact daily and should not be treated as separate entities. To demonstrate how these two frameworks may be utilized together for a holistic snapshot of risk, my research aims to identify high-risk areas of the park, assess perceptions of risk among visitors, and analyze the results from both efforts under the broader framework of risk. In addition to bridging this gap, this study will contribute to the risk perceptions literature by testing risk perceptions in an American National Park, which has not been done before to my knowledge. This study will also contribute by

focusing on tourists, which is a small but relevant sub-section of the related research due to their lack of local resources.

This holistic risk assessment uses GIS to model the risk posed by land sliding/slumping and rock falls, the two most relevant geohazards within BRCA as identified by the NPS (Thornberry-Ehrlich, 2005). Of course, seismicity and flash flooding are also concerns, however, they have not been included in this assessment. This is because seismic activity does not directly pose consequences, rather seismic events indirectly pose a risk by triggering mass wasting events, structural collapse, or liquefaction. Ordinarily, seismicity would be factored into a landslide/slumping assessment via either distance from faults or liquefaction, however, this model does not do so since all cells within the park are within 6.4 km of a fault scarp. Additionally, the data needed for a liquefaction assessment are not available. As for flash flooding, little risk is posed to visitors outside of sparsely used backpacking trails. While the main amphitheater contains several slot canyons and fins, many of these are either inaccessible to visitors, not under a headwater, or close enough to the plateau rim that accumulation is minimal. For example, if the Wall Street Trail area (Figure 3.7) were under a headwater or further from the plateau rim, its risk for flash flooding would be significant. However, due to a lack of these factors accumulation is minimal, limiting the risk visitors face from flash flooding.

While the Utah Geologic Survey has devoted considerable resources to identifying and mitigating geologic hazards, many of these efforts either focus on the Wasatch Range or the entire state, limiting results specific to BRCA. This knowledge gap not only limits the ability of park staff to mitigate against visitor injury or death but also impedes their ability to manage resources in high-risk areas – such as trails and critical wildlife. Additionally, most risk perception studies and risk assessment models tend to focus on only one hazard. This

Figure 3.7: Picture of Wall Street, a stretch of trail located within the Navajo Loop that includes steep switchbacks and sharp elevation changes (Photo: Tristan Surtel, Wikipedia Commons).

methodology is inherently limited in a multi-hazard environment given the interdependent nature of both risk perceptions and hazards themselves (Wachinger et al., 2013). Thus, this study will be one of the first to assess perceptions of tourists in a national park, while also adopting a multi-hazard approach and integrating a holistic risk assessment.

Chapter 4: Methodology

4.1 Risk Perception Surveys

4.1.1 Survey Participants

Participants consisted of 253 visitors at BRCA in May 2019. 15 surveys were removed from data analysis due to incomplete responses, leaving 238 surveys for data analysis. All participants were surveyed at one of five pre-determined park overlooks. Overlooks were chosen based on recommendations from park staff, with popularity, geologic variety, and location as the main factors.

This study utilized a non-probability purposive respondent sampling technique (Bird, 2009), where potential participants were directly approached at overlooks. Although this method presents a sampling bias, it is the best-suited method when considering the locality and sample population. Due to the nature of the survey and subject matter, a face-to-face sampling method was considered more appropriate than a remote survey (i.e. mail, phone, email surveys). Bird et al. (2010) dealt with the sampling bias by setting up a survey station within an Icelandic park's visitor center. They surveyed all the respondents who passed through the center – which was required for entry into the park. However, due to the high volume of visitors BRCA receives and NPS guidelines for conducting research, this methodology would not be viable either. To reduce sampling bias, surveys were administered throughout the day at multiple overlooks, with an even number (~50 participants) recruited from each locality. Respondents did not receive compensation for participating.

4.1.2 Survey Materials and Procedure

Within the risk perception literature, there is not a standardized methodology for assessing perceptions through a survey format. However, since many perception studies focus on international

communities with past experiences with hazard occurrence, methodologies typically consist of structured and semi-structured interviews (Ho et al., 2008; Lopez-Marrero, 2010; Nathan, 2008; Sullivan-Wiley & Gianotti, 2017, etc.). The few studies that do utilize surveys usually do so in combination with interviews or rely heavily on time-intensive question formats – such as rank order or open format questions (Bird et al., 2010; Corwin et al., 2017; Gaillard, 2008; Paradise, 2006). Given the time constraints tourists are under and NPS guidelines for conducting survey-based research, a time-intensive methodology is not appropriate for assessing visitor perceptions. To be approved for research by the NPS, surveys involving visitors cannot take longer than approximately 5-10 minutes. This is to minimize intrusion and to avoid interrupting the NPS visitor experience. To satisfy this requirement, many common survey structures used to assess hazard perceptions – such as open-ended questions, rank order questions, and interviews – are not viable options. Thus, this study's survey utilized checkbox answers, Likert scales, and a map-based question. These formats were chosen for their efficiency and ability to elicit quick judgments (Bird, 2009; Paradise, 2006).

All respondents completed a one-page paper survey, which started with reporting demographic data such as age, gender, and ethnicity. Following this, participants answered several questions regarding the number of times they've visited BRCA and their experience level in hiking and backpacking. One such question asks, "On average, how often do you hike and/or backpack?" Risk perceptions of ten different hazards were assessed using a 5-point Likert-scale modeled after Paradise's (2006) methodology. Surveyed hazards included geohazards (e.g. earthquakes and rockfalls) and human-environmental hazards (e.g. dehydration and wildlife). Participants were given a list of ten appropriate hazards and the following instructions: "Please circle the number that represents your concern of the following hazards in BRCA: 1=not at all concerned, 2=slightly concerned, 3=somewhat concerned, 4=moderately concerned, 5=extremely concerned".

On the following page, respondents were presented with a map of BRCA. The map used the same layout the NPS chose for their brochure maps and included important landmarks (i.e. main highways, visitor center, etc.), survey administration sites, and popular trails. Respondents were asked to "…please mark an 'X' on the areas you think are the most dangerous. Mark up to five 'X's." Following data collection, all X's marked by participants were digitized into the ArcPro 2.4 platform and appropriately visualized.

The survey questionnaire concluded with a brief comment section. Once participants turned in their survey to the research assistant, they were asked if they had any final questions and were thanked for their time.

4.2 Risk Assessment Analysis

4.2.1 Data Acquisition and Pre-Processing

Implementing a fuzzy logic workflow for each of the two identified hazards requires a variety of publicly available data sources. Many of these data sources were identified as relevant based on previous literature in arid, high elevation climates and publications from the Utah Geologic Survey (UGS). Datasets used to implement a fuzzy logic workflow include topographic data, historical climate data, and geologic data (Table 4.1).

4.2.1.1 Landslide Data

While a variety of ancillary data sources are available for integration in a landslide and/or slumping model, the most commonly used sources include topographic data, lithologic data, climactic data, and land use data (Daneshvar, 2014; Jiménez-Perálvarez, 2010; Utah Geologic Survey [UGS], 2016). Since the entire study site represents one land use unit, land use data was not included in this model. In addition, some sources use distance from faults as a secondary

variable, however, this variable was excluded from the model since all points within the park are within 4 miles of a fault scarp.

Table 4.1: Selected variables and data sources for the fuzzy logic models.

Data Set	Source	Data	Resolution	Data Type
Climate	PRISM	Annual temperature, annual precipitation, minimum temperature, maximum temperature	800 m	Raster
Geology	NPS	Geologic units	1:24,000	Polygon and Polyline Coverage
Elevation & Topographic derivatives	USGS	Elevation, slope, aspect	1m	Raster

Topographic data were obtained from the USGS 3D Digital Elevation Program (3DEP), which aims to provide raw LiDAR data and elevation derivatives for the entire contiguous U.S. by 2023. One-meter DEMs produced from this program were downloaded through the National Map Viewer. Aspect and slope layers – both in degrees – were obtained using the DEM and the slope tool in ArcGIS Pro. The aspect data layer was reclassified into three categories differentiating between flat land (-1°), sunny land (90° - 270°), and shady land (0° - 90° & 270° - 360°; Daneshvar, 2014). According to the prior research, sliding and slumping occurs more frequently on shady land, as shady hillslopes tend to have higher soil moisture and thus increased chemical weathering (Daneshvar, 2014). These characteristics make these slopes more susceptible to failure.

Slope values associated with hillslope failure were determined using a landslide susceptibility map produced by the Utah Geologic Survey (Giraud & Shaw, 2007). This susceptibility map was produced for the entire state of Utah and relies on only two data inputs: slope-angle thresholds and a state landslide inventory. Due to this, extrapolation from its results for BRCA is limited. However, the report does include classifications of slopes susceptible to sliding based on lithologic unit, making it suitable for determining the association between slope values and sliding/slumping earth movements.

Lithologic data for BRCA were acquired through the NPS' Integrated Resource Management Applications (IRMA) online portal. This inventory was produced by digitizing over existing geologic maps and aerial imagery and was mapped at a scale of 1:24,000 (NPS, 2013b). The data include a file geodatabase containing geologic units, geologic contacts, linear geologic units, geologic point features, geologic cross sections, folds and faults, and mine point features. For the purposes of modeling slumping and sliding, the geologic unit layer was the only data layer used. This layer was then transformed into a raster layer and reclassified to a numeric scale ranging from 1 to 10, with 1 representing units with little resistance to erosion and high susceptibility to slumping and sliding and 5 representing units with high resistance to erosion and low susceptibility to slumping and sliding (Table 4.2). Rankings were determined using the NPS' Geologic Resource Inventory for BRCA, which includes detailed unit descriptions for resistance to erosion and hazard susceptibility (Thornberry-Ehlrich, 2005)

Table 4.2: Ranking of geologic units for landslide susceptibility model. Rankings range from 1 (most susceptible) to 10 (least susceptible). Rankings determined using (ThornBerry-Ehrlich, 2005).

Geologic Unit	Ranking
Landslide Deposits	1
Quaternary Deposits	2
Tropic Shale	3
Claron Formation – Pink limestone	4
Straight Cliffs - Upper	5
Claron Formation – White limestone	6
Wahweap Formation	7
Conglomerate at Boat Mesa	8
Straight Cliffs – Lower	9
Dakota Formation	10

Finally, continuous climate data were obtained from the PRISM Spatial Climate dataset through the University of Oregon. For the purposes of this analysis, mean annual temperature and mean annual precipitation datasets were downloaded at an 800m resolution (PRISM Climate Group, 2019). While sliding and slumping events are better predicted by single event data – as in a continuous, geospatial dataset that represents the average highest amount of precipitation that cell receives in a single event, this data is not readily available. However, many sliding/slumping studies have used average, annual precipitation and climate data as a suitable substitute. Both datasets represent 30-year normals between 1981 and 2010 and were derived using a combination of DEMs and climatologically aided interpolation from ground weather stations.

4.2.1.2 Rockfall Data

Rockfall and sliding/slumping both fall under the breadth of mass wasting phenomena. However, rockfall phenomena are distinguished from sliding/slumping via the difference between hillslope failure and fragmentation and disaggregation processes. Sliding and slumping

phenomena are the movement of cohesive soil and bedrock masses down a failed hillslope, may occur either slowly or rapidly, and are the result of priming and triggering mechanisms. Alternatively, rockfalls refer to bedrock block detachment along steep cliffs due to weathering. Rockfalls occur rapidly and typically do not involve triggering mechanisms. Due to this, the variables used to model spatial probability of sliding/slumping and rockfalls can be similar, with significant variations. Based on previous literature that models rockfall probability based on GIS and geophysics, relevant variables include slope, aspect, elevation, lithology, and temperature variation (Shirzadi et al., 2017; Marquínez et al., 2003). While distance from roads and trails is also commonly used as a variable due to undercutting during construction, the inclusion of these factors did not benefit the model used for this study.

Topographic and lithologic derivatives were obtained and processed in the same manner described above in the landslide section. Similar to the sliding/slumping analysis, aspect was reclassified based on categorizations of sunny, shady, and flat slopes. However, for this analysis sunny slopes were classified as more suitable for rockfalls, as sunny slopes will experience a wider gap in daily temperature fluctuations. Since the primary weathering mechanism in BRCA is freeze-thaw cycles resulting from the drastic difference between daytime and nighttime temperatures, sunny slopes will propagate this pattern.

Geologic units were processed using the same methodology as described in the landslide subsection. Units were reclassified based on their susceptibility to rockfalls on a scale from 1 to 10. Units that received a ranking close to 1 are incredibly susceptibility to rockfalls, particularly when fractures, jointing or artificial undercutting (i.e. road or trail construction) are present. Units that received rankings close to 10 included those not susceptibility to mass wasting processes and those susceptible to slumping and sliding instead of rockfalls (Table 4.3).

Table 4.3: Ranking of geologic units for rockfall susceptibility model. Rankings range from 1 (most susceptible) to 10 (least susceptible). Rankings determined using ThornBerry-Ehrlich (2005).

