THESIS

ECONOMIC AND ECOLOGICAL IMPACTS ASSOCIATED WITH RECREATION ON COLORADO FOURTEENERS

Submitted by

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ABSTRACT OF THESIS

ECONOMIC AND ENVIRONMENTAL IMPACTS ASSOCIATED WITH RECREATION ON COLORADO FOURTEENERS

Research has shown that Colorado's 14ers (peaks reaching over 14,000 feet) are extremely popular hiking destinations, with estimates of over 500,000 people visiting the peaks each year. This study simultaneously explores the economic benefits that occur from the seasonal influx of visitors, and the associated costs to the environmental stability of these sensitive alpine areas. Through considering economic and environmental impacts together, this study creates a protocol to assess the environmental impacts on high recreation activity alpine areas such as 14ers. The study site is Quandary Peak, a 14er located just outside Breckenridge, CO. Findings from this study may be utilized by the Forest Service and other public lands management agencies and organizations to aid in establishing and refining recreational use policies.

Economic results show that visitor expenditures and willingness to pay (WTP) values on 14ers are high compared to other nature-based recreation experiences. Additionally, expenditures and WTP values in 2006 compared to 2009 prove to be statistically similar, signifying that this industry is stable during times of a national economic downturn. These findings have positive implications for the economic strength and diversity potential for the surrounding rural communities.

Data from this initial study also serves to address a methodological question of how the verbiage used in dichotomous choice WTP questions affects responses. Results indicate that asking questions *specifically* for an individual, verses a group, affects the WTP values. Correcting for this proves to be difficult, indicating that if researchers want individuals to answer on an individual basis this must be explicitly stated.

To assess current environmental conditions, measurements were made in terms of soil compaction, vegetation cover, carbon and nitrogen content, bulk density and porosity, and soil erosion. Results show that environmental health is generally lowest for sites on trail and on trail margins, indicating that human traffic stresses the stability and health of these areas. Furthermore, impacts are not confined within trail parameters, suggesting potential over-use and congestion of the trails.

The next stage of this study will be to assess the economic and environmental impacts of recreation on another 14er that has different visitation rates. Through such a comparison, a concept of carrying capacity can be developed to determine how increasing or decreasing levels of use influence the economic conditions of surrounding towns and the environmental conditions of the alpine peaks.

TABLE OF CONTENTS

Chapter One: Economic and Environmental Considerations of Alpine Recreation

1.1 Introduction

Nature-based recreation is a growing industry, generating $289 billion annually in retail sales and services across the United States (The Active Outdoor Recreation Report, 2006). Colorado is a particularly attractive place for recreationists, with more than one-third of the land designated as public lands available for camping, hiking, fishing, etc. Particularly, hiking Colorado's alpine peaks, dubbed 14ers because they reach over 14,000 feet, has become an increasingly popular activity. Colorado contains more 14ers than any other state, and visitors from all over the world visit Colorado to take advantage of the various recreational experiences associated with these peaks. According to some estimates, more than 500,000 people visit 14ers each year (Keske-Handley, 2004). Although visitation rates are difficult to confirm and will be addressed in subsequent sections, estimates indicate a trend of increasing recreation use. Some studies have even suggested that 14ers are synonymous with Colorado's identity, and that many visitors feel a sense of "place attachment" to these areas (Blake, 2002; Blake, 2008).

Despite the popularity of these peaks, there is a surprising lack of research focused on Colorado 14ers. In the mid to late 2000's, several articles were published addressing the economic potential of providing access to these areas. An early study by Keske and Loomis in 2007 led to further 14er economic research regarding visitor willingness to pay and trip related expenditures. Overall, results from these initial studies show that visitors have high expenditure values for trip related costs, and additionally, visitors highly value the opportunity to recreate in these alpine areas as represented by a high willingness to pay for the experience. These findings imply that 14er based visitor spending may present an avenue of economic growth for the surrounding rural mountain communities.

Thus, a tradeoff is presented: economic expansion, which is appealing to many local citizens who live and work in these communities, may come at the cost of increasing environmental pressures on these fragile alpine ecosystems. Most 14ers are on public land, and therefore are subject to over-consumption and can become "congestible public goods" (Loomis and Keske, 2009). The public good characteristics of 14ers indicate that consumption, or in this case hiking frequency, is not bound by depletion of the good or property rights. Thus, these areas may be over-used and exasperated environmental pressures may result. As early as the 1960's the challenge of balancing environmental sustainability and human preference was observed by Wagar (1964, p. 20) addressing the definition of carrying capacity as a means to manage to national parks:

> "recreational carrying capacity is a complex matter that requires difficult value judgments and must draw on rather complete statements of the desires of recreationists and the ecology of biotic communities."

There is sparse research published regarding the environmental changes due to human activity, or the ecological carrying capacity of this specific region. Studies by Kedrowski (2006) and Hesse (2000) are the only environmental assessments of these areas, but both studies focused primarily on assessing trail restoration needs based on visual assessments of trail conditions, and lack actual sampling and measurements of environmental quality. Alpine conditions in other regions have been assessed, such as a study by Price (1985) and another by Willard et al (2007), in which significant shifts in species and vegetation cover were found as a result of recreation and specifically trampling. These studies suggest that 14ers are at risk of environmental degradation, but as of yet there have been no in-depth environmental assessments published providing evidence to support this.

1.2 Outline of Study

The economic and environmental tradeoffs presented from increasing alpine recreation in Colorado, and the lack of current research addressing these tradeoffs present an avenue of study. The chosen study site is Quandary Peak, which summits at 14,265 feet, located just outside of Breckenridge, Colorado. The goal of this study is to use Quandary Peak to design a protocol for future 14er studies, addressing three primary research questions. First, several aspects of the economic opportunities associated with alpine recreation are evaluated, specifically assessing expenditures and consumer surplus values and how those values change over time. Second, soil properties are measured to serve as an indication of the current environmental status for areas not impacted by recreation use compared to impacted areas. Finally, through analyzing these data with future studies of comparable 14ers, a carrying capacity is estimated to provide evidence for the resulting environmental and social impacts that varying levels of use will have on alpine areas and the economies of surrounding areas.

The specific objectives of this study are as follows:

1) Test whether expenditures and WTP values reported in 2006 are statistically different from those reported in 2009. These values will provide evidence for the stability of this recreation industry. If 2009 values are equal to or greater than

2006 values, we can conclude that this industry is stable during times of national economic downturn.

2) Test how the phrasing of the dichotomous choice WTP question differing in terms of a general or specific “you” affects the values reported. The findings of this methodological question contribute to the knowledge base with respect to optimal survey design and WTP question verbiage.
3) Create a database of soils and vegetation data; formalize differences in environmental health between human impacted and non human impacted sites using soil quality indicators. These measurements provide a baseline of environmental conditions, incorporating changes in use intensity as well as physiographic features.
4) Take the first steps to better understand a carrying capacity of the area, in terms how changes in visitation rates impact local economies and alpine ecosystems. Defining a carrying capacity will aid in classifying levels of use that provide the greatest level of economic benefits balanced with the lowest levels of impact to the environment.

The intention of this research is to provide more information to all stakeholders, in terms of both environmental and economical considerations, and to potentially create a protocol which can be used to assess environmental and economic impacts of nature-based alpine recreation in other areas. This information provides governing agencies and organizations the means to manage peaks/high alpine recreation areas more effectively and efficiently, in order to yield economic benefits to local communities and environmental benefits to the alpine ecosystems.

Chapter 2: Economic Impacts

2.1 Colorado 14ers: Public versus Private Goods

Forty-six of the fifty-four 14ers in Colorado are on public land (Keske-Handley, 2004), which means that the experience of hiking a publicly owned 14er is considered a public good. Public goods differ from private goods in two primary ways: public goods are non-rivalrous, suggesting that consumption by one person does not affect the consumption of another person; and secondly, public goods are non-exludable, meaning that no one person has control over the good (Weimer and Vining, 1999). Loomis and Keske (2009) argue that the public good characteristics of 14ers, combined with their popularity, can result in congestion and over-use on a busy weekend. In situations where overcrowding is a concern, consumers are imposing costs on their fellow hikers, and they are simultaneously imposing costs on the environment. For example, a dozen hikers on a weekday would likely have little interaction with one another, and hikers would be expected to generally stay on the trail, concentrating and thus minimizing their ecological impact. On the other hand, hundreds of hikers on a weekend would be interacting much more, potentially disrupting the solitude of the peak and decreasing the level of consumer surplus (the value of the experience above and beyond expenditures) visitors derive. Additionally, a single file trail would not be enough to accommodate the need to pass other hikers and as a result the ecosystem would be impacted to a greater degree as trails become wider and vegetation trampled in these situations.

If a 14er hiking experience was a private good as opposed to a public good, the increase in use of these areas would result in an increase in revenues. These revenues could then be applied to trail development and maintenance, hiker education of stewardship measures, etc. There are eight 14ers that are partly or entirely privately owned (Keske-Handley, 2004). Many of these involve split estates, where the surface owner differs from the owner of the sub-surface minerals. The surface area of Quandary Peak is semi-privately owned, although the trail and general access places for visitors is on public lands and thus generally categorized as a publicly owned peak. However, accessing peaks that are entirely privately owned is subject to the desire of the land owners, and thus subject to a somewhat different economic model. Some peaks are entirely closed and have no trespassing signs posted; other owners charge visitors a fee to enter their lands. Culebra Peak in southern Colorado is an example of a fee-based peak. The owners charge hikers 100$ to access the area and limit the annual number of visitors to between 100 and 200 individuals. The fee helps with maintenance costs, and by deterring hiker demand with a high fee, associated social and environmental costs are attenuated. In an assessment of Culebra Peak, Kedrowski (2006) found no evidence of trails or environmental degradation, indicating that in the case of Culebra, charging a fee has helped to minimize disturbances caused by recreation.

Interestingly, coinciding temporally with much of the research for this study, the United States Forest Service (2010) proposed a recreation fee for South Colony Basin which is public land and includes three 14ers: Humboldt Peak, Crestone Peak, and Crestone Needle. The Forest Service contends that there are more challenges managing recreational use and protecting the environment in South Colony Basin than in other backcountry locations. These challenges include: maintaining summit trails, managing social and environmental impacts at campsites, restoring alpine ecosystems, supporting search and rescue operations, and dealing with waste issues. As a result, the Forest Service proposes fees of ten to twenty dollars per person to access these areas, and the fees will be used for various projects including but not limited to: maintenance of summit trails, ecological monitoring and restoration efforts, campsite development and upkeep, installation of dumpsters, search and rescue services, and to provide conservation education products and services. Currently this proposal is only under consideration, and is open to public comment. However, the proposal may provide a way to decrease the social and environmental costs of congestion and over-use.

2.2 Visitation Rates of Quandary Peak

Given the social and environmental concerns that must be accounted for when a public good is over-used, a natural question arises: do enough people visit Quandary Peak to result in congestion and over-use of these public lands? The Colorado Fourteeners Initiative, an organization dedicated to the stewardship of these peaks, estimates over 500,000 people nation-wide visit the Colorado 14ers each year (CFI, 2010). Visitation numbers for specific peaks are difficult to obtain, and are estimated based on extrapolating numbers for the year based on a few contact days. According to Brian Wallace (personal communication, May 3, 2010), in 2006 CFI contacted 121 people over 2 days, for an average of 60.5 hikers observed each day on Quandary Peak. In 2009, 500 contacts were made over 6 days, for an average of 83.3 hikers per day. This method can be slightly inaccurate but does provide a framework to determine visitation rates and the USFS also uses these visitation estimates.

Kedrowski (2008) used another visitor estimation method, acknowledging that "literature on Fourteener-specific studies is scarce, especially regarding any climbing frequency values associated with the peaks" (pg. 82). Kedrowski accessed the peak registers, a document on which hikers can voluntarily record their summit of the peak. The registers are archived by Colorado Mountain Club, in Golden, Colorado, and are available to the public. This method can also be inaccurate because the record is voluntary, and it is also a paper document exposed to the elements of alpine environments resulting in the occasional loss of information.

Visitation numbers compiled at the conclusion of this study generally support the estimations from other publications. Data from 2006 show 199 contacts were made over three days, for an average of 66.3 per day. Data from 2009 show on average 69 contacts were made per day based on 345 contacts over 5 days. Visitation estimates vary slightly from 2006, 2009, and within the CFI data set. Results indicate that there is high demand to hike Quandary Peak, and as well as a trend of increasing demand over time.