Geologic Unit	Ranking
Colluvium	1
Conglomerate at Boat Mesa	2
Claron Formation – White Limestone	3
Claron Formation – Pink limestone	4
Straight Cliffs - Upper	5
Straight Cliffs – Lower	6
Wahweap Formation	7
Tropic Shale	8
Dakota Formation	9
Quaternary Deposits	10

Unlike sliding/slumping, which can be successfully forecasted using annual averages as a proxy for single event data, rockfall is best modeled via climatic cycles. Raster temperature maximum and minimum datasets for the study site were obtained via the PRISM program. Both datasets were derived from 30-year normals between 1981 and 2010 (PRISM Climate Group, 2019). As a proxy for temperature variation, the ArcPro 2.4 Raster calculator was used to find the difference between the maximum and minimum datasets and create a new raster dataset representing this difference. Cells with larger degrees of difference are more suitable for rockfall than cells with smaller degrees of difference.

4.2.2 Data Analysis

Implementing a fuzzy logic workflow specific to ArcGIS Pro 2.4 involves the following workflow: Fuzzy membership tool, Fuzzy Overlay tool, and Reclassify function. The fuzzy membership tool represents the application of fuzzy membership values, where raw – or crisp – values of a dataset are transformed into a scale of 0 to 1. Values of 0 represent raw data values

that are entirely unsuitable – or not associated with hazard susceptibility at all – and values of 1

represent raw data values that are entirely suitable – or highly associated with hazard

susceptibility. The transformation between raw values and this scale is determined by the

mathematical relationship (i.e. bell-shaped curve, z-shaped curve, etc.) set by the analyst (Zhu et

al., 2014). The Fuzzy Membership tool offers seven different membership types: Gaussian, Near,

Linear, Small, Large, MS Small, and MS Large (Table 4.4).

Table 4.4: Descriptions, names, and equations for the seven membership classes ESRI offers for the fuzzy membership tool (Raines et al., 2010).

Membership Class	Description	Equation
Linear	Linear equation that either increases or decreases in membership between two specified inputs (max and min).	$\mu(x) = 0 \; if \; x < min^*$ $\mu(x) = 1 \; if \; x > max^*$ Otherwise $\mu(x) = \frac{(x - min)}{(max - min)}$
Gaussian	Bell-shaped distribution where a midpoint is identified as having absolute membership. As distance from the midpoint increases in either direction, membership decreases.	$\mu(x) = e^{-f_1{}^* \cdot (x - f_2{}^*)^2}$
Near	Similar to the Gaussian type, using a bell-shaped distribution with a midpoint. However, the Near function typically has a narrower spread.	$\mu(x) = \dfrac{1}{1 + f_1{}^* \cdot (x - f_2{}^*)^2}$
Large	Sigmoid curve where larger data values are considered more suitable, while smaller values are considered less suitable.	$\mu(x) = \dfrac{1}{1 + \dfrac{x^{-f_1{}^*}}{f_2{}^*}}$
Small	Sigmoid curve where smaller data values are considered more suitable, while larger values are considered less suitable.	$\mu(x) = \dfrac{1}{1 + \dfrac{x^{f_1{}^*}}{f_2{}^*}}$
MS Large	Sigmoid curve where large data values are considered more suitable. However, the shape is defined by the mean, standard deviation, and expert-determined multipliers rather than midpoint and spread inputs.	$\mu(x) = 1 - \dfrac{b^*s}{x - a^*m + bs} \; if \; x > am$ $otherwise \; \mu(x) = 0$ m = mean; s = standard deviation
MS Small	Sigmoid curve where small data values are considered more suitable. However, the shape is defined by the mean, standard deviation, and expert-determined multipliers rather than midpoint and spread inputs.	$\mu(x) = \dfrac{b^*s}{x - a^*m + bs} \; if \; x > am$ $otherwise \; \mu(x) = 1$ m = mean; s = standard deviation

Following the application of membership types, data layers are combined into a final output via the Fuzzy Overlay tool. ESRI offers five overlay functions: And, Or, Product, Sum, and Gamma. The most common of these functions are the Or, And, and Gamma equations. An And type overlay classifies each cell using the minimum value of the sets the cell belongs to. Conversely, an Or type overlay classified each cell using the maximum value of the sets the cell belongs to. A Gamma Overlay involves an algebraic product raised to the power of gamma (Equation 3) and is a mathematical compromise between the Product (Equation 1) and Sum (Equation 2) overlays.

$$Fuzzy\ Product = \ \mu(x) = \pi_{i=1}^{n}\mu_i \tag{1}$$

$$Fuzzy\ Sum = \ \mu(x) = \pi_{i=1}^{n}(1 - \mu_i) \tag{2}$$

$$Fuzzy\ Gamma = (Fuzzy\ Sum)^\gamma - (Fuzzy\ Product)^{1-\gamma} \tag{3}$$

All five overlay methods were tested for each of the susceptibility maps, with the Gamma Overlay consistently the most suitable overlay type for each product. This result is consistent across much of the literature using the ESRI Fuzzy Logic toolbox (Bick et al., 2018; Lewis et al., 2014; Tabaei et al., 2018; Zhang et al., 2015).

In the final step, the continuous model output was defuzzified using a Natural Breaks methodology into five classes: very low risk, low risk, medium risk, high risk, and very high risk.

4.2.2.1 Landslide Assessment

Environment variables were chosen using research that modeled sliding and slumping susceptibility in arid, badland topographies and include slope, aspect, elevation, mean annual precipitation, mean annual temperature, and lithology (Table 4.5). Slope, lithology, and mean annual precipitation constituted the most critical variables for modeling sliding and slumping

susceptibility. Mean annual temperature and aspect represent secondary, but important variables. Membership classes and parameters were assigned via a combination of expert opinion and relevant literature.

Table 4.5: Parameters used for Fuzzy membership tool within the landslide model, along with relevant settings.

Data Layer	Data Source	Membership Type	Midpoint	Minimum	Maximum
Aspect (in degrees)	3DEP	Linear		1	3
Slope (in degrees)	3DEP	Large	30	-	-
Elevation	3DEP				
Lithology	IRMA	Linear	-	10	1
Mean Annual Temperature (in Celsius)	PRISM	Small	6.5	-	-
Mean Annual Precipitation (in mm)	PRISM	Large	250	-	-

The Gamma Overlay type was determined to be the most suitable overlay type after analyzing and comparing the outputs for each type. The final product for analysis was produced using a Gamma Overlay type with a Gamma value of 0.7.

4.2.2.2 Rockfall Assessment

Choosing the environmental variables for rockfall hazard was done in the same way as it was done for sliding/slumping. Variables were chosen based on literature that uses heuristic models to assess rockfall in arid, mountainous settings. The chosen variables include slope, aspect, elevation, differences between maximum and minimum annual temperature, and lithology (Table 4.6). Slope, lithology, and temperature variation constitute the most critical variables for modeling rockfall susceptibility. Elevation and aspect represent secondary, but

important variables. Membership classes and parameters were assigned via a combination of expert opinion and relevant literature.

Table 4.6: Parameters used for Fuzzy membership tool within the rockfall model, along with relevant settings.

Data Layer	Data Source	Membership Type	Midpoint	Minimum	Maximum
Aspect (in degrees)	3DEP	Linear		1	3
Slope (in degrees)	3DEP	MS Large	-	-	-
Elevation	3DEP	Large	2100		
Lithology	IRMA	Linear	-	10	1
Annual Temperature Difference (in Celsius)	PRISM	Large	15.5	-	-

Similar to sliding/slumping, the Gamma Overlay type was determined to be the most suitable overlay type after analyzing and comparing the outputs for each type. The final product for analysis was produced using a Gamma Overlay type with a Gamma value of 0.75.

Chapter 5: Results

5.1 Perception Surveys

Participants tended to be middle-aged ($\mu = 46$ years; $\sigma = 17.54$), female (61%) and white (89%). Males constituted 39% of participants, while Asians were the second most populous ethnic demographic at 6.7% (16 participants). Black participants made up approximately 2.1% of the sample, while 1.6% of participants identified as Hispanic/Latino. Only one participant identified as other and none as Native American. As for completed educational demographics, the majority of participants had completed a bachelor's degree as their highest level of education (44%), while a prominent number of participants held graduate degrees as their highest level of attainment (30%). 17% of participants had finished high school or passed a GED and 11% obtained an Associate's degree. Only one participant marked 'Other' to indicate the status of some college. These demographic averages are representative of visitor averages to BRCA, where the average age is 46 and 61% of visitors are female (Holmes et al., 2009; NPS, 2013). According to overall NPS visitor statistics, 95% of visitors to NPS units are white, while 2% are Asian, 1% Black, and 7% Hispanic/Latino (NPS, 2014). Additionally, 11% had a high school diploma/GED, 24% attended some college, 32% had a bachelor's degree, and 32% had a graduate degree.

Overall, participants viewed BRCA as a safe landscape, with average rankings for Likert items hovering near or below 2.5 (Table 5.1). The Likert-scaled question with the highest mean response was falling into the canyon ($M = 2.73$, $SD = 1.24$), while the lowest was the earthquake question ($M = 1.34$, $Sd = .69$; Figure 5.1), resulting in a range of 1.39 points. The mean of the generalized perception measure was 2.1 ($SD = .75$). This measure was obtained by averaging the ten Likert scale responses for each participant ($\alpha = .86$).

Table 5.1: Table of mean ratings and standard deviations for all ten Likert items.

Dependent Variable	Mean Likert ranking	Sd Likert ranking
Hoodoo Topple	1.69	1.04
Trail Substrate Collapse	2.17	1.15
Rockfall/Landslide	2.23	1.02
Flash Flooding	2.09	1.10
Earthquake	1.35	.69
Lightning Strike	1.89	1.08
Getting Lost	2.43	1.25
Slipping/Falling into Canyon	2.73	1.24
Dehydration/stroke	2.61	1.25
Wildlife	2.14	1.17
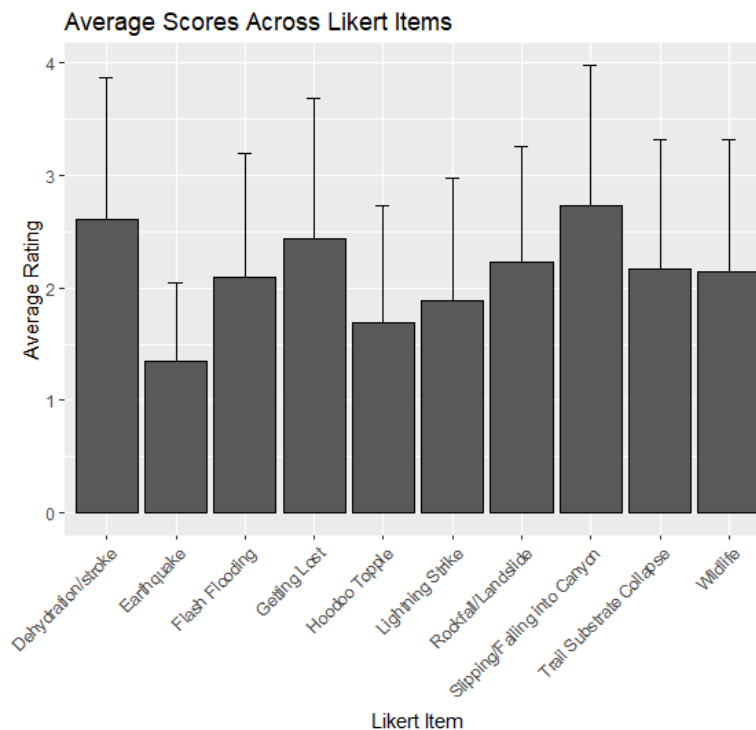
Figure 5.1: Histogram showing the mean ratings across individual Likert items. Errors bars for this – and all subsequent histograms – represent standard deviation, which may reveal additional patterns not apparent through means alone. However, standard deviation did not reveal additional information for any of the histograms. Histogram created in Rstudio.

5.1.1 Likert Items vs. SAR Records

When comparing the results from the general risk perception measure to SAR operations statistics, comparisons show that the gap between overall perceived and realistic risk is minimal. In 2017, only one fatality occurred in the park, while 86 SAR operations were deployed (NPS, 2018a) representing less than 1% of visitors.

When comparing individual Likert items to SAR statistics and other measures of frequency and magnitude (i.e. news articles, hazard inventories, NPS educational materials, etc.), the expected gap between perceived and realistic risk became more apparent. For example, lightning received an average rating of 1.89, while hoodoo topple received an average rating of 1.63. Despite their close ratings, lightning presents a significant risk to visitors and the NPS has multiple signs and brochures warning of its danger. Hoodoo topple, on the other hand, is a nonexistent and fictional phenomenon created to examine how its ratings compared to Likert items that pose realistic risks. This was based on the idea of semantic priming, where exposure to a stimulus affects subconscious thought patterns (Draine & Greenwald, 1998). In this example, we used hoodoo topple to explore two ideas: a) how it compared to other, legitimate hazards and b) if including it on the questionnaire in and of itself lent it legitimacy, thus resulting in higher concern ratings. Furthermore, the earthquake item received the lowest average Likert ratings (see Table 5.1), even though there have been 1,500 seismic epicenters within 50 km of BRCA borders from 1962 to 2016. Although many of these events have low local magnitudes, events with moderate local magnitudes have occurred. Given the right environmental conditions, an earthquake within 50 km of BRCA with a local magnitude of 4 or 5 could be enough to trigger a landslide or rockfall event.

5.1.2 Statistical Analyses

For data analysis, several appropriate correlation models and hypothesis tests were run to ascertain the relationships and effects of demographics and measures of experience on Likert scale responses. Statistical models were run on both the generalized risk perception measure and the individual Likert items. In doing so, this tests the effects of demographics and measures of experience both on the larger scale of risk perceptions and the smaller scale of perceptions of individual hazards.

A Spearman Rank-Order Correlation Test was used to determine the correlation between age and risk perceptions. A significant negative correlation was found between age and risk perceptions, wherein as age increases risk perceptions decrease ($\rho = -.21$, p = .001), p < .001 (Figure 5.2). Significant negative correlations were found for all individual Likert items except for Lightning Strike and Flash Flooding (see Appendix B for tables containing specific results from all conducted tests).

The association between gender and Likert ratings was explored using the Wilcox Rank Sum Test, where there were no significant differences between male ($M = 2.09$, $SD = .69$) and female ($M = 2.17$, $SD = .78$) Likert averages ($W = 6195$, p = .59), p < .6 (Figure 5.3). Further investigation using Wilcox tests found that males and females rated individual Likert items similarly (Figure 5.4), except for earthquakes ($W = 5702.5$, p = .047), p < .05. For earthquakes, males ($M = 1.22$, $SD = .466$) were significantly less concerned by earthquakes than females ($M = 1.45$, $SD = .79$). However, despite a lack of statistical significance, females rated most hazards as slightly more concerning than males, except for flash flooding and lightning strikes. On these items, males rated their concern as slightly higher than females.
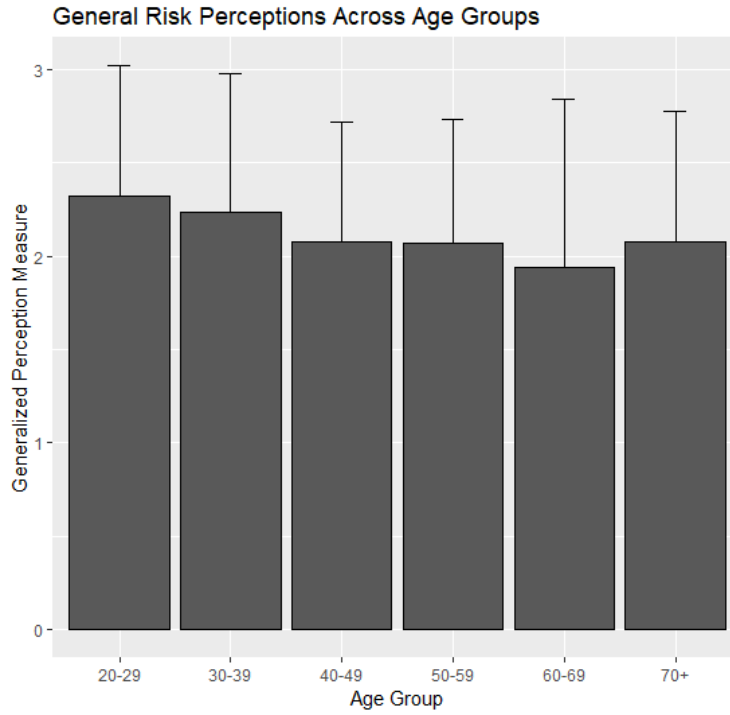
Figure 5.2: Histogram depicting age groups against the mean of their general risk perception ratings. Histogram created in RStudio.
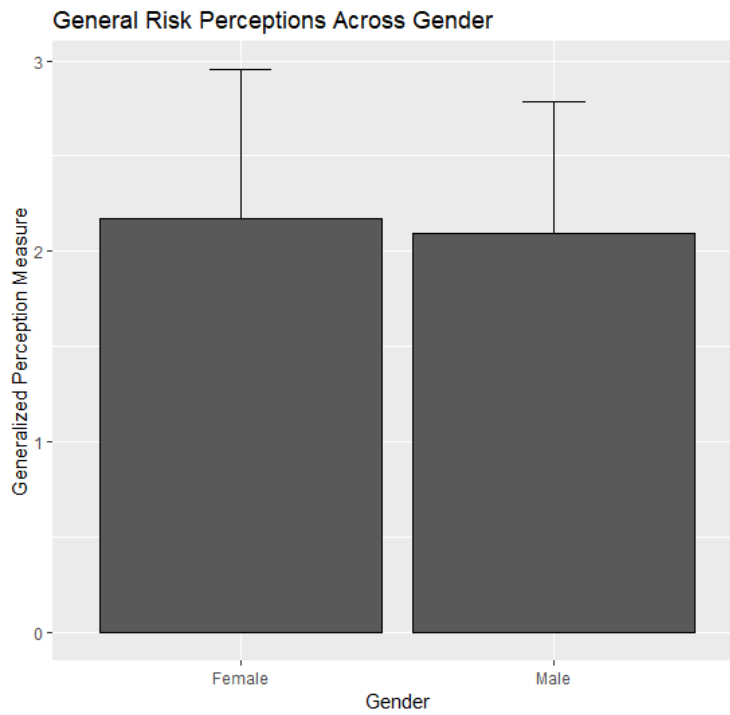
Figure 5.3: Histogram depicting gender against the mean of their general risk perception ratings. Histogram created in RStudio.

74
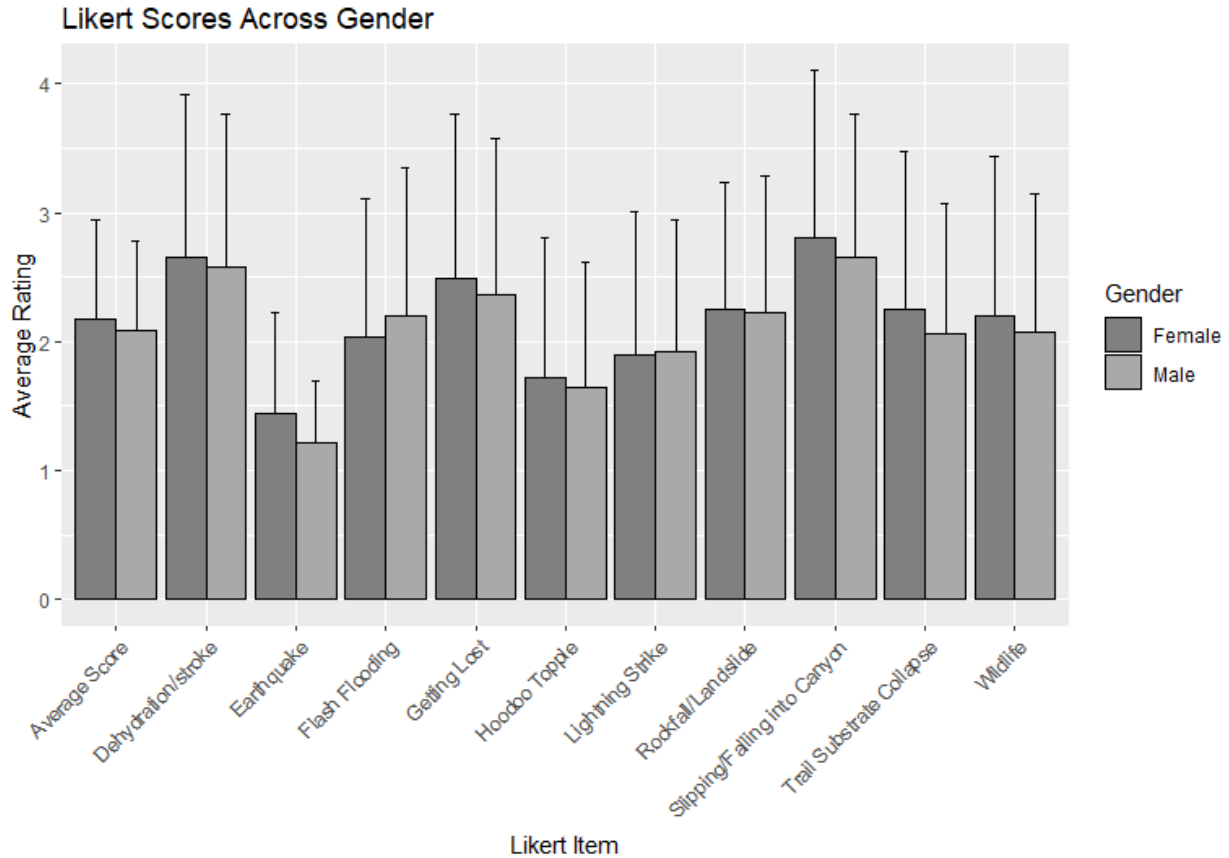
Figure 5.4 Histogram of average Likert ratings for individual items across gender. Histogram created in RStudio.

Differences between ethnic groups and Likert ratings were explored using the Kruskal-Wallace Test, where there were no significant differences between ethnic groups ($\chi^2 = 8.64$, df = 4, p = .064), p < .08 (Figure 5.5).

However, when testing for specific Likert items, there were significant differences between ethnic groups on the hoodoo topple and earthquake items, ($\chi^2 = 14.99$, df = 4, p = .005), p < .01 and ($\chi^2 = 15.54$, df = 4, p = .004), p < .01, respectively (Figure 5.6). A pairwise Wilcox post hoc test determined that the differences between ethnic groups for both items were between the white (*M* = 1.63, *SD* = 1.00 and *M* = 1.29, *SD* = .60, respectively) and Asian (*M* = 2.5, *SD* = 1.10 and *M* = 1.81, *SD* = 1.05) ethnic groups, where Asian participants tended to be significantly more concerned about these hazards than white participants. However, given the calculated

75

means and figures 5.5 and 5.6, I isolated the white and Asian groups and directly compared their

differences using a Wilcox test. When isolating the two groups, there is a significant difference

in Likert averages, (W = 2444, p = .003), p < .01, along with significant differences on the

getting lost (W = 2188, p = .046), p < .05, slipping/falling into canyon (W = 2343, p = .009), p <

.01, dehydration/heat stroke (W = 2386.5, p = .005), p < .01, and wildlife (W = 2285, p = .015),