2.3 Using WTP and CVM to Determine the Value of 14er Recreation

Based on the annual visitation estimates of 14ers which indicate high demand for alpine recreation, it is notable that there were no estimates of the economic value of 14er based recreation until recently. The findings of a study completed in 2006 highlight the positive economic impacts of recreation based visits to these peaks, showing a remarkably high visitor willingness to pay (Keske and Loomis, 2007). Willingness to pay (WTP) is a method to determine what an individual would hypothetically pay for a good (currently provided at no cost) in excess of their expenditures. Thus, WTP provides a measure of consumer surplus, or the value (in monetary terms) that visitors derive from their experience. The method used to determine the WTP of visitors is often determined by the Contingent Valuation Method (CVM). CVM was first implemented in a study by Davis (1963), and was later fully developed by Mitchell and Carson (1989). CVM estimates consumer surplus by creating a hypothetical market and asking visitors how much they would be willing to pay for the recreational experience, via a dichotomous choice question. One concern when using CVM is that it is indeed hypothetical, and therefore individuals may inflate their true WTP values. Several studies have shown a bias in stated versus revealed WTP values, specifically Cummings and Taylor (1999) and Loomis et al. (1996) in which results indicate actual payments were generally lower than projected payments by a factor of two. On the other hand, Carson et al., (1996) summarized how contingent valuation estimates for quasi-public goods correspond with estimates obtained from revealed preferences techniques. Overall, this study found contingent valuation estimates to be slightly smaller than their revealed preferences counterparts, but "based on the available comparisons summarized here, arbitrarily discounting contingent valuation estimates by a factor of two or more appears to be unwarranted" (p. 94). Although there is still some debate over using the contingent valuation method to determine an accurate WTP value, it remains an accepted and widely utilized method of gauging the value visitors place on outdoor recreation experiences.

2.4 Implications of High WTP Values for 14er Recreation

Many of the mountain communities that are geographically closest to these peaks are traditionally extraction and resource based economies (Keske and Loomis, 2008). For example, Leadville, Colorado, which lies 15 miles from Mount Massive, was established as a silver mining boomtown in the 1880's and continues to embrace a mining legacy through exhibits such as the National Mining Hall of Fame & Museum. However, mining can be a volatile and seasonal industry, creating irregular sources of income for both community members and municipalities as a whole. Accumulating empirical evidence indicates that mining is negatively associated with economic development. In the United States mineral wealth accounts for only 19% of natural capital, and a miniscule 0.8% of total capital (Davis and Tilton, 2005), although locally these numbers may signify a more substantial economic contribution at the regional level, as well as a national public good. Nevertheless, these numbers suggest that mineral extraction industries are not a stable sole source of revenue for communities, and due to the relatively minimal contributions mineral wealth makes to the US national economy, rural mountain communities may need to consider economic diversification as a means of sustaining and potentially expanding their economy.

The 2006 study assessing the economic value of 14ers, finding significant reported WTP values, generated much interest in the possibility of diversifying rural economies through recreation. Specifically, for visitors who were not willing to substitute another hiking experience, the mean WTP in 2006 was $294, with upper and lower confidence intervals of $397 and $232. Comparable studies found WTP for similar recreation experiences to be much lower, ranging from $20 to $56 (Loomis and Keske, 2009).

However, the 2006 study was conducted during times of economic prosperity, when the Dow Jones Industrial Average reached higher than 12,400 (Dow Jones Industrial Average History, 2010), and unemployment rates were under 5% (United States Bureau of Labor Statistics, 2009) for that time period. Contrastingly, during the

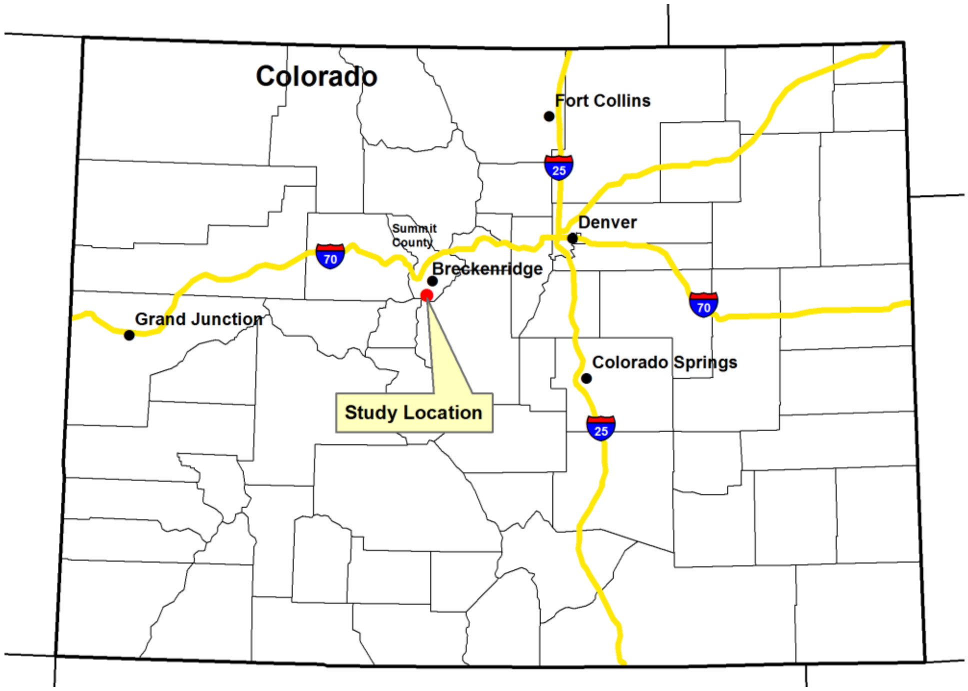
2009 follow-up study, the Dow Jones had fallen below 6,600 and unemployment topped 10% (United States Bureau of Economic Analysis, 2009).

Information regarding fluctuations in expenditures and consumer surplus can provide information for the communities that may benefit from 14er visitor spending, as well as for organizations and agencies responsible for management and land use planning of these peaks. If expenditures and consumer surplus for hiking these peaks is stable when the national economy is in a considerable recession, recreation in these areas may provide an opportunity to develop increasingly stable economic markets. Thus, a new question was posed: do changes in the strength of the national economy result in changes in expenditures and in changes in WTP values for 14er recreation experiences?

2.5 Study Site

The study site chosen to explore this question is Quandary Peak, located just outside the ski resort town of Breckenridge, in Summit County, Colorado. This area was selected first and foremost to replicate the 2006 economic study which had taken place at Quandary. This peak was also chosen because it is popular with hikers and is within 100 miles from Denver, making it an accessible study site.

Figure 2.5.1 Location of Quandary Peak



2.6 Outline of Study and Hypotheses

To answer the question of whether national economic fluctuations impact visitor expenditures and WTP, visitors were surveyed using the same methodology as 2006 (specified in section 2.7). Differences in expenditures were evaluated over the two time periods by comparing t-statistics of the mean hiker expenditures. The corresponding null hypothesis is:

H_o: $Expend_{i2006} = Expend_{i2009}$

The data from 2006 and 2009 were pooled into one model to test for WTP differences. To test for statistical differences, two dummy variables were created for the 2006 data set; one which interacts with the intercept and one which interacts with the travel distance coefficient. The following hypotheses test whether the two dummy variables are statistically significant:

$H_{o1}: \beta_2=0$

$H_{o2}: \beta_4=0$

As long as the dummy variables are not significant within the model, it is valid to pool the 2006 and 2009 data. To determine whether willingness to pay changed over the time period from 2006 to 2009, survey respondents were asked if they would still take the trip if travel costs were $X (bid amount) higher. The corresponding null hypothesis is:

$H_o: WTP_{2006} = WTP_{2009}$

Differences in WTP are determined by non-overlapping confidence intervals. If the hypotheses are not rejected, there is not a statistically significant difference in expenditures and in WTP values from 2006 to 2009, indicating that the national economic recession did not impact this industry. Alternatively, if the hypotheses are rejected it indicates that as the strength of the U.S. economy decreases, recreation-based revenues in this region decrease as well.

2.7 Methodology of Comparing 2006 and 2009 WTP and Expenditure Values

In 2006, 199 surveys designed according to Dillman's Tailored Design Method (Dillman, 2000) were distributed over three non-holiday weekend days. Hikers were asked at the conclusion of their hike to participate in the survey, completing it at their leisure and returning it via a pre-paid and addressed stamped envelope. Names and addresses of respondents were also collected to facilitate a second mailing, three weeks later, if the first survey was not returned. Out of 199 surveys distributed in 2006, 129 were returned yielding a response rate of 65 percent.

The 2009 control surveys were designed and distributed very similarly to the 2006 surveys. Differences included an increase from three to five distribution days, and out of 345 control surveys distributed, 248 were returned yielding a response rate of 72 percent.

The 2006 and 2009 surveys were identical, consisting of seven questions concerning trip specifics including the purpose of the trip, travel time, travel distance, travel mode, time spent at destination, and number of persons attending.

In addition to trip specifics, surveys included a chart in which respondents were asked to record total expenses for various categories, including food and equipment purchases, gasoline and supply purchases, lodging costs, etc. This section also included the WTP question as follows:

> "As you know, some of the costs of travel such as gasoline, campgrounds, and hotels often increase. If the **total cost** of this most recent trip to the recreation area where you were contacted had been $X **higher**, would you have made this trip to **this** 14er?"

Respondents were asked to circle a "yes" or "no" answer. Bid amounts ($X), ranged from $2 to $950.

The final sections of the surveys addressed demographics of respondents as well as recreation history and preferences, such as affiliation with outdoor organizations, recreation goals, etc.

The first hypothesis with respect to changes in visitor spending was evaluated by comparing mean hiker expenditures in the following categories: miles driven, gasoline purchases, retail supplies, equipment purchases, hotel and food in restaurants. Statistically significant differences were determined by comparison of the t-statistics of the difference in mean expenditure costs.

To test the second hypothesis regarding WTP values, a Logit regression model was used to determine the probability of the willingness of the respondent to pay the bid amount. The following equations (Hanemann, 1989) were then applied to determine whether the mean WTP in 2006 differed from 2009:

$$Mean\ WTP_{2006} = [\ln(1+Exp(\beta_o+\beta_2(2006Dum)+\beta_3(MeanTravelDistance_i) +\beta_4(2006Dum*MeanTravelDistance_i))]/|\beta_1|$$

$$Mean\ WTP_{2009} = [\ln(1+Exp(\beta_o+\beta_3\ (MeanTravelDistance_i))]/|\beta_1|$$

To evaluate whether the mean WTP estimates are statistically different, confidence intervals were calculated for each estimate using a procedure developed by Krinsky-Robb (1986) and applied to dichotomous choice modeling by Park et al (1991). If the confidence intervals overlap, the estimates are not statistically different (Creel and Loomis, 1991).

2.8 Results of Expenditure and WTP Values from 2006 Compared to 2009

As a preliminary note, monetary expenditures in 2009 were converted to 2006 dollars using the Consumer Price Index (United States Bureau of Labor Statistics, 2010). The data in this section is replicated from the working paper by Loomis et al (2010).

Table 2.8.1 shows the mean expenditures for 2006 and 2009. T-statistics indicate that there is not a statistical difference at the 5% level of any expenditure between time periods. The difference in gasoline purchases is significant at the 10% level, and may be attributable to fewer miles driven due to a $0.05/gallon increase in price (price data from the American Automobile Association, 2009).

Table 2.8.1. Comparison of 2006 and 2009 Per Trip Hiker Expenditures in Colorado ($2006)

Category	2006 Mean	2009 Mean	T-Stat (P-value)
Miles Driven	264	214	1.12 (.267)
Gasoline Purchases	$61.04	$42.00	1.69 (.092)
Retail Supplies	$13.24	$15.85	-.363 (.717)
Equipment Purchases	$25.14	$28.28	-.441 (.659)
Hotel	$81.62	$129.40	-1.29 (.196)
Food in Restaurants	$78.32	$80.48	-.401 (.689)
Total Expenditures	$246.11	$271.17	-.760 (.447)
Est. Total Seasonal Use*	1936-2126	2208-2665	NA
Est. Total Expenditures*	$476,469-$522,147	$543,411-665,031	NA

* Visitor use estimates are calculated from this study and from the Colorado Fourteener's Initiative for 32 non-holiday weekend days.