p < .05, items.
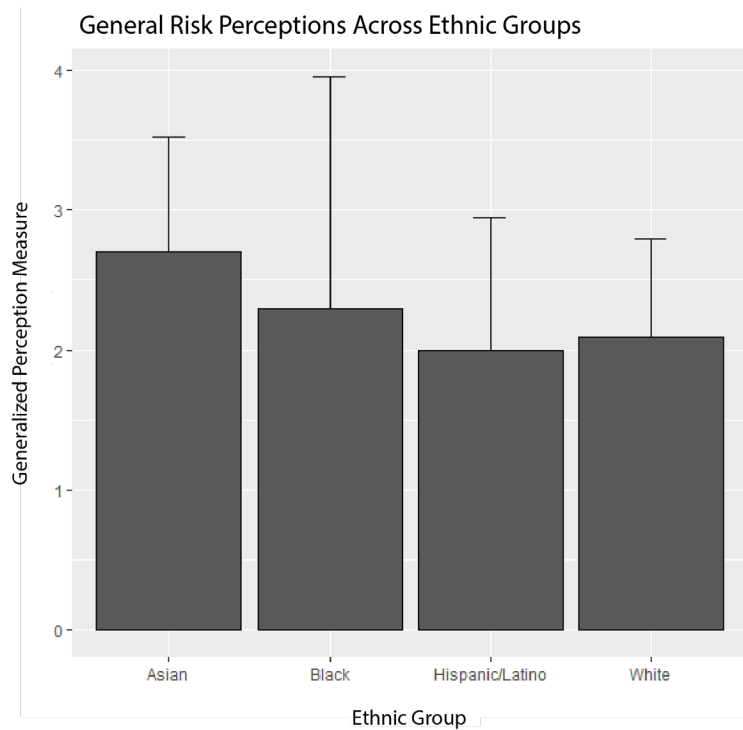
Figure 5.5: Histogram depicting ethnic groups against the mean of their general risk perception
ratings. Histogram created in RStudio.
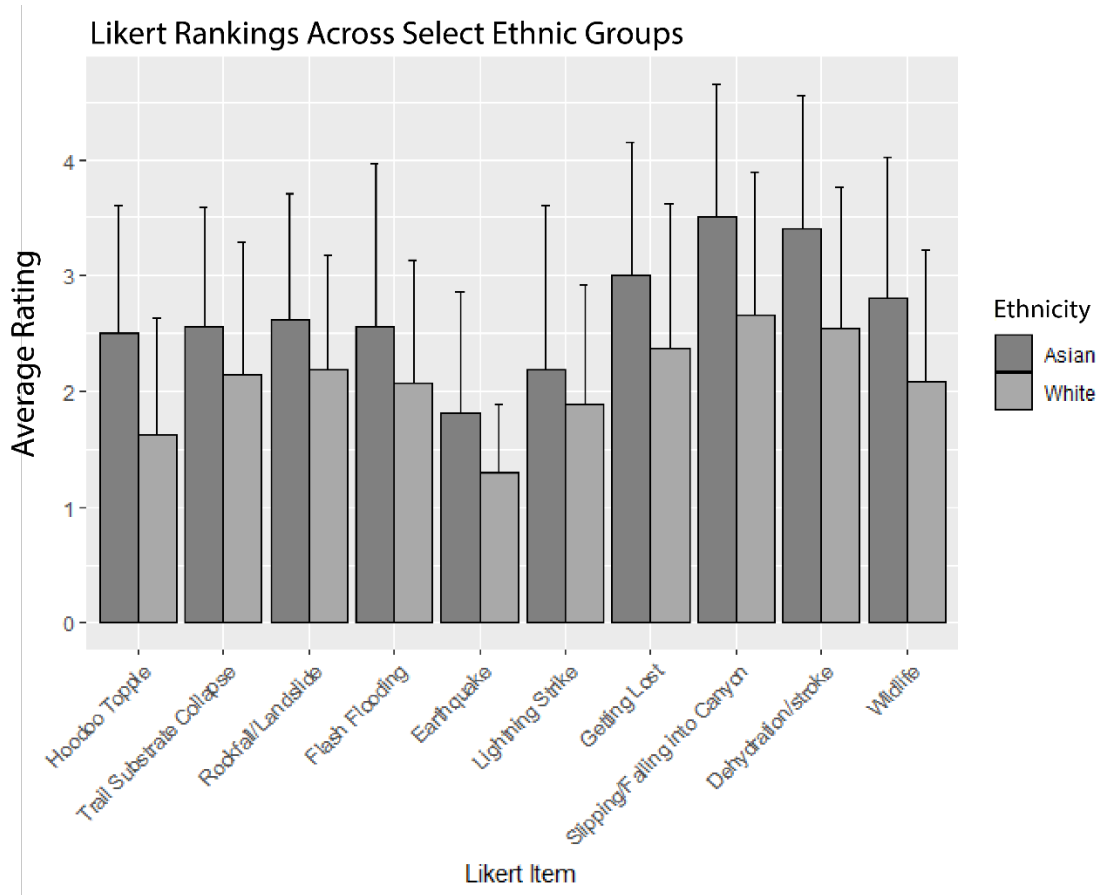
Figure 5.6: Histogram of average Likert ratings for individual items between Asian and White participants. Histogram created in RStudio.

Educational levels were also explored as an independent variable, with insignificant results (Figure 5.7). There was not a significant correlation between the educational attainment groups and Likert averages (ρ = .089, p = .16), p <.20. Further Spearman Rank-Order Correlation Tests found no significant correlations between completed education and ratings for individual Likert items.
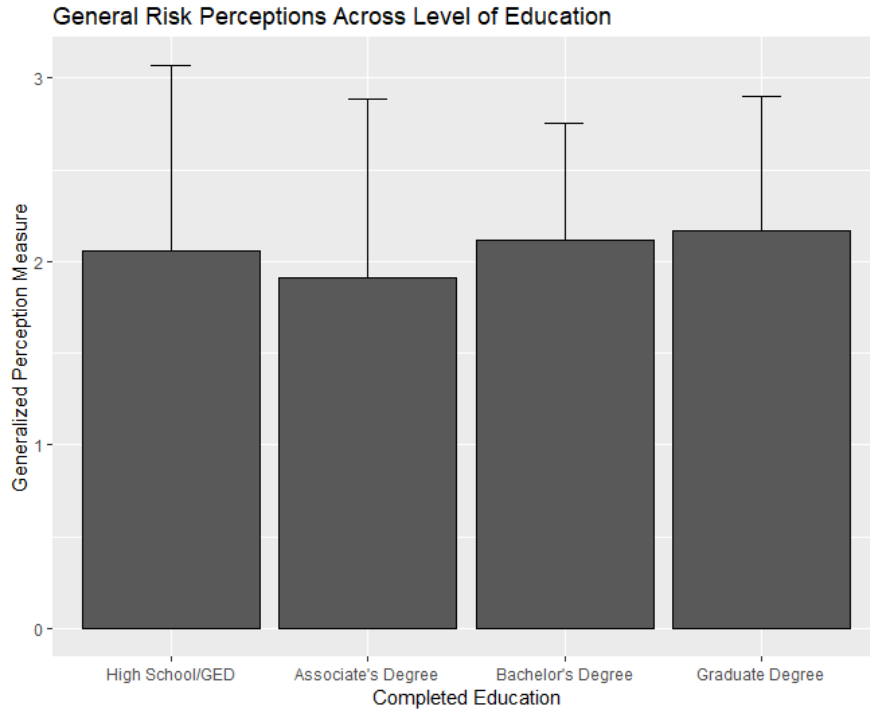
Figure 5.7: Histogram depicting completed education against the mean of their general risk perception ratings. Histogram created in R.

After exploring the effect of demographic information on hazard perceptions, the effect of experience and prior knowledge was tested using a series of Spearman Rank-Order Correlation models. Experience and prior knowledge were obtained via two ordinal questions on the surveys: "How many times have you previously visited Bryce Canyon National Park?" and "On average, how often do you hike and/or backpack?". Neither the number of times participants visited BRCA nor frequency in hiking/backpacking was significantly correlated with averaged Likert scores, $(\rho = -.127, p = .051)$, $p < .055$ and $(\rho = -.118, p = .07)$, $p < .08$, respectively (Figures 5.8 and 5.9).

However, the number of times visiting BRCA was negatively correlated with ratings on the slipping/falling into canyon item $(\rho = -.132, p = .042)$, $p < .05$ and highly correlated with the wildlife item $(\rho = -.185, p = .004)$, $p < .01$. Experience in hiking and/or backpacking was

insignificant across most of the Likert items, except for hoodoo topple and earthquakes, (ρ = -.153, p =.018), p < .05, and (ρ = -.136, p =.036), p < .05, respectively. All correlations between the two measures of experience and Likert items were negative, indicating that as experience increased concern decreased.
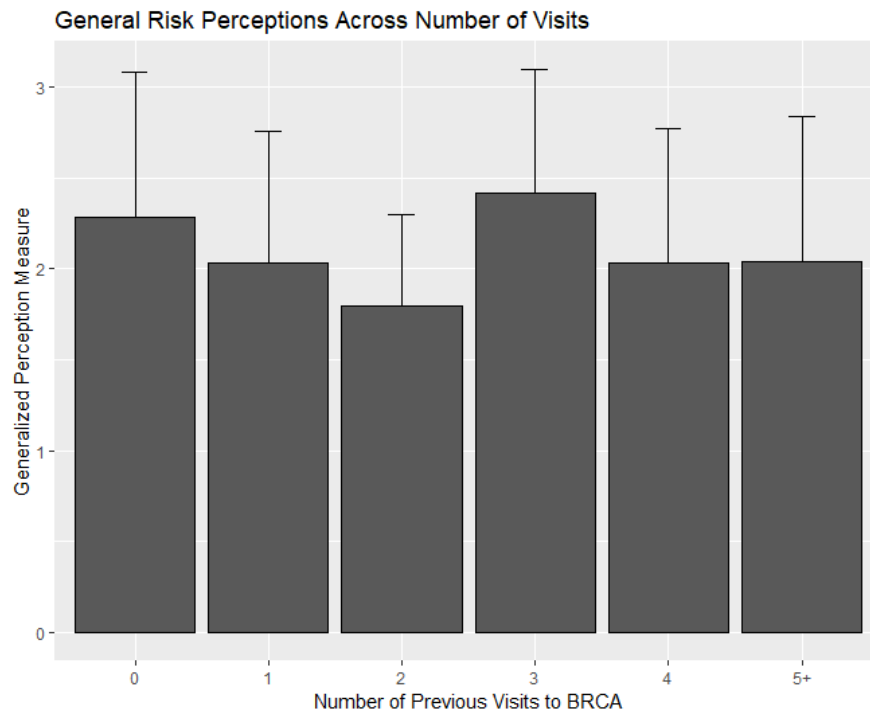
Figure 5.8: Histogram depicting the number of previous visits to BRCA against the mean of their general risk perception ratings. Histogram created in RStudio.
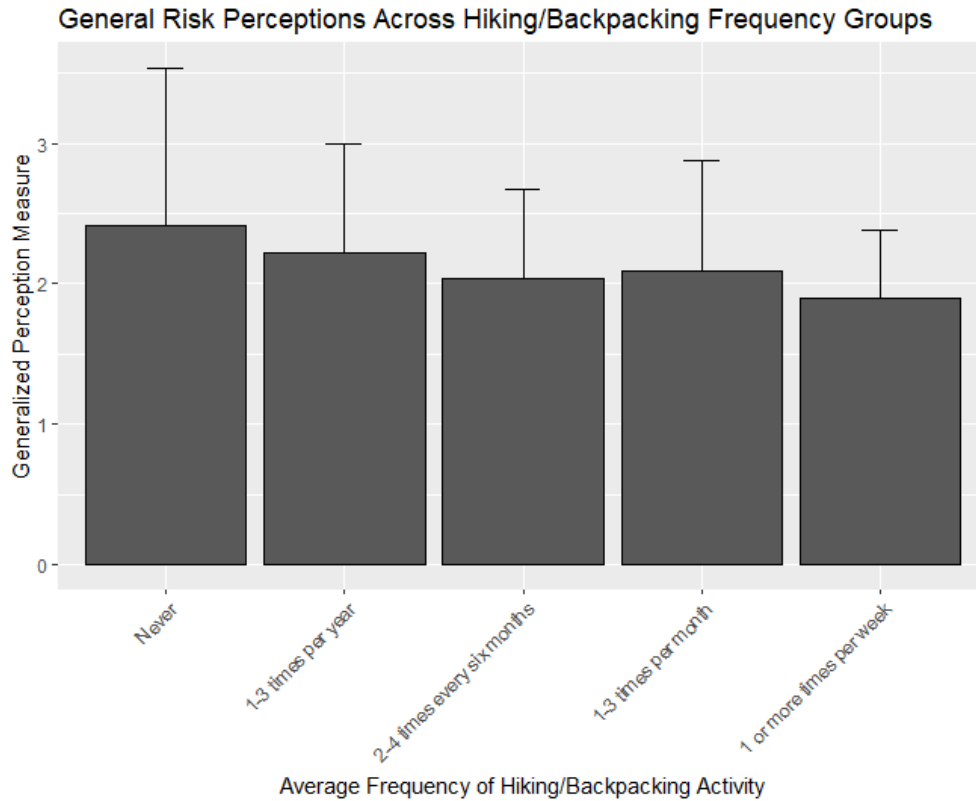
Figure 5.9: Histogram depicting frequency of hiking/backpacking against the mean of their general risk perception ratings. Histogram created in RStudio.

5.1.3 Mapping

In addition to performing the above statistical tests, results from the mapping portion of the survey were analyzed in ArcPro 2.4 and visualized in Illustrator. Overall, 65% of participants (156/238) marked at least one X. Out of the participants who did complete the mapping portion of the survey, each participant marked over 2 X's on average. As seen in Figure 5.10, 14.41% of responses marked Inspiration Point as a dangerous area. Sunrise Point, Queen's Garden Loop, Bryce Point, and Fairyland Loop were also considered dangerous by a large number of participants.

The comment section, which was placed by the mapping section of the survey, was used by several participants to explain why they marked X's in the locations they did. Many participants indicated the canyon rim due to steep drop-offs or Inspiration Point because it was

80

perceived as risky due to its lack of railings. In addition to this, comparing figure 5.10 against

figure 4.11, which depicts overlooks participants tend to visit, shows a general trend –

participants tended to rate the most highly visited overlooks as the most dangerous.
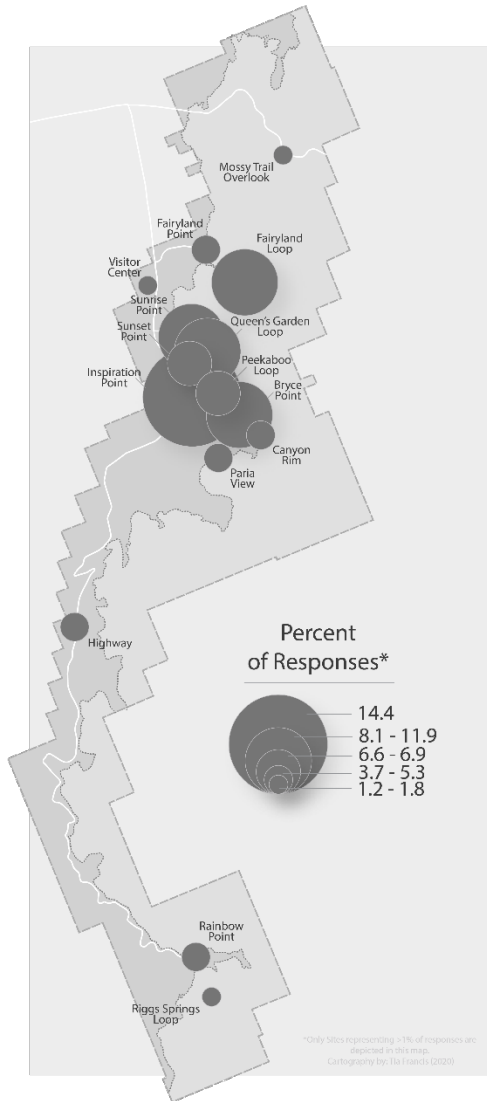
Figure 5.10: Map of survey responses depicting areas participants perceived as dangerous, with graduated circles representing the percent of responses which identified that spot as dangerous (Cartography by Tia Francis).
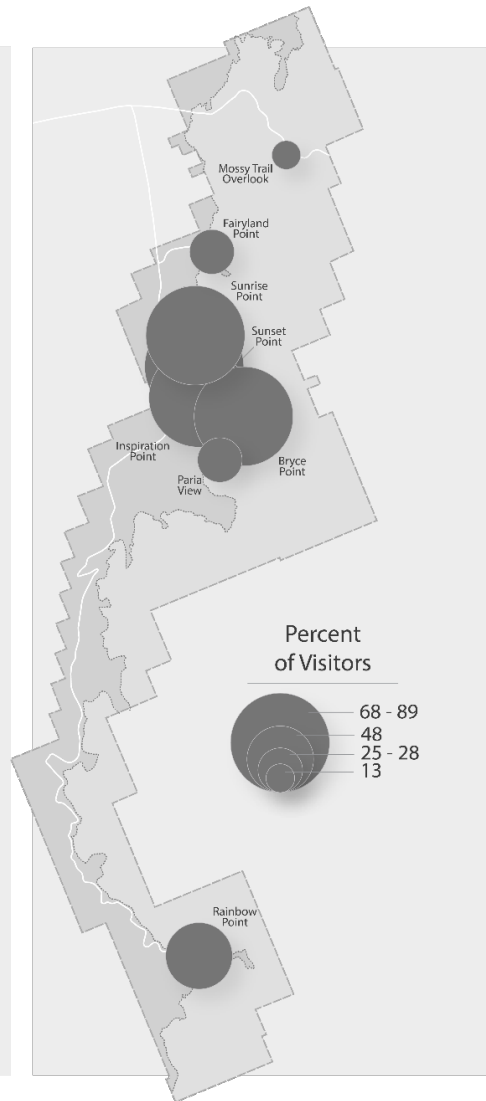
Figure 5.11: Map depicting the most widely visited overlooks within the park. Data was self-reported and did not include trails or non-overlook spots within BRCA. Data obtained from Holmes et al. (2009) (Cartography by Tia Francis).

5.2 Risk Assessment Analysis

The assessment models produced a 5 m resolution raster indicating very low, low, medium, high and very high risk. Results were qualitatively validated against hazard inventories, high-resolution satellite imagery, and previous assessment models.

5.2.1 Landslide Assessment

Within BRCA, 27% (39 km^2) of the park was classified as very low risk, 16% (23 km^2) as low risk, 19% (27 km^2) as medium risk, 24% (34 km^2) as high risk, and 14% (20 km^2) as very high risk (Figure 5.12). Results were qualitatively validated against the UGS's record of historical landslide activity and their statewide classification of areas risky for landslides. The few landslides that have occurred within the park fell within the high-risk classification zone. Additionally, there is a large grouping of landslide deposits in the Tropic Shale near the southern border of the park, matching the patterns seen within the park. Qualitatively, the statewide assessment and BRCA assessment seemed to match well enough, especially when considering the effect of modifiable areal unit problem and difference in variables used.
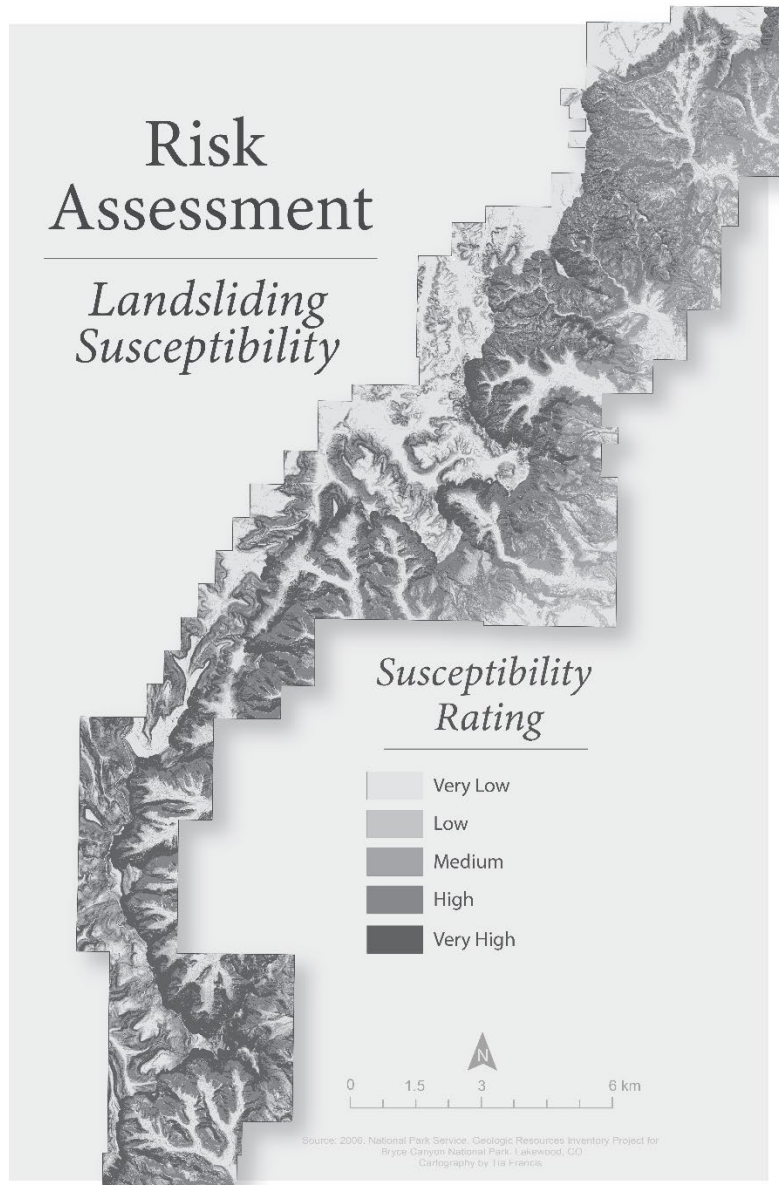
Figure 5.12: Landslide susceptibility map produced from the fuzzy logic model, with dark gray areas depicting very high-risk areas and light gray areas depicting very low-risk areas. Output from the model was visualized in Adobe Illustrator. (Cartography by Tia Francis).

5.2.2 Rockfall Assessment

Across the study site, 22% (32 km^2) of BRCA was classified as very low risk, 15% (22 km^2) low risk, 19% (28 km^2) medium risk, 27% (39 km^2) high risk, and 17% (25 km^2) very high risk (Figure 5.13). Results were qualitatively validated by comparing the output against 60 cm

NAIP imagery, with high and very high pixels corresponding well with interpreted scree slopes. According to the literature, scree slopes are indicative of rockfall activity and are commonly used to train statistical models (Marquínez, 2003).
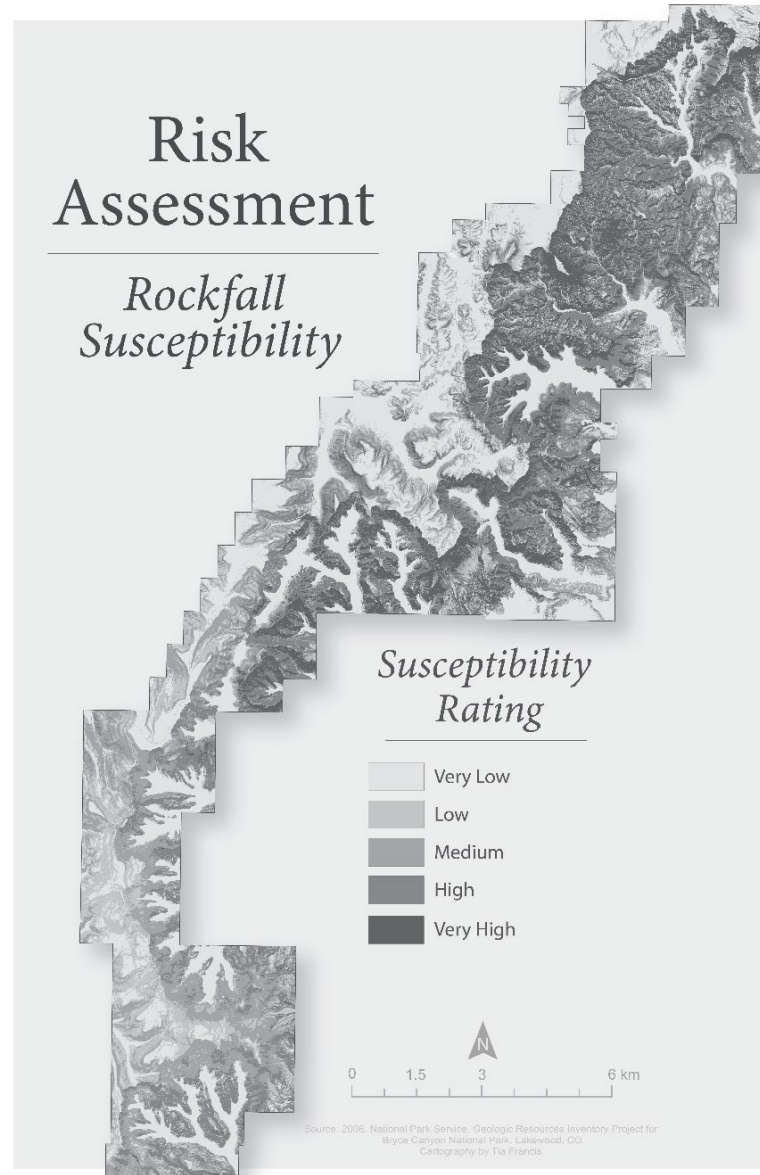
Figure 5.13: Rockfall susceptibility map produced from the fuzzy logic model, with dark gray areas depicting very high-risk areas and light gray areas depicting very low-risk areas. Output from the model was visualized in Adobe Illustrator. (Cartography by Tia Francis).

Chapter 6: Discussion

The purpose of this study was to explore the dichotomy between realistic and perceived risk and the integration of these two paradigms under a holistic risk assessment framework. To do so, this study assessed risk perception using Likert scales, explored the effect of demographics on risk perceptions, and estimated realistic risk of two prominent geohazards.

Results found that participants correctly perceived BRCA as a relatively safe landscape, however, their perception of individual hazard items revealed a significant perception gap for certain items. Demographic analyses revealed that age and race significantly affected overall risk perceptions, while gender and hiking frequency affected perceptions of potential hazardous events. The level of attained education did not affect either overall risk perceptions or the perceptions of individual items. Finally, estimations of realistic risk identified the main amphitheater as high and very high risk for both landslides and rockfalls. Additionally, the landslide/slumping model estimated that the southern section of the park was also at high and very high risk, while the rockfall model forecasted the northern section of the park as high and very high risk.

The remainder of this section delves into the results presented above and attempts to explain these patterns and their importance toward creating a dynamic risk assessment.

6.1 Perception Surveys

Overall, participants found BRCA to be a safe landscape. Generally, their assessment was justified, however, several caveats must be explored. As briefly mentioned in section 5.1, less than 1% of visitors were involved in SAR operations. However, between 2014 and 2017 the number of SAR operations substantially increased from 19 operations to 86 (Carlisle, 2018). Naturally, the increase in SAR operations corresponds with an increase in visitation numbers,

however, as visitation doubled in this period SAR operations tripled. If this trend continues in future years, then BRCA would reach a similar visitation to the SAR operation ratio as the Grand Canyon, with 290 operations for 6 million visitors annually (NPS, 2018a).

This perception of safeness – and other attitudes reflected on the Likert-scaled questions – may be explained through the comment section of the survey, which revealed three primary attitudes participants held towards safety: a) reliance on personal skills to navigate risky situations, b) reliance on the NPS's SAR resources or c) unfamiliarity with the park. Many participants expressed self-preservation and wilderness skills as important in determining safety. As summarized by one respondent's comments, "All areas could be dangerous. Be smart, pay attention and you will be safe." Another, blunter comment stated that "I do not think there are any hazards unless a person is careless, stupid, or ignorant!" As discussed by Slovic thoroughly under the psychometric paradigm, these comments suggest that many participants felt the risks they faced were controllable and known (Slovic & Weber, 2002).