Based on these results, the null hypothesis is not rejected, signifying that there is no difference in expenditures between 2006 and 2009. These findings show nature-based recreation in these areas produced similar revenues between the two time periods, and therefore, this recreation industry may be less prone to fluctuate with variations in the national economy and this stability may have positive implications for rural mountain economies.

The findings of the hypothesis tests used to check the validity of the pooled Logit regression model show the coefficient on the 2006 intercept dummy is not significant (p=.5258). The dummy variable that interacts with travel distance is also not statistically significant (p=.8983). Therefore, we fail to reject the null hypothesis that there is not a statistical difference between the data of 2006 and 2009.

Using the coefficients from Table 2.8.2 (which represents pooled WTP responses from 2006 and 2009) the mean WTP values were calculated. These values are shown in Table 2.8.3 below. The bid coefficient indicates that the probability of a "yes" response decreases by .006 for every dollar increase in bid amount, demonstrating that individuals responded realistically, and as the $ Bid Amount increased, so did the number of "no" responses to the WTP question. The travel distance coefficient indicates that the probability of a "yes" response increases by .002 for every mile increase in travel distance, suggesting that people who travel further distances to participate in 14er recreation are willing to pay slightly more for the experience.

Table 2.8.2 Logit WTP Model Results

	2006 and 2009
Constant	0.861***
(T-statistic)	(4.280)
$ Bid Amount	-0.00579***
(T-statistic)	(-8.021)
Travel Distance	0.0023***
(T-statistic)	(4.090)
2006 Dummy	0.2182
(T-statistic)	(.634)
2006 Travel Dummy	-0.000144
(T-statistic)	(-.1278)

McFadden R-squared	0.301
Log likelihood	-168.098
LR statistic	144.841
Probability (LR stat)	0.000
N	348

***statistically significant at the 1% confidence level

Table 2.8.3 Mean WTP Per Person Per Trip and 90% Confidence Intervals

	Mean WTP	**90% Lower CI**	**90 % Upper CI**
2006	$152	$123	$190
2009	$139	$119	$167

In 2006 dollars, the mean WTP per person per trip in 2009 is $139, compared to $152 in 2006. Although this is a nine percent difference, the 90% confidence intervals overlap. These results show there is no statistical difference between the WTP per person per trip in 2006 and 2009. As a result, the null hypothesis is not rejected.

There are several measures of perceived wealth, including actual income, housing values, and the strength of investments in the stock market. As these measures fall, it is expected that individuals would have lower expenditures and WTP for recreation experiences. It is possible that expenditures and WTP for 14er recreation experiences did not decrease over this time period due to a relatively small income loss for this particular demographic. Income levels between 2006 and 2009 show on average a 5.3 percent drop with an associated p-value of 0.42, indicating no statistical difference in household income between the two time periods. Nevertheless, regardless of actual income, it would be expected that changes in the stock market and housing values would have a psychological impact on perceived wealth, leading to reductions in spending and WTP. Interestingly these expectations did not come to fruition for nature-based recreation on this Colorado 14er. Based on the results from expenditure and WTP comparisons, the national recession had little impact on the 14er recreation industry in this area.

2.9 Methodological Question: Do WTP Responses Vary Depending on the Verbiage of the Question?

In addition to using data from these surveys to analyze changes in expenditures and consumer surplus during times of economic growth compared to times of economic recession, surveys were distributed with different wording of the willingness to pay question to analyze if verbiage influences visitor responses. Considering that the responses from WTP questions are used to gauge the value visitors place on 14er recreation, which has implications for the strength and long term stability of the industry, it is important to address whether researchers are asking WTP questions in ways that reduce ambiguity and elicit the most accurate responses.

Although there is some debate over CVM dichotomous choice questioning potentially over or under estimating WTP responses as explained in section 2.3, there is a surprising lack of debate over the way in which these questions are actually worded.

Various studies have focused on the "payment vehicle," such as one study by Ivehammer (2009) in which WTP responses were examined from a question which varied only based on the proposed type of payment vehicle. The results showed that the payment vehicle does matter and in any planned study it is important to consider which payment vehicle should be used as it will affect the results.

The process of developing survey questions has been addressed thoroughly by Dillman (1991), who stresses the need to select and phrase questions in ways that will result in respondents providing accurate information. Boyle (1989) found that the description of the item being valued affects the resulting contingent valuation estimates. A publication by Champ et al., (2003) details the development and specification of survey questions. The authors emphasize the importance of using common vocabulary and appropriate language for the respondent population, choosing appropriately between open-ended versus close-ended questions, avoiding confusion by not using double-barreled questions, and considering a proper order and format of questions.

Flachaire and Hollard (2008) investigated individual sensitivity to framing effects, hypothesizing that even small changes in the design of a survey may influence respondents' answers, implying that two different surveys may lead to two different valuations of the same object. The findings showed that respondents are in fact sensitive to question framing, specifically showing a "statistically significant relationship between the mainstream variable and the sensitivity to framing effects" (p. 303).

Although the research done by Champ et al., Boyle, and Flachaire and Hollard most closely parallels the focus of our study in that it directly examines dichotomous question wording and framing, there has been little further empirical research measuring the effects of alternatively worded dichotomous choice questions. Many of the previously cited studies used surveys that were received, answered, and returned solely by one person. However, in the case of recreational outings such as hiking, it is common to encounter couples or groups of people who may answer survey questions individually or as a group. The issue of whether respondents answer dichotomous choice questions as an individual or as a member of a group has not been specifically documented.

Therefore, to address this gap in the literature, we compared results from the original or "control" survey to results obtained from an "experimental" survey to determine if the wording of the dichotomous choice willingness to pay question impacts visitor responses. The control survey verbiage mirrored the 2006 verbiage used in the dichotomous choice question, addressing a general "you." However, we suspected that there may be various interpretations of that wording. If an individual answered the survey alone, they may have answered per person. However, as surveys were distributed per carload, it is possible that some surveys were answered by one or more people, resulting in over or under estimation of WTP values. Therefore, the experimental surveys specifically worded dichotomous choice willingness to pay questions per individual. Visitors were surveyed using the same methodology as the previous studies, asking a variety of questions regarding expenditures in and around the recreation area, travel distance and costs, recreation intentions, and a dichotomous choice question regarding WTP.

2.10 Hypotheses of Verbiage Inconsistencies

If the results yield different estimates of WTP for the control verses the experimental surveys, it suggests that respondents are interpreting the WTP question in the control survey as a group expense, instead of a per person expense, a difference clearly outlined in the experimental survey. The corresponding null hypothesis for this test is:

H_{o1}: *Mean* $WTP_{control}$ = *Mean* $WTP_{experimental}$

In anticipation of the possibility that individuals answered control survey WTP questions on a per group basis, another null hypothesis (reflecting a proposed transformation) is posed as:

H_{o2}: *Mean* $WTP_{control/group\ size}$ = *Mean* $WTP_{experimental}$

The statistical significance of the two mean WTP estimates is evaluated by whether the confidence intervals of the estimates overlap. The results of these regressions are discussed in section 2.12.

2.11 Methodology of Comparing Verbiage

The 2009 experimental surveys were designed and distributed very similarly to the other surveys. However, distribution took place over three days and of 200 experimental surveys distributed, 122 were returned for a response rate of 61 percent.

The experimental survey also asked the seven questions concerning trip specifics, but included an extra question concerning prior time spent planning the trip. The experimental expenditure section was similar to the other surveys, also including the WTP question, as follows:

> "As you know, some of the costs of travel often increase. **If your share** of the total cost of this most recent trip to the recreation area where you were contacted had been $X **higher**, would **you** have made this trip to **this** 14'er?"

The 2009 experimental WTP question was very specific in addressing the individual, to clarify any ambiguity in respondent interpretation of the 2009 control WTP question, which is listed below again for reference:

> "As you know, some of the costs of travel such as gasoline, campgrounds, and hotels often increase. If the **total cost** of this most recent trip to the recreation area where you were contacted had been $X **higher**, would you have made this trip to **this** 14'er?"

Again, respondents were asked to circle a "yes" or "no" answer. Bid amounts ($X), ranged from $2 to $950.

The final sections of the experimental survey also addressed demographics of respondents as well as recreation history and preferences, such as affiliation with outdoor organizations, recreation goals, etc. The experimental survey asked an additional question, including a certainty scale, as follows:

"Under current laws, 80 percent of any fees collected on site must be spent on improvements at that site. If a small fee ($20 or less) were required at this site, would you visit this site?"

To determine whether there were differences in willingness to pay values from the control survey compared to the experimental survey, a Logit regression model was used and then Hanemann's formula was applied to determine whether each mean WTP differed:

$$MeanWTP_i = [ln(1+Exp(\beta_o+\beta_2\mathbf{X}_2))/|\beta_1|] ,$$

where X_2 is the travel distance recorded for each survey. WTP values were then averaged over the number of observations.

For the second null hypothesis in which Mean $WTP_{control/group\ size} =$ Mean $WTP_{experimental}$, each WTP value was calculated again with individual travel distances, and then divided by individual group sizes. These new WTP values were then averaged over the observation number. The statistical significance of the two mean WTP estimates was evaluated by overlapping confidence intervals (Creel and Loomis, 1991).

2.12 Verbiage Results

Table 2.12.1 shows the regression results for the 2009 control and experimental data. Using these coefficients, the mean WTP values were calculated. These values are shown in Table 2.12.2 below. Table 2.12.3 shows the WTP values calculated after transforming the data by dividing the WTP by group number, as expressed in the second null hypothesis. Again, the coefficient for $ Bid Amount is negative, indicating that individuals responded realistically, and as the $ Bid Amount increased, so did the number of "no" responses to the WTP question. Additionally, the travel coefficient indicates once again that there is a positive relationship between distance traveled and value placed on the experience.

Table 2.12.1 Logit WTP Model Results

	2009 Control	**2009 Experimental**
Constant	0.8835***	0.6014***
(T-statistic)	(4.201)	(1.927586)
$ Bid Amount	-0.00599***	-0.0080***
(T-statistic)	(-6.576)	(-4.127057)
Travel Distance	0.00235***	0.0029***
(T-statistic)	(3.984)	(2.639503)
McFadden R-squared	0.307	0.3308
Log likelihood	-111.938	-51.6974
LR statistic	99.026	51.1157
Probability (LR stat)	0.000	0.000
N	233	114

***statistically significant at the 1% confidence level

Table 2.12.2 Mean WTP Per Person Per Trip and 90% Confidence Intervals

	Mean WTP	Lower CI	Upper CI
2009 Control	$275	$260	$290
2009 Experimental	$181	$165	$197

Table 2.12.3 Mean WTP Per Person Per Trip and 90% Confidence Intervals

	Mean WTP	Lower CI	Upper CI
2009 Control/Group Size (Transformed)	$124	$111	$137
2009 Experimental	$181	$165	$197

The WTP values for the control unadjusted and experimental surveys are statistically different, as shown above by non-overlapping confidence intervals. This lack of consensus prompted a data transformation of dividing the control WTP amount by group size. However, this transformation also failed to yield statistically similar results. Only the results of the preceding two regressions are shown, although variations of these regressions were run. Variations included dividing the non transformed control WTP by the size of the group who shared trip expenses, and dividing the initial bid amount by group size before running the regression. However, these data transformations overcorrected for discrepancies in WTP values, yielding control survey WTP values that were much lower than the experimental survey values. No data transformation yielded results that were statistically similar. Thus, the null hypothesis was rejected: there is a statistical difference between WTP values of control surveys and experimental surveys. This lack of consensus between the WTP values indicates a marked difference in individuals' interpretation of survey questions. Therefore, if researchers want respondents to answer on a per person basis, this needs to be explicitly stated to avoid over or underestimating WTP values.

However, these results do not change the implications of the initial economic study. WTP estimates for 14er recreation are still very high, and by addressing methodological questions such as how verbiage affects responses, researchers can better understand ways in which error can be reduced in survey design and in the phrasing of WTP questions.

2.13 Economic Summary

Analyses of expenditures and WTP values indicate that these values have not changed statistically from 2006 to 2009, suggesting that this industry is not prone to fluctuations with the strength of the national economy. Additionally, WTP values remain high even with slightly increased visitation estimates, indicating that current and perhaps increasing levels of use do not negatively impact the value visitors derive from their recreation experience.