On the other hand, several respondents commented on the managerial influence of the park service, indicating trust in officials and administration. These comments may be tied indirectly to reliance and trust in the NPS SAR staff, should a hazard occur. According to one participant, "The park is very well maintained and seems really safe!", while another remarked, "The forest service [sic] do a great job on maintenance." In addition to the statements written in the respondents' comment section, several participants verbally expressed during data collection that they were not concerned about safety due to the presence of NPS SAR staff. Alternatively, many participants indicated that they did not know the park well enough to accurately judge its riskiness, such as "Not enough time in park." Although prior research typically suggested that lack of knowledge results in heightened risk awareness (Slovic & Weber, 2002), this was not the

case in BRCA. Instead, based on first impressions, many participants who indicated they did not know the park well enough to judge also indicated that they felt safe. For example, one participant remarked, "I've just started a trip, it does not look dangerous."

Although using the assumptions of the psychometric paradigm might lead readers to assume participants who just arrived should experience higher risk perceptions, lack of knowledge regarding a landscape does not necessarily reflect a perceived lack of knowledge regarding risks. Additionally, trust in authorities can produce lowered risk perceptions despite a lack of knowledge, especially when combined with the tendency to place higher levels of trust in authorities that conduct search and aid operations (Bronfman et al., 2016). Although there is no empirical data from this survey to affirm whether or not visitors trusted NPS staff and personnel, several participants indicated a high level of trust in the National Park Service through the comment section.

To further this point, visitor surveys conducted by the NPS and the University of Idaho (Holmes et al., 2009) found that 92% of visitors rated the quality of assistance from park staff as good or very good, and 97% of visitors rated the condition of trails as good or very good (Holmes et al., 2009). Additionally, only 22% of visitors indicated that something detracted from their enjoyment of their visit, with many citing crowding as the main detraction. Although neither this survey nor the NPS survey (2009) directly assesses trust in communicating or managerial institutions, the previously discussed comments and ratings above indicated positive feelings towards staff - or authority figures in this setting - positive experiences with hiking trails, and an overall positive experience. Given the available data, it is reasonable to use these positive ratings as a proxy measure of trust toward park administrators and staff.

6.1.1 Likert Items vs. SAR Incidences

Although participants fared well in perceiving the overall risk of visiting BRCA, this perceptiveness faltered on many of the individual Likert items. According to the safety page of the BRCA website (NPS, 2016), the top nine hazards that injure visitors are as follows:

1. Bad Choice of Footwear
2. Over-exertion
3. Leaving the trail
4. Dehydration
5. Lightning
6. Ignoring Extreme Weather
7. Feeding wildlife
8. Cimbing/sliding down cliffs
9. Unsafe driving

As discussed in section 5.1.2, lightning was severely underestimated by many participants. This underestimation is illustrated by a quote overheard while administering surveys, wherein a young woman remarked that she was not concerned about lightning since the warning sign she saw said "only" six people had died from it since 1928. Despite this lack of concern, a woman was killed by a lightning strike in 2011 and another seriously injured in 2014 in BRCA alone (Repanshek, 2011; Thompson, 2014). Getting lost, feeding wildlife, and dehydration all received moderate to high Likert ratings when compared to the mean ratings of other Likert items (see table 4.1). However, even if these ratings are comparatively moderate to high, their means still suggest that participants were only slightly to somewhat concerned by three of the park's biggest hazards.

To further this point, many participants identified slipping/falling into the canyon as a significant concern in both Likert scaled questions and the comment section of the survey. However, comments did not consider or mention intentional climbing or sliding. Many participants clarified their concerns as a lack of railings and tourists who stand too close to the

cliff edge, indicating a fear of accidentally falling. In addition to the list above, the NPS' official

twitter account quoted one rescued visitor as saying:

> "There was a little path down to it so I thought it was fine, and I scooted forward about an
> inch or two, then the rocks just went out from underneath me and I started sliding all the
> way down to the edge of a 20-ft cliff. It was the scariest moment of my life."
> - Bryce Canyon NP (2019)

A follow-up tweet from the park explained that social trails will always pose a risk and

reinforced the theme that fall-related injuries are often a product of climbing formations and

following social trails, rather than accidentally falling or slipping from the rim.

Additionally, as discussed in section 5.1.2, a significant perception gap was revealed

regarding the earthquake item. This gap was also reflected in the mean ratings regarding possible

rockfall/landslide events, which indicated participants were slightly concerned by mass wasting

events. Despite this, BRCA is a prime landscape for mass wasting, with many examples in the

park's recent history. The Navajo Loop and Wall Street – a section of the Navajo Loop Trails –

are especially susceptible, with a decades-long record of rockfalls and landslides (Baril et al.,

2018; Greco, 2005). BRCA staff close sections of the trail multiple times each year and the trail

has been relocated multiple times with little mitigative impact (Greco, 2005).

In the winter of 2004-2005, abnormally high precipitation caused rockfalls, landslides,

and debris flows that caused deterioration to many of the park's trail. The damage to The Navajo

Loop Trail was so extensive that NPS staff from the Geologic Resources Division conducted a

geomorphological risk assessment of the trail (Greco, 2005). However, majors rockfalls

continued to occur in 2006, 2011, 2012, and 2016 (Baril et al., 2018). The 2006 rockfall was

described in a news release by the NPS as follows:

> "The rock debris covers an area roughly 60 feet long, 15 feet deep and 15 feet wide.
> There is approximately 400-500 tons of rock in this area. The rocks range in size, the

largest being the dimensions of a midsized car."
-    NPS, 2006

In 2010, a small rockfall occurred in the Navajo Loop Trail that trapped two hikers and caused minor injuries (NPS, 2010). In 2016, the NPS reported another rockfall in the trail loop, describing it as "thousands of pounds of limestone," (National Parks Traveler Staff, 2016). Most recently, the Navajo Loop Trail was closed on March 5, 2020 due to the collapse of a retaining wall (Bryce Canyon National Park, 2020). In addition to the rapid deterioration of the Navajo Loop trail and sidewalls, it is not uncommon for all under-the-rim trails to present mass wasting risks (Baril et al., 2018). Further known mass wasting events outside of the Navajo Loop Trail system include a rockfall and landslide above the Peak-a-boo connector in 2013, a 2015 rockfall from a heavily weathered hoodoo that closed the Fairyland Loop Trail, and small-scale mass wasting along the Mossy Cave Trail in 2014 and 2015 (Baril et al., 2018). In addition to the mass wasting events the main amphitheater experiences, Highway 12 has been closed several times for landslide and rockfall events – once in 2015 and 2017. The 2017 Landslide was so severe that the NPS is undertaking a safety improvement project, which will include slope stabilization and drainage rerouting. Of course, these events are hardly representative of all mass wasting events within BRCA, as BRCA staff only record events that effect visitor services, leaving many minor or off-trail events unrecorded (Baril et al., 2018).

In conclusion, while participants seemed to understand the overall risk presented in BRCA, a perception gap exists between perceived and realistic risk when assessing individual hazard events. This pattern is repeated in the following section, which addresses the perception of anomalies between significant demographic groups.

6.1.2 Statistical Analyses

Results based on the statistical analyses revealed that Likert findings were significantly different between age and racial groups, a result that simultaneously confirm and rebuke prior studies. This study found that as age increases, risk perceptions decrease. Additionally, Asian participants found the park significantly riskier when compared to white participants. However, male and female participants found BRCA equally risky, which is contrary to much of the risk perception literature. This is because of "the white male effect" – a phenomenon studied extensively where white males tend to have lower perceptions of risk when compared to white females and non-white men and women (Finucane et al., 2000). These white males also tend to have a higher than average level of education and income and are politically conservative. Ironically, young, white men are also the demographic most likely to be deployed for a SAR operation (Carlisle, 2018).

Given the *white male effect* and the perception that older adults are perceived as more cautious and avoidant of risk compared to younger counterparts, the finding that younger participants found the park riskier than older participants is counterintuitive (Bonem, 2015). However, research has shown that the correlation between age and risk perceptions is mixed. While multiple studies have shown that older adults are less concerned by a wide variety of hazards that range a variety of risk domains (i.e. smoking, gambling, aviation accidents, skin cancer, fires in home, etc.; Bonem et al., 2015), it has also been shown that older adults are less inclined to participate in risky behaviors. This inclination to avoid risky behaviors has been interpreted as a heightened level of risk perceptions, however, concern regarding a hazard and behavior do not always correlate (Slovic, 1992). Perhaps older adults avoid certain activities,

limiting the risk they are exposed to. In turn, since their exposure is limited, perhaps they are not concerned by the risk the activity poses.

In one study, age had a significant effect on perceptions for all hazards except skin cancer (Savage, 1993), suggesting that perceived personal exposure was the leading determinator of risk perceptions when isolating age. To extend this line of thought to the current study, perhaps older participants rated their concern as lower because they were less likely to stand close to the canyon rim, less likely to go hiking or backpacking, and more likely to spend their time sightseeing. In doing so, this would limit their exposure to many of the hazards listed on the survey (i.e. dehydration, rockfall/landslide, trail substrate collapse, slipping/falling from rim, etc.).

The lack of differences between male and female respondents was surprising. However, while the *white male effect* seems intuitive, recent research has shown that it is more complex than originally thought (Kahan et al., 2007; Palmer, 2010; Rivers et al., 2010). Recent research suggests that political ideologies, individual worldviews, and attitudes towards the environment can affect the *white male effect* both within white males and nonwhite male groups. This notion is supported by the original authors who hypothesized the *white male effect*, as they admitted the effect was due to a subsection (1/3) of white males with the above characteristics (Finucane et al., 2000). Due to this, several researchers believe gender is not a primary determinant of risk perceptions, but rather gender is strongly correlated with attitudes that do affect perceptions (Kahan et al., 2007; Palmer, 2010; Rivers et al., 2010).

Of these characteristics, one study was able to isolate politically conservative ideologies as the driving force behind the *white male effect*, particularly in terms of environmental risks (McCright & Dunlap, 2012). Thus, perhaps the lack of difference between males and females in

this study can be attributed to political ideology, wherein participants tended to be liberal/progressive and thus mitigated the white male effect. Although there is no empirical data directly supporting that liberals/progressives tend to visit national parks more than conservative individuals, there is data suggesting that when liberals/progressives travel they travel further and tend to visit cities such as Denver, Seattle, and Park City (WY). Alternatively, conservative groups tend to visit Branson (MO), Springfield (MO), Kansas City, and Little Rock (Chinni, 2019).

Although ethnic groups were not significantly different in overall risk perceptions when comparing all four groups, isolating Asian and White respondents revealed significant differences. Significant differences were also found across multiple individual Likert items. While the *white male effect* could be used to explain this, this is unlikely given the above discussion. Additionally, the *white male effect* does not explain the lack of difference found between white participants and all other non-white participants. While the explanation for this result isn't well understood, the key may be found in cultural differences, which are often associated with ethnicity. One study that explored the intersection of nationality and risk perceptions found that American and Argentinian participants had similar risk perceptions, while Japanese participants had significantly higher risk perceptions across all risk domains (Gierlach et al., 2010). Although Japanese perceptions of risk cannot be generalized to all Asian populations – as Argentinian perceptions cannot be generalized to all Hispanic/Latino populations and American perceptions cannot be generalized to all white populations – perhaps there was a cultural influencer which led to increased risk perceptions.

In addition to demographic analyses, measures of experience showed little correlation with overall risk perceptions. Although prior experience with a hazard is significantly correlated

93

with risk perceptions, there is no literature on whether experience with an activity or location heightens or diminishes perceptions. However, as with many of the demographic analyses, these measures of experience did correlate with individual items. For the hoodoo topple item, which was negatively correlated with hiking/backpacking frequency, this makes sense as hoodoo topple was priming mechanism used for comparison. The correlation between hiking/backpacking frequency and the earthquake item is considerably less intuitive. However, the correlations between number of visits and the slipping/falling into canyon and wildlife items seem explainable. Slipping or falling into the canyon is a rare occurrence, despite high concern levels. Perhaps repeated visits to the park confirms that, despite steep slopes and drop-offs, losing one's footing and accidentally tumbling to one's death is rare. Similarly, although wildlife is a concern in BRCA, many of the larger and dangerous wildlife (bears, mountain lions, etc.) avoid the crowded plateau top and rim trails. In fact, very few bears or mountain lions are spotted within the park despite their known presence. Due to this, perhaps perceptions of risk regarding wildlife decrease as visitors continue to return with no wildlife sightings.

The effect of demographic data and experience on risk perceptions is wide and varied within BRCA, with multiple theories needed to explain the effects of different demographic categories. The effects of demographics are known to be influential but not well understood. Nonetheless, understanding these interactions is an important facet of geospatial risk perceptions and holistic risk assessment efforts, since understanding risk perceptions of the general population is only half of the battle. Understanding which demographic groups may be more inclined to inaccurate risk perceptions and how these groups affect or sway the perceptions of overall populations is important for mitigation efforts. This allows BRCA staff to understand

which populations may be at greater risk due to inaccurate perceptions and which communities should be targeted in educational outreaches.