Assessment of the methodological question regarding the verbiage used in dichotomous choice WTP questions shows that the phrasing of the question does impact reported values. Correcting for this problem via data transformation was difficult and no results yielded statistically similar results. This suggests that if researchers want individual as opposed to group responses to WTP questions this needs to be explicitly stated. However, these findings do not change the overall findings of the initial study—visitors still have relatively high expenditures and WTP values for 14er recreation.

These findings bode well for the economies of rural towns in these areas. However, it is also important to consider the environmental conditions of these fragile regions to ensure that these areas can support recreation in the long-term. The following chapter addresses the current conditions of impacted and non impacted sites on 14ers to assess how human recreation activities influence factors of environmental health and stability.

Chapter 3: Environmental Impacts

3.1 Introduction

Particularly for highly popular recreation destinations such as Quandary Peak, there are systemic human induced changes to the environment. On Quandary Peak, these changes include trails and other manmade additions to the environment, such as bridges and culverts which exist to mitigate the visual evidence of erosion. Despite these visible alterations of the natural environment, there have been no formal environmental assessments of the conditions on Quandary Peak. In addition to compounding potential impacts from recreation, alpine areas are particularly vulnerable to environmental damage because the physiography is conditioned by low stature vegetation, steep slopes, high winds, shifting rock fields, and seasonal snow run-off (Hesse, 2000). These terrain attributes, along with the extreme climate, short growing season, and limited accessibility make management and restoration efforts more challenging than comparable areas at lower elevations (Bay, 2001).

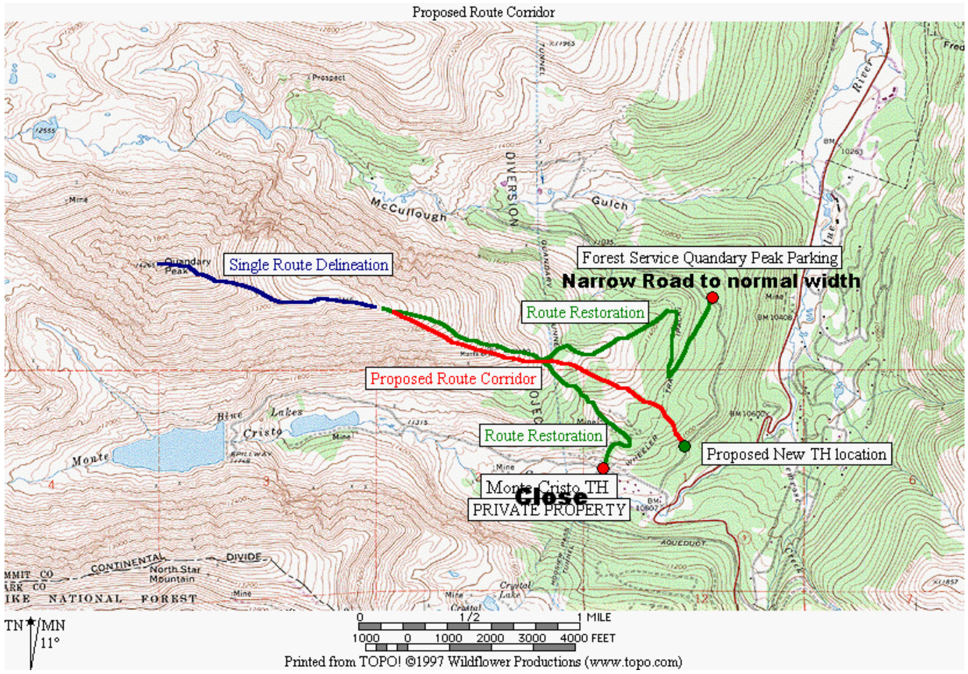
Several restoration assessments as well as restoration projects have been undertaken on Quandary Peak, due to the evident changes and impacts to the ecosystem. The following section provides an overview of restoration efforts that have occurred on 14ers based solely on visual assessments of resource damage.

3.2 Mitigation and Restoration Efforts

Management efforts on 14ers are governed by the United States Forest Service and the Colorado Fourteeners Initiative (CFI), who deploy rangers and volunteers during the summer seasons to monitor peak use, give and gather information, and conduct trail restoration projects. CFI is the primary organization that manages 14er stewardship. The organization was created in 1994 after the Forest Service, the Colorado Mountain Club, and various other stakeholders realized the need to better manage these increasingly popular peaks. Members from these organizations also sit on the CFI Board. CFI works in partnership with government agencies and nongovernmental organizations to protect and preserve the natural integrity of 14ers through stewardship and public education (CFI, 2010).

In 2001, CFI collaborated with other stakeholders to establish the Quandary Peak Restoration Plan in order to assess which trail sections were in primary need of restoration (Bay, 2001). A major component of this plan was to move the start of the trail from the Monte Cristo Trailhead to another site on county highway 851. This move was deemed necessary due to perceived severe resource damage and concern over trespassing on private lands. Additionally, the plan included measures to decommission trails that deviated from the main trail, stabilize trail sections with terracing and drainage structures, and to re-vegetate disturbed areas. The goal of these restorative efforts was to keep hikers off steep and dangerous social trails while simultaneously reducing the area impacted by visitors. Further objectives of the restoration plan included measures to mitigate erosion, which if not addressed could “completely degrade the ecosystem, decreasing the system’s ability to retain water as well as changing the water drainage patterns and the contour of the slope” (Bay, 2001, p. 6). Figure 3.2.1 shows portions of the trail that received some level of restoration in 2001 and 2002 as a result of the Quandary Peak Restoration Plan.

Figure 3.2.1 Quandary Peak Trail Restoration



In spite of the work of the afore mentioned organizations to mitigate impacts and restore trails, due to the limited resources of these organizations and the popularity of 14ers, impacts from recreation continue to be an issue on popular peaks, potentially resulting in soil erosion and vegetation loss and shifts. The following section provides a brief summary of research that has been conducted on 14ers and high alpine regions in similar eco-regions and potential impacts of outdoor recreation.

3.3 Environmental Damage in Recreation Areas

In 1980 and 1986, Summer published two studies assessing the impacts of horse traffic in Rocky Mountain National Park near Estes Park, Colorado. The 1980 study indicated that degradation was measurable on certain trail sections, but the study did not connect this to use intensity. In 1985, Price studied the effects of camping, horse traffic, and hiking on various sites within alpine environments in North America. The study focused primarily on the effects these activities had on vegetation, finding that hiking specifically caused direct mechanical damage to the aerial parts of plants and this resulted in physiological changes and changes in species composition and plant cover.

Various other studies have found similar ecological impacts due to hikers, including two studies by Cole (1991) and Cole and Monz (2002). The 1991 study addressed deterioration on trails over time, finding that although the trail system as a whole did not change significantly, several trail segments showed distinct changes. The 2002 study focused on trampling disturbances of high-elevation vegetation, finding that "low levels of trampling cause substantial reductions in cover and height, but rates of change decreased as trampling intensity increased" (p. 365). Although these studies provide evidence of how human disturbances impact environmental conditions, they were conducted in the northern Rocky Mountain region at lower elevations. Thus the findings from these studies may not necessarily represent recreation impacts across any given alpine environment, or at elevations above 10,000 feet.

Research and quantitative measurements of human impacts on Colorado 14ers is limited. In 2000, the Rocky Mountain Field Institute (RMFI) published the *Mount Humboldt Climbing Route Improvement and Restoration Project: A Case Study Addressing Recreation Impacts on Colorado's Wilderness Peaks* (Hesse, 2000). The focus of the project on Mount Humboldt was primarily to mitigate ecological impacts reported in an earlier assessment, which suggested that the west ridge route had become heavily eroded, with a severe erosion gully from 12,000 to 13,000 feet. Further findings indicated major soil erosion and vegetation losses occurred on trails and in many cases, popular trails surpassed acceptable or desirable levels of disturbance. The primary conclusion of this study was that increasing popularity of climbing 14ers creates the potential for even greater levels of disturbance in the future and thus managing these areas effectively is an important land planning and management issue. Although the RMFI study provides a basis for environmental assessment of alpine areas, it differs from this study in that restoration was the main goal of the RMFI project.

Kedrowski (2006) developed the Fourteeners Environmental Degradation Index (FEDI), used to indicate the restoration needs of peaks based on trail degradation. This index accounts for trail characteristics including but not limited to trail continuity, trail braiding, existing and needed switchbacks, and trail width. Based on the FEDI, Kedrowski found that Quandary ranked as the 40th peak in need of restoration. Within the Mosquito Range specifically, Quandary ranked as the last of five peaks in need of restoration, indicating that trail restoration work done by CFI on Quandary from 2000 to 2002 may have impacted these findings, resulting in reduced trail degradation on Quandary in 2006. In general, findings indicated that highly impacted 14ers would benefit from wider trails to accommodate high volume of hikers, and more switchbacks were needed to reduce soil erosion.

The studies by Hesse and Kedrowski address general trail impacts from human foot traffic. However, to date there is a lack of specific measurements of the damaged components of these ecosystems. There is a need to measure potentially disturbed features of the environment, and to formalize the condition of characteristics which contribute to the health and stability of the high mountain environments.

3.4 Soil Quality Indicators of Environmental Health

There is increasing awareness that soil is a critically important component of the biosphere, as a key factor in the production of food and fiber and also in the maintenance of local, regional, and global environmental quality (Glanz, 1995; Doran and Zeiss, 2000). Furthermore, Doran et al. (1996) suggest: "soil is a dynamic living resource, whose condition is vital both to the production of food and fiber and to global balance and ecosystem function, or in essence, to the sustainability of life on earth" (p. 3). A study by Gomez et al. (1996) provides a conceptual framework for measuring the sustainability of a system based on the quantification of "soil quality" indicators.

The studies cited previously suggest that soils are an integral component of ecosystem health and stability, and much of the limited 14ers ecological research noted changes in soil structure, e.g. erosion, as a result of increased recreation. Therefore, the following question is posed: *can indicators of "soil quality" or "soil health" (measured through key properties) be used as a proxy for overall ecosystem status?*

The following definitions provide a framework to address the otherwise potentially subjective terms of "soil quality" or "soil health." Soil health is *"the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation"* (Karlen et al., 1997, p. 6). In other words, soil health is *"a measure of the condition of soil relative to the requirements of one or more biological species and/or to any human purpose"* (Johnson et al., 1997, p. 586).

With regards to indicators, Dale and Beyeler (2001) argue that ecological indicators must capture the complexities of an ecosystem, while remaining simple enough to be easily monitored. Additionally, the authors propose that ecological indicators should meet the following criteria: easy to measure, sensitive to stresses on the system, and predictable in responses to disturbances and stresses. Specifically to soils, Singh and Khera (2009) define quality or health indicators as soil properties (e.g. physical, chemical, and biological properties) that reflect the ecosystem productivity and can indicate whether the soil's status with regard to health is improving, remains stable, or is declining

The previous studies provide guidelines, but do not specifically outline which soil properties should be measured in order to gauge the "capacity of a soil to sustain plant and animal productivity" or "enhance water and air quality." Soil properties range from abiotic properties such as the texture or pH of a soil, to the biotic properties of a soil such as the existence of earthworms, soil microbes, etc. Indicators of soil health vary depending on the ecosystem and the services it provides, and are conditioned by climate, soil type and the specific land use. Assessment indicators generally fall into the categories of physical, chemical or biological. Physical indicators include measurements of aggregate stability, water content, bulk density, infiltration, slaking, soil crusts, soil structure, and porosity (United States Department of Agriculture, 2008). These indicators reflect limitations to root growth, seedling emergence, infiltration, and water and air flow within the soil profile. Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and elemental concentration (United States Department of Agriculture, 1996). These indicators influence soil-plant relations, water quality, matric and osmotic potentials, and elemental movement. Finally, biological indicators include measurements of microorganisms and macro-organisms and their byproducts (United States Department of Agriculture, 1996). These indicators influence soil aggregation and structure, as well as decomposition rates, affecting soil organic matter content.

Much of the focus on soil health is emphasized for soils used in agricultural production, although Duiker (2003) outlines general soil quality indicators for all regions including high elevation areas as: soil texture, compaction, erosion, surface cover, soil organic matter, and vegetation growth. McQuaid-Cook (1978) found that in the Canadian Rockies, an environment that shares characteristics with the Colorado Rockies in which our study site falls, the type of terrain, user type, soil type, soil water content, and intensity of use were the primary factors controlling soil compaction and the resulting trail incision. Manning (1979), found seven factors that primarily influence soil quality, including presence of leaf litter, soil organic matter content, macroporosity, air and water permeability rates, water infiltration rate, rate of runoff, and finally, soil erosion. In a comprehensive report Yonker (1981) selected the following independent variables, based on inputs from the Universal Soil Loss Equation (Wischmeier and Smith, 1965) and the United States Department of the Interior Bureau of Land Mangement (1973) erosion indicators, to predict wildland soil erosion: percent sand, percent silt, percent clay, percent live cover, percent litter, percent surface rock, percent bare soil, percent slope, aspect in degrees, and slope position. Yonker also applied the Erosion Condition Classification (ECC), developed from the BLM, which defines the soil erosion status, scaled from 0-100.

After evaluating a number of soil quality indicators used in other studies and those used by the BLM to classify erosion condition, categories of indicators were chosen for the current study. These are outlined in section 3.8. These indicators will provide a barometer of the overall stability and quality of the soils associated with the hiking trails on Quandary Peak. Additionally these data will provide a baseline of the existing environmental conditions, and can function as the initial entries in a database that can be expanded over time.

3.5 Carrying Capacity

Although soil quality indicators can be measured and analyzed together to provide an assessment of overall soil and environmental quality, this assessment does not provide a complete picture of the long term sustainability of the system. Most indicators provide a view of the current conditions of an environment, or possibly changes if compared to a “benchmark” or undisturbed areas over time. Defining how much change is too much, or if the current conditions are stressing the environment falls into the realm of assessing a carrying capacity for these areas. The ecological carrying capacity of ecosystems with regard to recreational activities can be defined as the amount of “visitor use” that can be accommodated in a specific recreation activity and geographic area. Unfortunately, efforts to determine and apply carrying capacity to areas such as national parks have sometimes failed, as the principle difficulty lies in determining how much impact, such as visitor use (amounts and intensities), is too much (Manning, 2002). Manning further explains that *indicators of quality* are measurable traits that can lead to defining management practices, whereas *standards of quality* define the minimum acceptable condition of indicator variables.

To provide comprehensive and useful information of the environmental conditions on Quandary Peak, it is necessary to identify indicators of quality with the hope that these metrics can be used in support of assessing a carrying capacity. There are several interpretations of carrying capacity, but for this study the focus is primarily on social and ecological carrying capacity. Lavery (1974) asserts that social carrying capacity is the optimum level of recreational use visitors can achieve before they experience a reduced level of attraction to the area. This idea is reflected in chapter two of this document, referencing the over-use and congestion of public lands, resulting in external costs imposed on hikers and a decrease in consumer surplus. Lavery further states that ecological capacity is the highest level of recreation use that can occur before there are damages to the ecosystem. Social carrying capacity can be determined by interviewing visitors to gauge whether they felt the value gained from their experience was lessened by factors of congestion or over-use. However, defining an ecological carrying capacity can be more difficult due to the challenge of determining exactly when recreational impacts turn into excessive or irreversible damage within an ecosystem.

The concept of ecological carrying capacity has been around since the 1930's, but interest peaked in the sixties and seventies as increases in outdoor recreation raised questions about appropriate amounts and types of use (Stankey and Manning, 1986). Publications such as the *Recreation Carrying Capacity Handbook: Methods and Techniques for Planning, Design and Management* (Urban Research and Development Corporation, 1980) were developed to address the need for more definitive carrying capacity guidelines to preserve recreation qualities and for use in "preventing and correcting problems of overcrowding, overuse, and underuse of recreation resources" (p. 1). Stankey et al. (1985) developed the *Limits of Acceptable Change (LAC) System for Wilderness Planning*, in an effort to address two problems. The first issue was to determine a viable means to express and determine carrying capacity. The second issue was to include citizens (who were expecting and demanding to play a participatory role) in natural resource decision making (Krumpe and Stokes, 1994). As one offshoot of the *LAC* system, the National Park Service developed the *Visitor Experience and Resource Protection (VERP) Framework 9*, to better understand and manage the ways in which use levels, types, timing, and location impact visitor experiences and park resources (U.S. Department of the Interior, 1997).

The above cited publications focus widely on the planning and management aspect of carrying capacity, and not on the technical aspect of determining capacity. This may be due to the fact that, as argued by Stankey et al. (1984), "establishing levels of *acceptable change* is ultimately one of personal judgment, not science" (p.25). Conversely, Kuss and Morgan propose (1984) that physical carrying capacity can be equated with an ecosystem's sensitivity to erosion, and that the stability and productivity of an ecosystem are functions of erosion potential. The authors suggest that factors which contribute to soil erosion (rainfall, slope, vegetative characteristics, etc.) are the same primary determinants of carrying capacity, and therefore, by applying the universal soil loss equation which includes these soil erosion factors, it is possible to measure physical carrying capacity.

Morgan and Kuss (1986) later proposed using a measure of vegetation cover, which is defined in the soil loss equation as C (cover management factor), combined with factors of soil loss, to determine carrying capacity in recreation areas. Values of the C factor relate to the effects of cover and management practices on soil erosion. In this study the capacity limits were arbitrarily set on the basis of percentage of cover required to prevent possible erosion from exceeding the annual soil loss tolerance. Areas or sites requiring more than 80 percent ground cover were designated as having low carrying capacities, those that require 60 percent to 80 percent as moderate, and environments requiring less than 60 percent cover to ensure sustained soil productivity as having high recreation carrying capacity.

Given the research supporting the use of soils data as a measure of carrying capacity in recreation areas, we hope to use data collected on Quandary Peak as a means to extrapolate a technical measure of carrying capacity for these alpine recreation areas. Specifically, in order to determine an ecological carrying capacity using components from the previously discussed studies, data needs to be compiled over time to assess changes in erosion sensitivity. This includes changes in compaction, vegetation cover, and erosion conditions, as well as changes in annual visitor use and management factors. By assessing these changes over time at different rates of use, researchers will be better able understand the range and variability of environmental and soil quality at different rates of visitor use. Alternatively, these data could be collected from similar 14ers (e.g. geologically and biologically similar settings), with different rates of use, to serve as a comparison to the findings on Quandary.

3.6 Objectives of Study

Soil and vegetation characteristics have direct impacts on the status and health of ecosystems in alpine regions, although there is little scientifically defensible data collected for these purposes and therefore knowledge gaps do exist. To address this scientific need, this research will characterize soils and other pedological attributes to make a first order assessment of the environmental status (e.g. degradation) of trails and associated acreage along Quandary Peak. These measurements will provide a current status of conditions which can then be used as a benchmark for future studies, and serve as a basis for future monitoring to assess future changes in the ecosystem. It is hoped that these types of analyses may also serve as a means of determining a technical carrying capacity of the system. The resulting survey of the environmental conditions on Quandary Peak can then be used with recent economic studies conducted in 2006 and 2009, and together these studies will be useful planning tools for government agencies, nongovernmental organizations, community-based businesses, and the general public.

The objectives of this study were to:

1) Survey changes in soil properties associated with hiking along trails of 14ers.
2) Assess the degree of erosion and characterize the current state of the soil resources.
3) Provide the necessary data for modeling the carrying capacity of the ecosystem with regard to recreational use of the 14ers.

Specific considerations with regard to these objectives include:

a. account for changes on the trail sites compared to the control sites with respect to elevation, aspect, and slope.
b. account for changes in density measurements at and below the soil surface, as these changes will reflect the degree of anthropogenic impact.

3.7 Study Area Location and Description

Corresponding with the economic studies of 2006 and 2009, environmental data were gathered on Quandary Peak through the summer season of 2010. As previously stated, Quandary Peak is partly privately owned, but the trail and summit fall within the White River National Forest. The trailhead elevation of Quandary is approximately 11,000 feet and the summit elevation is 14,265 feet, resulting in an overall gain of 3,450 feet. The primary aspect of Quandary is southeast; geographic coordinates at the trail head are 39° 38.66'N, 106° 06.20'W and at the summit are 39° 23.83'N, 106° 6.38'W. Climate data from the closest weather station, Dillon 1 E Summit County, reports average maximum and minimum temperatures ranging from 73.0 and -1.2 °Fahrenheit (World Climate, 2010). Average yearly rainfall and snowfall values in this region are respectively 16 inches and 130.5 inches.

Table 3.7.1 provides the life zone classifications and community types (Bay, 2001), as well as the geologic formations (Stoeser et al, 2005) and soil great groups (Soil Survey Staff, 2004) on Quandary Peak.

Table 3.7.1 Life Zones, Community Type, Geologic Formations, and Soil Great Groups of Quandary Peak

Site ID	Life Zone	Geologic Formations	Soil Great Groups
1,2,3	subalpine (11,000-11,720 feet) spruce and fir forests subalpine meadows riparian areas	biotite gneiss, schist	Dystric Cryochrepts deep, well-drained moderate permiability glacial till low erosion hazard
4,5,6	alpine (11,720-13,100 feet) rock streams snow bed communities limestone communities grassy meadows moist meadows	biotite gneiss, schist limestone, quartzite	Typic Cryochrepts deep, well-drained moderate permiability glacial till
7,8,9	high alpine (13,100-14,265 feet) tallus fields fell fields	glacial drift, none	Typic Cryorthents deep, well-drained moderate permiability extremely sloped areas

3.8 Selected Environmental Health Indicators

The indicators listed below were selected for analysis of soil quality on Quandary Peak after exploring soil quality indicators outlined by the United States Department of Agriculture, the Bureau of Land Management, and other related studies. Specifically, based on Yonker's (1981) study, percent cover, erosional features, and geographic position (including elevation, slope and aspect) were selected as contributing variables. Based on Duiker's (2003) study compaction was included, and various studies including Duiker (2003), McQuaid-Cook (1978), and Manning (1979) prompted the selection of measuring soil properties such as texture, organic matter content, and porosity.

1. Soil Compaction: compaction results in decreased pore space, leading to increased runoff and erosion; compaction decreases the ability of plant roots to penetrate the soil profile, reducing vegetation cover and quality; additionally compaction reduces oxygen flow reducing microbial activity and soil respiration.

2. Percent Cover: the presence of rocks, lichens, litter and vegetation decreases the potential for soil erosion by creating physical barriers; additionally, vegetative covers increase soil quality through nutrient cycling and soil stability through root structure.

3. Erosional Features: includes soil movement, surface litter accumulation, surface rock, pedestalling, presence of rills and presence of gullies, all of which indicate erosion.

4. Terrain Data: includes percent slope, aspect, and elevation; the universal soil loss equation incorporates factors of geographic position as determining factors of erosion sensitivity.

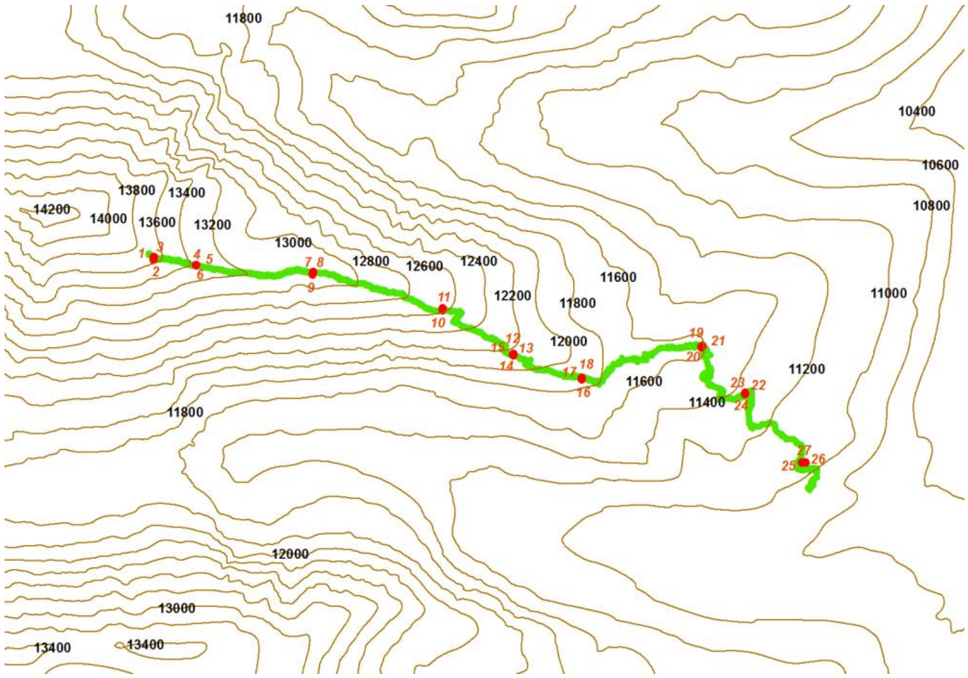
5. Soil Samples: soil samples analyzed for bulk density, porosity, and carbon and nitrogen content; bulk density provides a measure of the mineral content of the soil, represents compaction levels (with values for soil BD generally ranging between 1.0 and 1.6 $cm^{3)}$, and is inversely related to percent porosity; organic carbon is considered to be a very good indicator of ecosystem status (Burke et al, 1989), leading to better soil aggregation, water holding capacities, and nutrient and cation retention; nitrogen has implications for the vegetation of the area, as primary production and decomposition processes are dependent on the availability of nitrogen.