6.1.3 Mapping

When participants were asked to map areas they felt were dangerous within the park, most marked the overlooks above, and trails within the main amphitheater, while less than 5% of responses marked overlooks above or trails within the northern or southern sections of the park. When comparing the results of this mapping section to visitation numbers, there was a general trend where participants tended to rate the most widely visited overlooks as the most dangerous. This could be because these overlooks are also considered crowded (Holmes et al., 2009), which may increase perceived risk. Alternatively, this trend could also be explained by salience, where overlooks respondents visited were more familiar. Thus, they may have felt more comfortable rating them as dangerous versus overlooks they did not visit (Sponarski et al., 2015).

6.2 Risk Assessment Analysis

6.2.1 Landslide Assessment

The fuzzy logic model categorized many of the high and very high-risk cells in the main amphitheater and southern section of the park, which is consistent with hazard inventories and NPS reports of landslides within the park. These high and very high cells tended to be in Tropic Shale or pink limestone member of the Claron Formation, under the rim of the plateau, on very steep slopes, and in high precipitation areas. Low and very low cells tended to be found in alluvial deposits in ephemeral channels, on the plateau top, and on gradual or flat slopes. Traditionally, the literature identifies lithology, slope, and precipitation as the primary influencers of landslide occurrence, indicating the success of the presented model.

6.2.2 Rockfall Assessment

For the rockfall assessment, high and very high-risk cells were found in the main amphitheater and northern section of the park. These areas are consistent with NPS reports and satellite imagery of scree slopes in the park, which are indicative of rockfall activity. High and very high-risk cells are associated with areas of large temperature fluctuations and incredibly steep slopes, along with the pink limestone member of the Claron Formation, colluvial deposits, and the Boat Mesa Formation. These cells also tended to be below the canyon rim and surrounding roads and trails. Low and very low-risk cells were associated with the plateau top, areas with small temperature fluctuations and small slope gradients, along with alluvial channels and the Tropic Shale. As with landslides, these factors are consistent with previous studies, where slope, lithology, and temperature variations are the primary determinants of rockfall occurrence.

6.3 Limitations

Several survey limitations exist and while they do not diminish the results of this study, they must be thoroughly discussed. Primarily, this study – as all risk perception studies do – relies on self-reporting and measures perceptions of risk as a Likert scale from 1 to 5 representing levels of concern. Some studies operationalize risk perceptions as the tendency to engage in or avoid risky behavior, even though research shows that one may consider a behavior risky but still engage in it (Slovic, 1992). Other studies operationalize risk perceptions as levels of worry, danger, or degree of an issue being a problem. However, no matter the method of operationalization, all risk perceptions contain a certain level of error inherent to self-reporting and Likert scale methodologies.

Mean responses for Likert-scaled questions were compared against the available SAR data. However, the data available for comparison were limited, as it relied on self-reporting from each park unit. Additionally, while it did include some basic demographic information, the data were compiled on a nation-wide scale. This means that the data did not include information on what event types (i.e dehydration) deployed SAR operations or the specific localities of SAR events within parks. Additionally, this dataset only included data from the year of 2017, meaning it may not fully represent patterns apparent from analyzing data across a larger temporal scale. A Freedom of Information Act request for SAR data specific to BRCA from 2010 to 2018 was submitted to the NPS in November 2019, however, as of writing (March 2020) this request has not been fulfilled.

Due to this lack of data, readers should be careful when comparing the results from the mapping portion of the survey to the two fuzzy logic outputs. This is because respondents considered a wide variety of hazards when marking 'X's that ranged from automobile accidents to scheduled burnings, however, the risk assessment models only considered landslides and rockfall risk within its assessment. If the data had been available, results assessing the realistic risk of a wider variety of hazards would have been produced. This is a limitation with which future studies in BRCA could be expanded on (discussed in further detail in section 6.4).

Finally, fuzzy logic models depend on the subjectivity of expert opinions. Although input from NPS and BRCA staff was requested, this information was not obtained, leaving the researchers to determine relevant variables using the prior studies and limited field observations. Although the results were satisfactory and held up to qualitative validation, this introduces a level of error. However, other risk assessment methods – primarily the statistical method – also rely on subjective field interpretations and introduce similar levels of bias.

6.4 Future Research

Specific to BRCA, studies should continue to assess perceptions as visitation numbers increase. Additionally, future studies should attempt to directly compare realistic risk and perceptions of risk. Although the spatial risk of landslides and rockfalls was determined, this does not capture the entire breadth of risks visitors face within the park. Specifically, my analysis was not able to account for human-environmental risks due to the lack of specific SAR records from the park. Future studies could remedy by obtaining SAR records and mapping results, allowing for direct comparison between the mapping section of the survey. Another measure of realistic risk could be obtained by distributing surveys to park personal as a proxy measure of realistic risk. The author was unable to do this due to temporal and financial constraints.

Future research should also continue to refine and adapt the author's mass wasting models for large-scale modeling. Due to time constraints, this model was not operationalized using ESRI's modelbuilder, however, doing so would expand the replicability of the model. Additionally, using modelbuilder would allow for this methodology to be applied to similarly arid regional-scale study sites. Using this, further research could refine the scale of this model by focusing on areas critical for visitor services (i.e. popular trails, lodging, etc.).

More broadly, future research should be devoted to understanding the effects of demographics on risk perception. Although it is widely understood that demographics affect risk perceptions, the nature of this effect is poorly understood and multiple theories exist for each demographic category. Additionally, little to no research investigates the association between event type within a risk domain and demographics, instead focusing on differences between risk domains. This was not discussed at length in section 5.1.2 because there were little prior studies that could explain this phenomenon. However, the results of this study support further

investigation. For example, overall risk perceptions of BRCA tended to be accurate, however, individual Likert items indicated a broader gap between real and perceived risks in BRCA. Furthermore, males and females rated general risk perceptions similarly on all items except when measuring concern of earthquakes. Conversely, Asian participants repeatedly rated hazards as more concerning than white participants, except for trail substrate collapse, rockfall/landslides, flash flooding, and lightning. This indicates that even within broader, general trends, ratings are influenced by event type in a way that has yet to be explored.

Additionally, further research should be devoted to creating holistic risk assessments – this includes both multi-hazard assessments and assessments which integrate risk perceptions. Very few study sites are susceptible to only one hazard and future risk assessments should work to include multi-hazard approaches. This is the first study of its kind that combined an assessment of risk perceptions and realistic risk under one methodological framework despite, as discussed in Chapter 3, their interdependence on one another.

Chapter 7: Conclusion and Implications

This study aimed to pioneer a holistic risk assessment that addressed perceived and realistic risk in a remote environment and among a vulnerable population. This project successfully assessed risk perceptions, compared those perceptions to limited SAR data and hazard inventories, identified gaps in perceptions among demographic groups, and estimated areas of the park at risk for rockfalls and landslides. This study is one of the first to thoroughly assess perceptions and model risky areas within BRCA and certainly the first to do so using a geospatial framework and visualization techniques.

Although respondents considered the park to be relatively safe, increasing visitation numbers in the coming years could significantly alter the number of deployed SAR operations. If visitation trends from 2014 to 2017 continue, BRCA could reach a similar SAR operation-to-visitor ratio as the Grand Canyon (NPS, 2018a). If this is the case, understanding the perceptions of visitors and the areas where they could face danger will be imperative to visitor safety.

Demographic differences in perceived risk were found between age and ethnic groups, with gender, educational attainment, and experience having little to no effect on perceptions. As age increased, perceptions decreased. This result is hypothesized to be a result of exposure, wherein older visitors refrain from many of the activities that would expose them to environmental risks. Asian participants also found the park and multiple Likert items to be riskier than white participants, which may be a result of cultural differences (Gierlach et al., 2010).

Generally, visitors categorized areas with high visitation as spatially dangerous areas. This categorization partially overlapped with the risk assessment outputs, as all three maps identified the main amphitheater as risky. However, few participants categorized the Northern or

100

Southern sections of the park as having risky areas, whereas the landslide assessment found the Southern section risky and the rockfall assessment found the Northern section risky. In this, both assessments categorized steep slopes and areas identified as the pink limestone of the Claron Formation as risky. Climatic and other topographic variables were also significant for both assessments to varying degrees.

To summarize, the main findings follow:

- Perceived Risk:
  - As the age of participants increased, concern regarding general and specific risks decreased.
  - Asian participants perceived BRCA as significantly riskier than white participants.
  - Participants tended to identify the most popular overlooks and trails as the most dangerous
- Realistic Risk as determined by the two GIS models:
  - The main amphitheater is very high and high risk for both landslides and rockfalls.
  - Most of the northern section of the park is at very high or high risk for rockfalls, while most of the southern section is at very high or high risk of landslides.

Future research should directly compare Likert data to SAR data for BRCA, as the author was unable to do this given time constraints and bureaucratic complications. More broadly, researchers should continue to study the effect of demographics on risk perceptions within National Parks and further strides should be made in bridging the divide between risk perception studies and realistic risk assessments.

In addition to suggestions for future research, the NPS should continue to standardize SAR operation logs and their dissemination to the public. Currently, SAR operations are logged as anecdotal incident reports, meaning any site-specific analyses ranging over multiple years would require obtaining and digitizing each incident report into excel by hand. Although the NPS has publicized some of their SAR data through ArcGIS Online dashboards for select years, these datasets are missing information of interest to researchers. Namely, these dashboards aggregate data by park unit, which eliminates the ability to easily obtain specific case details (i.e. location of incident, type of SAR event, etc.). Thus, these dashboards cannot help researchers understand what types of events are deploying operations or which localities within parks are high risk for visitors.

Specific to BRCA, staff should continue to educate visitors through brochures, ranger programs, and preventative Search and Rescue (PSAR) personnel. Additional materials on lightning strike risks and being aware of surroundings to mitigate rockfall risks should be produced. Currently, all PSAR staff at BRCA are unpaid volunteers and work in long, two-person shifts. However, providing paid positions and increasing PSAR personnel numbers may help combat rising SAR operation cases. Although the effectiveness of BRCA's PSAR program is unknown, the positive effects of PSAR at Grand Canyon National Park is well documented, where all PSAR personnel are paid (NPS, 2017). Additionally, BRCA staff should continue to stabilize areas at high risk for mass wasting events. Currently, mitigation techniques include monitoring triggering parameters – primarily precipitation – and closing trails when conditions become unstable. However, geomorphological hillslope stabilization projects may alleviate some of the uncertainty inherent in this mitigative technique. Finally, at least preliminary records should be kept for as many mass wasting events within the park as possible – not just those that

effect visitor services. Doing so would allow researchers to better identify the parameters which contribute to mass wasting in the park, such as elevation or lithology.

While the NPS and BRCA staff go to great lengths to ensure the safety of visitors, more can always be done and understood. Knowledge and understanding of the different facets of risk is paramount for protecting vulnerable populations, such as tourists within an unfamiliar and remote landscape. It is only by understanding these variables that the NPS can properly mitigate risks and continue to promote their units as a safe destination for families, tourists, and travelers.

Furthermore, this research provides an important step forward in contributing to the field of risk quantification and demonstrating that the frameworks of risk perception and risk assessment research can be utilized together. Most importantly, this study emphasizes that when investigating risk, land managers, park superintendents, city planners, and other authority figures need to consider both perceptions of risk and the modeling of realistic risk when designing or contracting studies. As discussed throughout this paper, the quantification of perceived risk and so-called realistic risk are inextricably intertwined as two sides of the same coin. Ignoring one method of quantification in favor of the other does not provide the full picture, as understanding where realistic risk lies may not be helpful if public perceptions of risk significantly differ. Ignoring one side of risk quantification also leaves decision-makers unaware of the full breadth of mitigative actions that need to be taken to protect their communities. Due to this, the complete separation of risk perception research from risk assessment research is short-sighted at its best and deadly at its worst.

Chapter 8: References

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107

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Chapter 9. Appendices
Appendix A: Survey Instruments and Approvals

Appendix A1: University of Arkansas IRB approval letter.

UNIVERSITY OF ARKANSAS

To:	Tia Marie Francis BELL 4188
From:	Douglas James Adams, Chair IRB Committee
Date:	04/01/2019
Action:	**Exemption Granted**
Action Date:	04/01/2019
Protocol #:	1812162574
Study Title:	Geologies of Danger: A geospatial analysis at the intersections of geology, landscape, and risk perceptions

The above-referenced protocol has been determined to be exempt.

If you wish to make any modifications in the approved protocol that may affect the level of risk to your participants, you must seek approval prior to implementing those changes. All modifications must provide sufficient detail to assess the impact of the change.