3.9 Field Work and Methodology

Field work was conducted in June and July of 2010. Three major life zones (bioclimatic regimes) were identified along the elevation gradient. Sampling sites were chosen at approximately equal elevation distances within each life zone, with slight variations due to local topography.

The following methodology is based on the methodology of previous studies, such as Yonker (1981), Summer (1986) and Cole and Monz (2002). Within each elevation zone, three transects approximately 6 meters in length were oriented perpendicular to the trail for a total of nine transects. Transect one was oriented at the highest sampling elevation (approximately 13,600 feet), and transect nine was oriented at the lowest elevation (approximately 11,100 feet). Each transect contained the following three sampling quadrants (0.5 m^2): a sample site directly in the middle of the trail, referred to as *on trail or site a,* which represents the primary area impacted by human use; a sample site adjacent to the trail, referred to as *adjacent to trail or site b,* which represents use that extends beyond the parameters of the trail; a sample site generally two meters (depending on topographic features) from the middle of the trail, referred to as *off trail or site c,* serving as the control site, presumably not impacted by recreation use. Thus, for each of the three life zones, there were three transects with three sampling sites per transect, for a total of 27 sampling sites. Figure 3.9.1 below shows the trail of Quandary Peak, with the study sites depicted as red dots.

Figure 3.9.1 Map of Quandary Peak Trail Depicting Soil Sampling Sites



To assess the quality indicator associated with soil compaction, three readings were taken at random points within each sampling site by one person with a Field Scout Penetrometer (Spectrum Technologies, 2010). The resistance readings recorded in kilopascals were then averaged to provide an estimate of relative compaction for each off trail, adjacent to trail, and on trail site.

To assess percent cover, a $0.5m^2$ quadrant was placed on the ground surface and photographed in each sampling site, as shown in Figure 3.9.2. Photographs were taken from a 1.5 meter vertical distance above the ground surface with a hand held camera. Percent cover was later estimated from the photographs using an overlain grid in GridFox (Puidokas, 2009).

Figure 3.9.2 Photograph of Quadrate Used to Estimate Percent Cover (Site 3b)

To assess indicators of erosion, surface features that reflect the degree of erosion were recorded based on classifications shown in Figure 3.9.3, which define the distinctions of each level of resource damage as outlined by the United States Department of the Interior Bureau of Land Mangement (2008). Classifications are as follows: stable, 0-20; slight, 21-40; moderate, 41-60; critical, 61-80; and severe, 81-100.

Figure 3.9.3 Indictors and Ratings for Degree of Soil Disturbance Adapted from Yonker (1981).

Form 7310-12
Determination of Erosion Condition Class
Soil Surface Factor (SSF)

Well Name/Number: ______________________ Date: ______________________

Operator: ______________________ Collector: ______________________

Soil Movement	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is 0 – 0.1 in (0 – 2.5 mm). **0 or 3**	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is 0.1 – 0.2 in (2 – 5 mm). **5**	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is 0.2 – 0.4 in. (5 – 10 mm) **8**	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is 0.4 – 0.8 in. (10 – 20 mm) **11**	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is > 0.8 in. (20 mm) **14**
Surface Litter	No movement, or if present, < 2% of the litter has been translocated and redeposited against obstacles. **0 or 3**	2 – 10% of the litter has been translocated and redeposited against obstacles. **6**	10 – 25% of the litter has been translocated and redeposited against obstacles. **8**	25 – 50%% of the litter has been translocated and redeposited against obstacles. **11**	> 50% of the litter has been translocated and redeposited against obstacles. **14**
Surface Rock Fragments	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is < 0.1 in (2.5 mm). **0 or 2**	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is 0.1 – 0.2 in. (2.5 – 5 mm). **5**	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is 0.2 – 0.4 in. (5 – 10 mm). **8**	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is 0.4 – 0.8 in. (10 – 20 mm). **11**	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is > 0.8 in. (20 mm). **14**
Pedestals	Pedestals are mostly < 0.1 in (2.5 mm) high and/or have a frequency < 2 pedestals/100 ft. **0 or 3**	Pedestals are mostly 0.1 – 0.3 in. (2.5 – 8 mm) high and/or have a frequency of < 2 – 5 pedestals/100 ft. **6**	Pedestals are mostly 0.3 – 0.6 in. (8 – 15 mm) high and/or have a frequency of < 5 – 7 pedestals/100 ft. **9**	Pedestals are mostly 0.6 – 1 in. (15 – 25 mm) high and/or have a frequency of < 7 – 10 pedestals/100 ft. **11**	Pedestals are mostly > 1 in. (25 mm) high and/or have a frequency of > 10 pedestals/100 ft. **14**
Flow Patterns	If present, < 2% surface area shows evidence of recent translocation and deposition of soil & litter. **0 or 3**	2 – 10% surface area shows evidence of recent translocation and deposition of soil & litter. **6**	10 – 25% surface area shows evidence of recent translocation and deposition of soil & litter. **9**	25 – 50% surface area shows evidence of recent translocation and deposition of soil & litter. **12**	> 50% surface area shows evidence of recent translocation and deposition of soil & litter. **15**
Rills	If present, are < 0.5 in (13 mm) deep and at intervals > 10 ft. **0 or 3**	Rills are mostly .5 – 1 in. (132 – 25 mm) deep, and at intervals >10 ft. **6**	Rills are mostly 1 – 1.5 in. (25 – 38 mm) deep, and at intervals > 10 ft. **9**	Rills are mostly 1.5 – 3 in. (38 – 76 mm) deep, and at intervals >10 ft. **12**	Rills are mostly 3 – 6 in. (76 – 152 mm) deep, and at intervals > 5 ft. **14**
Gullies	If present, < 2% of the channel bed and walls show active erosion (no vegetation), gullies make up <2% total area. **0 or 3**	2 – 5% of the channel bed and walls show active erosion (no vegetation), gullies make up 2 – 5% total area. **6**	5 – 10% of the channel bed and walls show active erosion (no vegetation), gullies make up 5 – 10% total area. **9**	10 – 50% of the channel bed and walls show active erosion (no vegetation), gullies make up 10 – 50% total area. **12**	Over 50% of the channel bed and walls show active erosion (no vegetation), gullies make up >50% total area. **15**

The GPS coordinates of each site were recorded to provide information on slope, aspect, and elevation, as these conditions correlate to other indicators. Finally, samplings of surface soil horizons were collected within each site and analyzed for carbon and nitrogen content, and bulk density and porosity. Samples for the top 10 cm were collected by tile spade and stored in plastic sample bags.

3.10 Results and Discussion

GPS Results

Table 3.10.1 reports the average values for percent slope, elevation, and aspect for each life zone (percent slope from Gesch, 2007; Gesch et al., 2002). The alpine zone has the highest average slopes of approximately 25 percent, followed by the subalpine at 17 and the high alpine at 14 percent. In the following results and discussion section, slope is a contributing factor explaining quality indicator results. Elevation is also a contributing factor, and is accounted for through life zone divisions (subalpine, alpine and high alpine). Aspect is consistent throughout sites and therefore is not considered a primary variable.

Table. 3.10.1 Average Values of Percent Slope, Elevation, and Aspect for Each Life Zone

Site ID	Slope	Elevation (feet)	Aspect
High alpine	14.4	13393	Southeast
Alpine	24.9	12251	South
Subalpine	16.5	11391	Southeast

Compaction Results

Penetrometer readings as a measure of soil compaction levels for the top five centimeters of the soil profile are reported below in Table 3.10.2. The raw data are provided in Appendix A, as well as the standard deviations for these values. In general for "on trail" segments, eight out of nine sites have higher compaction levels than the control, with values ranging from a 15 to a 284 percent increase. The average percent change in compaction for on trail sites relative to the control is a 104 percent increase. For "adjacent to trail" segments there is much more variability, with four sites showing a decrease in compaction ranging from -31 to -4 percent, and five sites showing an increase in compaction compared to the control, with values ranging from a 20 to 211 percent. The average percent change in compaction for adjacent to trail sites is a 45 percent increase. Sites five and six show relatively high compaction rates, potentially explained by variations in reported values, which is supported by high standard deviation values.

Table 3.10.2 Percent Change in Compaction Compared to Control Sites
(recorded in kilopascals; positive values indicate compaction increase; negative values indicate compaction decrease)

Site ID	On Trail	Adjacent to Trail
1	15.08	-30.85
2	69.76	68.51
3	23.12	-30.40
4	-19.64	-3.79
5	284.38	138.56
6	244.06	211.01
7	117.04	50.01
8	104.84	19.89
9	98.94	-21.50

Figure 3.10.1 shows compaction levels in the top five centimeters of the soil profile averaged for high alpine, alpine and subalpine sites. The subalpine zone has the highest averages, ranging from 1430 to 1740 kilopascals. The alpine zone has the lowest averages, ranging from 700 to 1250 kilopascals, and high alpine averages range from 875 to 2236 kilopascals. Below three centimeters the trends of compaction for subalpine and high alpine change, indicating that recreational induced compaction may be concentrated

in the top centimeters of the profile and below that changes are a result of environmental conditions.

Figure 3.10.1 Average Compaction for Subalpine, Alpine and High Alpine Zones

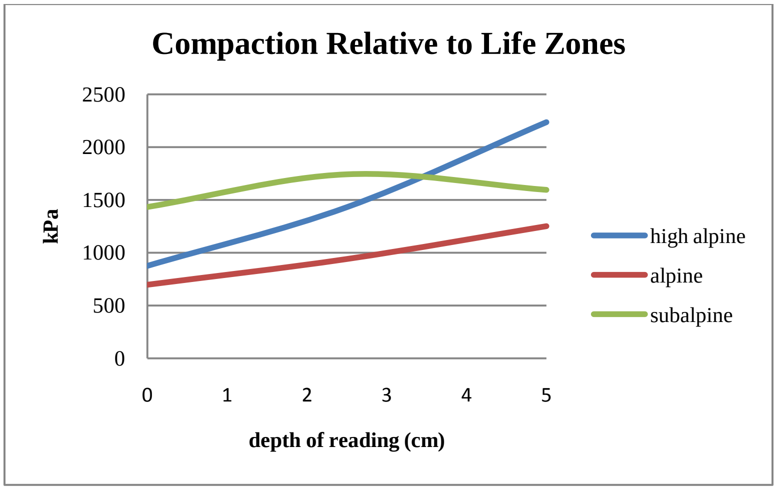


Table 3.10.3 reports compaction levels of on trail, adjacent to trail and off trail sites within each elevation zone. Average values range from approximately 2500 in the subalpine on trail zones, to approximately 600 kilopascals in the off trail alpine zone. General trends show that on trail and adjacent to trail sites have higher relative compaction levels, and the alpine zone generally has lower compaction levels than subalpine or high alpine, which is confirmed in previous results (Table 3.10.2 and Figure 3.10.1).