If you have any questions or need any assistance from the IRB, please contact the IRB Coordinator at 109 MLKG Building, 5-2208, or irb@uark.edu.

cc: Thomas R Paradise, Investigator

SCIENTIFIC RESEARCH AND COLLECTING PERMIT

Grants permission in accordance with the attached general and special conditions

United States Department of the Interior National Park Service

Bryce Canyon

Study#: BRCA-00080
Permit#: BRCA-2019-SCI-0001
Start Date: May 15, 2019
Expiration Date: May 22, 2019
Coop Agreement#:
Optional Park Code:

Name of principal investigator:
Name: Tia Francis Phone: 4795754359 Email: tmfranci@uark.edu

Name of institution represented:
University of Arkansas

Additional investigators or key field assistants:
Name: Thomas Paradise Phone: 4795754359 Email: paradise@uark.edu

Study Title:
Geologies of Danger: A Geospatial Analysis of Geologic Hazards and Risk Perceptions in Bryce Canyon National Park

Purpose of study:
The purpose of the proposed study is to analyze risk perceptions of visitors at BCNP via surveys (attached under the "documents" heading). These surveys will be used for three purposes: to statistically analyze the gap between realistic and perceived risk at BCNP, to create zonation maps comparing high and low risk areas in terms of perceived and realistic risk, and to link perceptions of risk to the park's geomorphological landscape. Products of this research will include identification of high risk areas in BCNP, identification of visitor misconceptions regarding geologic risks, and the first study to conclusively link varying geomorphological features to risk perceptions. These products are not only a worthwhile contribution to the scientific literature, but also a useful tool for future NPS decisions in construction and land management decisions.

Subject/Discipline:
Geology / General
Geomorphology / Surface Processes
Recreation / Aesthetics
Social Science

Locations authorized:
Administration of the surveys will be limited to the designated overlooks along Highway 63. Surveys will be administered at all 15 overlooks, which are identified and labeled in the attached survey. No surveys will be administered on trails or in backcountry/remote areas.

*Park Note- PI has submitted a revised proposal which reduces the number of survey locations to 6 identified overlooks. The PI must adhere to this revision. See Specific Conditions and Requirements section for further limitations on survey locations.

Transportation method to research site(s):
Overlook sites will be accessed using either a personal vehicle or the park's shuttle system, depending on the overlook.

Collection of the following specimens or materials, quantities, and any limitations on collecting:
Copies of all data and associated materials must be submitted to the park's museum curator:
Miriam Watson,
BRCA/CEBR/ZION Museum Curator
Zion National Park
State Route 9
Springdale, UT 84767
Phone: (435) 772-0146
Fax: (435) 772-3426
Miriam_Watson@nps.gov

Please see SOPs on Curation Research Requirements for guidance.

Name of repository for specimens or sample materials if applicable:

NPS General Conditions for Scientific Research and Collecting Permit (available at the RPRS HELP page) apply to this permit. The following specific conditions or restrictions, and any attached conditions, also apply to this permit:

Appendix A2: National Park Service research permit, page 2.

•This permit must be carried by the investigator at all times while conducting research in the park.
•Investigators must keep park staff informed of exact dates and times they intend to conduct research within the park. Investigators must also check in with their respective park contacts upon their initial arrival.
•Additional National Environmental Protection Act (NEPA) compliance, Section 7 consultation with the US Fish and Wildlife Service, and compliance with Section 106 of the National Historic Preservations Act (NHPA) may need to be completed prior to the implementation of any research project.
•An annual report of findings must be submitted through the Research Permit and Reporting System (RPRS) by January 31 of each year following field work.
•Any data generated through research in the park must be shared with the park. See Standard Operating Procedures on Curation Research Requirements for guidance.
•Hardcopies of any reports or publications (theses, dissertations, journal articles, etc.) resulting from this permitted research shall be provided to BRCA/CEBR/ZION Museum Curator, Zion National Park, State Route 9, Springdale, UT 84767. See Standard Operating Procedures on Curation Research Requirements for guidance.
•Specimens will not be collected unless prior approval has been granted. A signed Appendix A form is required to be on file prior to the collection of specimens that are not consumed or destroyed as a result of research activities.
•Any unusual wildlife sightings or encounters will be reported to park staff.

In addition to the Specific Conditions and Restrictions, the park requires the PI of this study to observe the following:
-Surveys must not impede park visitors from accessing viewpoints, trails, or other services. Surveys should be conducted away from overlooks and trail heads. Please use open areas, such as parking lots or concourses to conduct surveys. Do not survey near ranger program meeting places 30 minutes before to 30 minutes following a program.
-Use park shuttle to access viewpoints when available.
-If the number of target surveys is not met at the conclusion of the research period, PI must request an extension from the park. Do not exceed allotted time without park permission.
-The PI must make clear to participants this survey is not funded, designed, or conducted in any way by the federal government.

Recommended by park staff(name and title):	Reviewed by Collections Manager:
Eric Vasquez Biological Science Technician	Yes ✓ No____
Approved by park official:	Date Approved:
Knide C. Mazzu	*4/17/19*
Title:	
Park Superintendent	

I Agree To All Conditions And Restrictions Of this Permit As Specified
(Not valid unless signed and dated by the principal investigator)

_____   _____
(Principal investigator's signature)   (Date)

THIS PERMIT AND ATTACHED CONDITIONS AND RESTRICTIONS MUST BE CARRIED AT ALL TIMES WHILE CONDUCTING RESEARCH ACTIVITIES IN THE DESIGNATED PARK(S)

Outdoor Recreation Risk Perception Survey

UNIVERSITY OF ARKANSAS

GEOSCIENCES

Gender: ☐Male ☐Female ☐Other: _____   Status: ☐Single ☐Married ☐Widowed ☐Divorced

Age in years: _____   Current Residence: City, State/City, Country: _____

Completed Education: ☐High school degree/GED ☐Associate Degree ☐Bachelor's degree ☐Graduate degree

☐Other: _____

- -

1. Are you a native English speaker? ☐Yes ☐No

    If not, how many years have you been speaking/reading/studying English? _____

- -

2. How many times have you visited Bryce Canyon National Park (BRCA)?   ☐0 ☐1 ☐3 ☐4 ☐5+

3. On average, how often do you hike and/or backpack?

☐ 1-3 times per year ☐2-4 times per every six months ☐1-3 times per month ☐1+ times per week

4. When preparing for a hike, what injuries/illnesses/natural hazards do you consider?

    _____

    _____

- -

Please circle the number that represents your concern of the following risks in BRCA:
1=not at all concerned, 2=slightly concerned, 3=somewhat concerned, 4=moderately concerned, 5=extremely concerned

1. Hoodoo topple *(concussion, bodily injury, or death)*	1	2	3	4	5
2. Trail substrate collapse *(slipping/falling, suffocation, bodily injury, or death)*	1	2	3	4	5
3. Rock fall/landslide *(concussion, suffocation, bodily injury, or death)*	1	2	3	4	5
4. Flash flooding *(drowning, bodily injury, or death)*	1	2	3	4	5
5. Earthquake *(slipping/falling, substrate collapse, bodily injury, or death)*	1	2	3	4	5
6. Lightning strike *(third degree burns, bodily injury, or death)*	1	2	3	4	5
7. Getting lost *(dehydration, heat stroke, starvation, or death)*	1	2	3	4	5
8. Slipping/falling into canyon *(concussion, bodily injury, or death)*	1	2	3	4	5
9. Dehydration/heat stroke *(cardiac arrest or death)*	1	2	3	4	5
10. Wildlife (mountain lions, bears, snakes etc.) *(venomous bite, mauling, or death)*	1	2	3	4	5

Please note a mistake on Question 2, section 3. This question should read "How many times have you previously visited Bryce Canyon National Park (BRCA)?" and "2" should be an option. This mistake was remedied by informing participants at the beginning of the survey and instructing them to write in a "2" if applicable.

BRYCE CANYON
NATIONAL PARK

♦ Points of Interest
● Vista Points
— Highways
— Canyon Rim
-- Park Boundary
-- Trails

On this map, please mark an 'X' on the areas you think are the most dangerous.

Mark up to five 'X's.

Comments:

_____

_____

_____

_____

_____

_____

_____

_____

Survey Administered at:

Appendix B: Further Tables with Results for all Statistical Analyses Conducted

Appendix B1: Table of results from all Spearman Rank-Order Correlations Tests for Age. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

Dependent Variable	ρ	S	p
Hoodoo Topple	-.13	2512800	.04*
Trail Substrate Collapse	-.15	2554100	.02*
Rockfall/Landslide	-.24	2742100	.00002 ***
Flash Flooding	-.11	2470300	.08
Earthquake	-.18	2625800	.005**
Lightning Strike	.044	2120800	.450
Getting Lost	-.13	2509200	.04*
Slipping/Falling into Canyon	-.18	2617400	.005**
Dehydration/stroke	-.13	2514900	.04*
Wildlife	-.18	2615600	.006**

Appendix B2: Table of results from all Wilcox tests for gender, where Sd = Standard deviation. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

Dependent Variable	W	p	Mean Female group	Sd Female group	Mean Male group	Sd Male group
Hoodoo Topple	6324.5	.75	1.72	1.08	1.65	.97
Trail Substrate Collapse	6057.5	.39	2.25	1.23	2.06	1.01
Rockfall/Landslide	6291.5	.72	2.25	.99	2.22	1.07
Flash Flooding	6975	.29	2.04	1.07	2.20	1.15
Earthquake	5702.5	.047*	1.44	.79	1.22	.47
Lightning Strike	6702	.62	1.90	1.11	1.92	1.02
Getting Lost	6134	.49	2.49	1.27	2.36	1.21
Slipping/Falling into Canyon	6137.5	.50	2.80	1.30	2.65	1.12
Dehydration/stroke	6289	.72	2.65	1.27	2.58	1.19
Wildlife	6207.5	.58	2.20	1.23	2.07	1.08

Appendix B3: Table of results from all Kruskal-Wallace tests for ethnic groups. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

Dependent Variable	χ^2	Df	p
Hoodoo Topple	14.99	4	.005 **
Trail Substrate Collapse	4.43	4	.35
Rockfall/ Landslide	2.90	4	.57
Flash Flooding	3.25	4	.52
Earthquake	15.54	4	.004 **
Lightning Strike	2.09	4	.72
Getting Lost	5.36	4	.25
Slipping/Falling into Canyon	7.39	4	.12
Dehydration/ stroke	8.11	4	.09
Wildlife	7.51	4	.11

Appendix B4: Table of results from Wilcox tests comparing Asian and White participants, where Sd = standard deviation. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

C	W	p	Mean Asian group	Sd Asian group	Mean White group	Sd White group
Hoodoo Topple	2514	.0002***	2.5	1.10	1.63	1.00
Trail Substrate Collapse	2098.5	.09	2.56	1.03	2.15	1.14
Rockfall/Landslide	2049.5	.14	2.62	1.09	2.19	.99
Flash Flooding	2017.5	.19	2.56	1.41	2.07	1.06
Earthquake	2265	.003**	1.81	1.05	1.29	.60
Lightning Strike	1851.5	.51	2.18	1.42	1.88	1.04
Getting Lost	2188	.04*	3	1.15	2.38	1.24
Slipping/Falling into Canyon	2343	.009**	3.5	1.15	2.66	1.23
Dehydration/stroke	2386.5	.005**	3.4	1.15	2.54	1.22
Wildlife	2285	.01*	2.81	1.22	2.08	1.14

Appendix B5: Table of results from all Spearman Rank-Order Correlations Tests for Education.

Dependent Variable	ρ	S	p
Hoodoo Topple	-.057	2687000	.37
Trail Substrate Collapse	.08	2342100	.22
Rockfall/ Landslide	-.03	2618600	.64
Flash Flooding	.06	2368200	.37
Earthquake	-.02	2534300	.74
Lightning Strike	.07	2304700	.27
Getting Lost	.08	2337100	.21
Slipping/Falling into Canyon	.07	2324900	.18
Dehydration/ stroke	-.004	2553000	.95
Wildlife	.07	2352100	.24

Appendix B6: Table of results from all Spearman Rank-Order Correlations Tests for number of previous visits. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

Dependent Variable	ρ	S	p
Hoodoo Topple	-.12	2507100	.07
Trail Substrate Collapse	-.09	2449400	.17
Rockfall/ Landslide	-.11	2492100	.09
Flash Flooding	-.01	2215300	.83
Earthquake	-.08	2420900	.23
Lightning Strike	-.08	2070900	.22
Getting Lost	-.12	2524700	.06
Slipping/Falling into Canyon	-.13	2542700	.04*
Dehydration/ stroke	-.09	2460200	.14
Wildlife	-.19	2662600	.004**

Appendix B7: Table of results from all Spearman Rank-Order Correlations Tests for frequency hiking/backpacking. * = significance at .05 level, ** = significance at .01 level, and *** = significant at .001 level.

Dependent Variable	ρ	S	p
Hoodoo Topple	-.15	2591000	.02 *
Trail Substrate Collapse	-.08	2437600	.19
Rockfall/ Landslide	-.07	2412200	.26
Flash Flooding	-.01	2269800	.88
Earthquake	-.14	2552600	.04 *
Lightning Strike	-.02	2291600	.76
Getting Lost	-.18	2424700	.22
Slipping/Falling into Canyon	-.12	2517700	.06
Dehydration/ stroke	-.05	2368200	.41
Wildlife	-.12	2516500	.06