Table 3.10.3 Compaction Related to Site Location and Elevation Zone

Site ID	Compaction
Subalpine on trail	2539.4074
High alpine on trail	1840.2222
High alpine off trail	1416.6667
Subalpine adjacent	1401.0741
High alpine adjacent	1285.463
Alpine on trail	1187.2593
Alpine adjacent	1013.7963
Subalpine off trail	665.98765
Alpine off trail	578.96296

Compaction Discussion

Due to the highest levels of recreation traffic occurring directly on the trail, the highest compaction changes occur between the control and on trail sites. Somewhat unexpectedly, these data also indicate that there is a substantial increase in compaction between the control and adjacent to trail sites. If recreation was confined to the trail, it would be expected that the control and adjacent to trail sites would be very similar. This disparity indicates that recreation traffic is occurring off trail, suggesting that use levels may be higher than what current trails can accommodate.

Figure 3.10.1 shows that average compaction levels in the subalpine zone are highest. This may be due to the fact that the subalpine zone likely has the highest levels of use. Interestingly this trend does not hold true in the subsequent zone, the alpine zone. This reduction in compaction between subalpine and alpine may be explained by the fact that the alpine zone has the highest average slopes (25 percent). These steep slopes may result in several situations. First, some visitors may not continue upon encountering these steep slopes, resulting in less use and therefore less compaction. Secondly, on flat slopes hikers tend to spread out, perhaps choose these areas to take lunch breaks, etc.

This will result in overall more use in flatter areas, as opposed to steep sloped areas in which hikers tend to stay on trail and single file. Finally, steep slopes may reduce the direct downward compaction induced by hikers, as well as reduce the overall surface area of the foot that is contacting the slope (perhaps using only the toe of the foot to step). The high alpine zone shows an increase in compaction following the lower compaction levels in the alpine zone, indicating that flatter slopes and perhaps physiographic features play a role in affecting compaction at very high elevations.

Table 3.10.3 synthesizes the data in terms of both site location and elevation zone. In terms of compaction, subalpine on trail sites are most impacted by recreation, followed by on trail sites in the high alpine. Additionally, the adjacent to trail segments in these zones also show impacts, indicating that hikers are hiking on the trail margins. This suggests two potential scenarios: hikers may not be educated as to the impacts of going off trail and more education is needed; or, hikers are going off trail in cases of congestion and overcrowding as a need to avoid one another.

Percent Cover Results

Table 3.10.4 reports the average percent values of cover for on trail sites, adjacent to trail sites, and off trail sites. Table 3.10.5 reports average percent cover values with respect to elevation zone. Finally, Table 3.10.6 reports average percent cover values as a combination of site location and elevation. The full data set is available in Appendix A. On trail sites have an average of 30 percent cover which is primarily rock. The remaining 69 percent is exposed bare soil. In high alpine zones where the average slope is 14 percent, the on trail sites are dominated by rock cover whereas in alpine and subalpine zones the trail sites are dominantly not covered (bare soil) with average slopes of 25 and 17 percent. Adjacent to trail sites had a 30 percent vegetation cover, 21 percent rock cover and 13 percent lichen cover. With respect to cover on adjacent to trail sites, vegetation occurs mainly in subalpine and alpine zones, lichens are found primarily in high alpine zones, and rock and litter are distributed throughout elevation gradients. Off trail sites show 30 percent vegetation, approximately equal percent lichens and litter, and 10 percent rock covering. Lichens are present at high elevations, whereas vegetation and litter are found at lower elevations, with rock cover distributed throughout.

Table 3.10.4 Average Percent Values for Bare Soil and Various Cover Types by Site Location

Site ID	Bare	Rock	Lichen	Litter	Vegetation
On trail	**69**	**30**	0	1	0
Adjacent	**31**	21	13	4	**31**
Off trail	21	10	21	17	**31**

Table 3.10.5 Average Percent Values for Bare Soil and Various Cover Types by Elevation Zone

Site ID	Bare	Rock	Lichen	Litter	Vegetation
High alpine	22	**42**	31	2	3
Alpine	**46**	14	3	8	**30**
Subalpine	**54**	5	0	12	**30**

Table 3.10.6 Average Percent Values for Bare Soil and Various Cover Types by Site Location and Elevation

Site ID	Bare	Rock	Lichen	Litter	Vegetation
High alpine on trail	29	70	1	0	0
High alpine adjacent	22	38	34	2	4
High alpine off trail	14	19	58	4	5
Alpine on trail	81	19	0	0	0
Alpine adjacent	33	15	6	3	43
Alpine off trail	22	8	4	19	46
Subalpine on trail	95	2	0	2	0
Subalpine adjacent	38	9	0	7	46
Subalpine off trail	28	3	0	27	43

Percent Cover Discussion

Sites most at risk of erosion with regards to the cover indicator are sites that have no physical barriers to erosion, e.g., sites with high percentages of exposed bare soil. Erosion may be worsened by steep slopes, allowing gravity to compound factors of erosion. On trail sites in subalpine and alpine zones are dominated by bare soil (lacking any type of cover), and as these zones have the highest average slopes, these areas will likely be at risk for the highest erosion. Other sites with high percentages of bare soil exposed include adjacent to trail sites in the subalpine and alpine zones, suggesting these sites may also have a high erosion potential, albeit potentially mitigated by a higher vegetative cover than the on trail sites. Generally, the data indicate that in natural or human caused disturbance events such as rainfall or trampling, on trail sites in subalpine and alpine zones would be expected to have the highest rates of erosion and therefore may warrant more restoration and management efforts.

Carbon and Nitrogen Results

Table 3.10.7 shows average organic carbon and nitrogen levels, as well as the carbon to nitrogen ratio by site location. Table 3.10.8 shows these levels by elevation zone. The full data set is included in Appendix A. Carbon levels range from 0.299 to 43.69 and nitrogen levels range from 0.13 to 2.3. Average carbon levels for on trail sites is 3.6, for adjacent to trail sites is 9.7 and for off trail sites is 18.6. Average nitrogen levels for on trail is 0.23, for adjacent to trail is 0.71 and for off trail is 0.98. The average respective carbon to nitrogen ratios are 16.2, 15.4 and 19.6. Additionally, when averaged over life zones, high alpine zones had carbon and nitrogen levels of 9.0 and 0.73, alpine zone levels were 10.0 and 0.83, and subalpine zone levels were 12.8 and 0.37.

Table 3.10.7 Average Carbon and Nitrogen Levels and Ratios by Site Location

Site ID	Carbon	Nitrogen	C:N
On Trail	3.6	0.2	16.2
Adjacent to Trail	9.7	0.7	15.4
Off Trail	18.6	1.0	19.6

Table 3.10.8 Average Carbon and Nitrogen Levels and Ratios by Elevation Zone

Site ID	Carbon	Nitrogen	C:N
High alpine	9.0	0.7	11.0
Alpine	10.0	0.8	11.2
Subalpine	12.8	0.4	29.0

Carbon and Nitrogen Discussion

Off trail sites have the highest organic carbon and nitrogen levels, as well as the highest carbon to nitrogen ratios. Off trail sites also have the highest biotic component, reinforcing the relationship between biota and nutrient levels/cycling. Additionally, the lower elevation sites have higher carbon concentrations when compared to the alpine and high alpine sites. These data are supported when examined in light of biotic cover distribution—soil organic carbon is highest at lower elevations, where biotic cover is also highest. As elevation increases, general biotic cover decreases as do carbon levels, and carbon to nitrogen ratios. These results indicate that soil stability and productivity will be highest off trail sites at low elevations, and decreases with impacts from recreation and increases in elevation.

Bulk Density and Porosity Results

Table 3.10.9 reports the average bulk density and porosity values of on trail, adjacent to trail and off trail sites for each life zone. Bulk density values range from 0.4 to 1.6, and porosity values range from 40 percent to 85 percent. On trail sites have the highest average bulk density at 1.24 and 53 percent porosity. Adjacent to trail sites have values of 0.7 and 74 percent, and off trail sites have values of 0.8 and 68 percent, respectively. When averaged over life zones, high alpine zones had values of 1.1 and 57 percent, alpine had 0.7 and 73 percent, and subalpine had 0.9 and 65 percent, respectively.

Table 3.10.9 Average Bulk Density and Porosity Values by Site Location and Elevation Zone

Site ID	Bulk Density (cm^3)	Porosity
On Trail High Alpine	1.25	52.90%
On Trail Alpine	1.24	53.03%
On Trail Subalpine	1.24	53.26%
Adjacent to Trail High Alpine	0.57	78.31%
Adjacent to Trail Alpine	0.46	82.83%
Adjacent to Trail Subalpine	1.03	61.00%
Off Trail High Alpine	1.6	39.66%
Off Trail Alpine	0.41	84.62%
Off Trail Subalpine	0.51	80.73%

Results show that on trail sites have the highest bulk density and lowest porosity values. Additionally, the high alpine sites generally have higher density and lower porosity values than the corresponding location in a different elevation zone. These results indicate that recreation directly on the trail has resulted in more compact soils, and as a result the porosity is low meaning that rainfall events result in runoff as opposed to penetration, increasing the potential erosion. Additionally, the water and air flow within the soil will be generally lower, resulting in less productive soils. These impacts may be compounded in high alpine sites. With regards to marginally impacted sites, in the subalpine zone the adjacent to trail sites have an average density of nearly double the off trail site, indicating hikers are expanding outside the trail parameters and impacting the trail margins.

Erosion Condition Classification Results

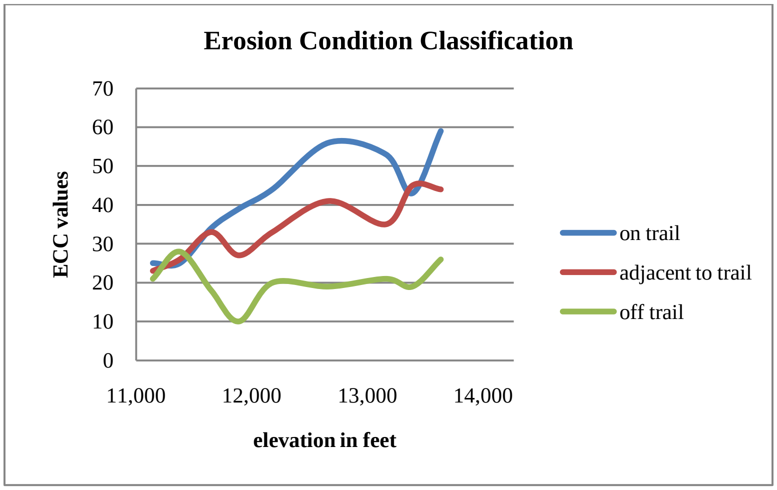
The complete table of Erosion Condition Classification (ECC) values is listed in Appendix A. The values range from 10, a stable condition, to 50, classified as a moderation level of erosion. On trail sites have an average value of 42, adjacent to trail sites have an average value of 34, and off trail sites have an average value of 20. All site ECC values averaged over elevation show that high alpine areas have a value of 38, alpine sites have a value of 32, and subalpine sites have a value of 26. Table 3.10.10 shows ECC values averaged over site location and elevation zone. These results show that the highest values of 52 and 46 are associated with on trail sites in alpine and high alpine zones, followed by adjacent sites in the alpine and high alpine zones with values of 41 and 34.

Table 3.10.10 Average ECC Values by Site Location and Elevation Zone

Site ID	ECC Value
High alpine on trail	52
High alpine adjacent	41
High alpine off trail	22
Alpine on trail	46
Alpine adjacent	34
Alpine off trail	16
Subalpine on trail	28
Subalpine adjacent	27
Subalpine off trail	22

Figure 3.10.2 below shows ECC values for on trail, adjacent to trail and off trail sites compared to changes in elevation. Subalpine values range from 22 to 28, alpine range from 16 to 46, and high alpine range from 22 to 52.

Figure 3.10.2 Erosion Condition Classification Related to Elevation



Erosion Condition Classification Discussion

ECC values are highest for on trail sites, indicating that recreation on the trail has significant impacts to the overall stability of the soils. As expected, off trail sites are the most stable. Additionally, alpine and high alpine sites also show high ECC values, indicating that the on trail erosion impacts of recreation may be compounded at higher elevations. Adjacent to trail sites in these zones also show high ECC values, indicating once again traffic on trail margins. Figure 3.10.2 shows much less variability between on trail, adjacent to trail and off trail sites at lower elevations, but increasing ECC values and disparity between sites at higher values. Thus, sites at lower elevations that receive higher levels of use still remain structurally more stable than higher elevations receiving lower levels of use.

3.11 Environmental Summary

Section 3.10 provided an overview of the data associated with each indicator. Table 3.11.1 and Table 3.11.2 synthesize the previous information in terms of sites with the highest levels of impact for each indicator.

Table 3.11.1 Sites with Highest Impact Levels in terms of Compaction, Cover and Carbon and Nitrogen

	Compaction	Cover	Carbon/Nitrogen
Highest Level of Impact	subalpine on trail	subalpine on trail	high alpine on trail
Secondary Level of Impact	high alpine on trail	alpine on trail	alpine/subalpine on trail

Table 3.11.2 Sites with Highest Impact Levels in terms of Bulk Density and Porosity and Erosion Condition Classifications

	Bulk Density/Porosity	Erosion Condition Classification
Highest Level of Impact	high alpine off trail	high alpine on trail
Secondary Level of Impact	high alpine/alpine/subalpine on trail	alpine on trail

Table 3.11.3 and Table 3.11.4 synthesize the results of indicator properties in terms of which sites show impacts on trail margins.

Table 3.11.3 Sites with High Impact Levels on Trail Margins in terms of Compaction, Cover and Carbon and Nitrogen

	Compaction	Cover	Carbon/Nitrogen
Third Highest Level of Impact	subalpine adjacent	subalpine adjacent	subalpine adjacent
Fourth Highest Level of Impact	high alpine adjacent	alpine adjacent	alpine adjacent

Table 3.11.4 Sites with High Impact Levels on Trail Margins in terms of Bulk Density and Porosity and Erosion Condition Classifications

	Bulk Density/Porosity	Erosion Condition Classification
Third Highest Level of Impact	subalpine adjacent	high alpine adjacent
Fourth Highest Level of Impact	high alpine adjacent	alpine adjacent

These data show that for every indicator with the exception of bulk density, the sites with the highest levels of impact occur on trail. There is no clear case for which elevation zone is most impacted. However, lower elevations are expected to have the highest levels of use, and would therefore be expected to show the highest levels of degradation. This indicates that there are inherent physiographic features of the alpine and high alpine zones that make these areas perhaps more susceptible to damage, even at lower levels of use.

Tables 3.11.3 and 3.11.4 report the third and fourth most impacted sites for each indicator. In each case, adjacent to trail sites have the highest levels of impacts. The adjacent to trail and the control sites should have similar characteristics if recreation is confined to the trail. The trail margins (adjacent to trail sites) should only show impacts if hiking activities are expanding outside of the trail boundaries. Results show trampling on trail margins is occurring on Quandary Peak. This suggests that hikers may not be educated about the environmental impacts of leaving trail boundaries (or that they are apathetic). These results also suggest that hikers might leave the trail boundaries due to congestion. Either situation has implications for peak management, indicating a need for better education, potentially imposing use limitations or developing trail expansion projects.

Chapter Four: Summary and Conclusions

4.1 Summary

Previous studies have shown that visitors to Colorado 14ers have a relatively high willingness to pay to recreate on these peaks. Additionally, estimations indicate high numbers of visitors to our specific 14er study site, Quandary Peak. However, the data indicating high expenditure and WTP values and high visitation estimates were gathered before the recession that crippled the US economy in the late 2000's. Thus, it was appropriate to ask whether changes in the strength of the US economy result in lower WTP values and lower visitation rates on Quandary Peak.

This study shows that even in times of a national recession, 14er visitors spend similar amounts in terms of expenditures, and they continue to value their recreation experience in terms of consumer surplus, indicated by similarly high WTP values. Additionally, visitation rates remain steady, if not slightly higher. In conjunction with this economic study, we also addressed a methodological question of how the verbiage used in WTP questions influences responses. Findings showed that using language specifically addressing the individual, as opposed to a more general "you," does in fact impact reported WTP values. Findings further indicate that correcting for this problem via data transformations is difficult and does not yield statistically similar results. However, the results of the methodological study do not change the implications of the overall study. WTP estimates for 14er recreation are still very high, but through addressing methodological questions such as verbiage we can reduce error in WTP estimates.

The economic results have implications across the board. First of all, these results confirm the 2006 study data indicating high WTP values for 14ers. Secondly, these results may contribute to and support other studies, such as Blake's research addressing how 14ers create a sense of "place attachment" and "community identity" because expenditures and WTP remain statistically unchanged even during times of economic hardship. Third, these results have broad implications for the surrounding communities and their economies, with the potential to serve as a means to strengthen and diversify rural economies. Additionally, the similarly high values of consumer surplus between 2006 and 2009, regardless of slightly increased visitation, suggest that high rates of visitation are sustainable in terms of economic growth.

However, the high visitation rates indicated in the economic study have implications for the environmental health of 14ers. This final point was taken into consideration and studied concurrently. Environmental assessments were made as a function of soil and vegetation quality indicators. Additionally, several measurements were made of soil characteristics to serve as a database for future studies. Geographic information was also accounted for, such as elevation aspect and slope, as these factors influence quality indicators.

On trail sites showed the highest levels of environmental degradation in terms of every indicator (with the exception of bulk density), which is expected as these sites receive the highest levels of direct impact from recreation. However, elevation and topographic features also play a role in the health and overall resistance to impacts of the area. For example, the high alpine sites, which most likely receive the lowest levels of use, showed the highest values for erosion classifications, indicating that there are inherent properties in this region resulting in complex and sometimes amplified impacts. There was no clear relationship across the board between impacts and elevation, but values for particular indicators showed higher impacts at higher elevations despite lower use intensities. Additionally, trail margins (adjacent to trail sites) in every life zone showed levels of impact, indicating that there is use outside of the trail parameters. This indicates that there is indeed overcrowding at times, suggesting the need for further trail development, visitor use limitations, and overall peak management.

4.2 Next Steps and Future Studies

This study serves to design a protocol of methods to assess the economic and environmental impacts of visitors to Colorado 14ers. However, to really gain an understanding of how much use these mountains can sustain, in terms of maximizing the economic potential of alpine recreation and minimizing environmental impacts, it is necessary to compare health indicators (temporally on Quandary or to another location) at varying use levels. Once this protocol is used to assess other peaks we can also gain a better understanding which variables are significant and what variations in indicators across sites may suggest for the ecosystem health as a whole. In conjunction with analysis of the current environmental conditions, some peaks may need to be assessed for previous impacts due to other types of land use. For example, other peaks in the Mosquito Range such as Mount Democrat and Bross retain old mining claims. Thus, in these instances environmental pressures from varying types of use should be assessed to gauge which activities may be most impactful, in comparison with the associated economic revenues.

Additionally, it would be useful to gain information about use intensity within the subalpine, alpine and high alpine zones to better understand whether variations in data between zones are results of use or physiographic features. There is also a need to continue to develop this protocol in terms of environmental assessments to better adjust some of the parameters for alpine use. For example, some of these indicators, such as the erosion condition classifications, are not specific to alpine areas and therefore may not account for the innate fragility of these systems.

Finally, with respect to management options based on the findings from this study, the cost of trail development and restoration should be compared with the revenues generated to assess whether the derived benefits of 14er recreation outweigh the costs of maintaining these areas. Specifically, expenditures and consumer surplus values should be weighed against costs associated with trail closures, use limitation, and or trail restoration projects.

4.3 Conclusions

Quandary Peak was used as a protocol to separately assess the economic and environmental impacts of visitors to Colorado 14ers. Analyses show that 14er recreation is associated with high expenditures and high WTP values. These two economic metrics provide evidence that nature based recreation on 14ers is a stable source of revenue for these rural mountain communities. Given that expenditures and WTP values were stable during times of economic turmoil in the national economy further suggests that this industry may provide an opportunity of economic stability and growth for these areas. However, to maintain this economic stability and growth in the long term, the environment must also be able to sustain high visitation numbers. Assessments show that environmental indices of soil quality and stability are negatively impacted by human traffic. On trail sites and trail margins across elevation zones show lower levels of health and stability compared to non impacted control sites, which indicates that depending on the degree of impact, different management policies may need to be established.

Through understanding economic and environmental conditions and visitation rates for more 14ers and surrounding communities, it will be possible to assess how slight changes in visitation affect the overall economic strength and environmental health of the area, eventually defining a carrying capacity, in terms of environmental and economic sustainability. Using this protocol, other peaks can be assessed to gauge economic opportunities in other parts of rural Colorado while simultaneously considering the environmental health of these fragile and valued ecosystems. This study sets the stage to further assess 14ers and gain a broad and in-depth understanding of the balance between economic benefits and environmental costs, optimizing use levels to maximize economic revenues and consumer surplus, while simultaneously mitigating environmental impacts.

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APPENDIX A

Table A1: Geographic Information

Site ID	Elevation (ft)	Percent Slope	Aspect	Latitude	Longitude
1a (on trail)	13635	25.6	SE	39.4	-106.1
1b (adjacent to trail)	13638	24.8	S	39.4	-106.1
1c (off trail)	13622	28.5	S	39.4	-106.1
2a (on trail)	13389	11.0	SE	39.4	-106.1
2b (adjacent to trail)	13386	11.0	SE	39.4	-106.1
2c (control)	13389	11.0	SE	39.4	-106.1
3a (on trail)	13163	3.7	NE	39.4	-106.1
3b (adjacent to trail)	13159	3.7	NE	39.4	-106.1
3c (control)	13159	10.1	S	39.4	-106.1
4a (on trail)	12664	29.0	S	39.4	-106.1
4b (adjacent to trail)	12674	23.6	SE	39.4	-106.1
4c (control)	12684	17.3	SE	39.4	-106.1
5a (on trail)	12182	29.0	S	39.4	-106.1
5b (adjacent to trail)	12185	29.0	S	39.4	-106.1
5c (control)	12205	22.9	S	39.4	-106.1
6a (on trail)	11893	24.4	S	39.4	-106.1
6b (adjacent to trail)	11890	24.4	S	39.4	-106.1
6c (control)	11886	24.4	S	39.4	-106.1
7a (on trail)	11650	11.1	E	39.4	-106.1
7b (adjacent to trail)	11650	11.1	E	39.4	-106.1
7c (control)	11647	15.1	E	39.4	-106.1
8a (on trail)	11375	17.5	SE	39.4	-106.1
8b (adjacent to trail)	11378	17.4	SE	39.4	-106.1
8c (control)	11381	17.4	SE	39.4	-106.1
9a (on trail)	11145	22.0	SE	39.4	-106.1
9b (adjacent to trail)	11145	18.7	SE	39.4	-106.1
9c (control)	11145	18.7	SE	39.4	-106.1

Table A2: Averages and Standard Deviations of Compaction by Site

	kPa at 0 cm	kPa at 2.5 cm	kPa at 5 cm	kPa at 7.5 cm	kPa at 10 cm
1a Average	1076	1240	3660.6667	2889	3205
1a Stnd. Dev.	1187.5504	323.8935	1430.6157	358.07401	544.09926
1b Average	631.5	1076.3333	1883.3333	2772.3333	2397.6667
1b Stnd. Dev.	70.5	456.44751	1352.8046	947.50004	225.95206
1c Average	1181.6667	2070.3333	1941.6667	2175.6667	1929.6667
1c Stnd. Dev.	567.32912	355.75319	122.91596	1125.6146	809.36045
2a Average	1239.6667	1532.3333	1894.6667	2210.6667	2760.3333
2a Stnd. Dev.	1401.999	1140.728	655.37953	1017.5	1350.0853
2b Average	971	1509	2152.3333	3404	2655.3333
2b Stnd. Dev.	848.57115	774.37652	415.77197	1338.9742	476.18729
2c Average	503	772	1474	1731.3333	2023.6667
2c Stnd. Dev.	780.48511	650.20689	491	281.24781	894.17299
3a Average	959.33333	2175.6667	2783.6667	1579	3052.6667
3a Stnd. Dev.	649.04725	185.76957	1048.1628	1338.9742	783.36284
3b Average	667	947.66667	1731	2070.3333	3052.6667
3b Stnd. Dev.	155.74555	1041.0267	1195.7372	690.47789	1279.3953
3c Average	643	1556	2608.3333	3064.6667	2982.6667
3c Stnd. Dev.	934.46883	992.46511	521.05406	1314.276	1916.3135
4a Average	368.5	631.5	1345	2199	1813
4a Stnd. Dev.	298.5	280.5	123.43824	833.50525	571.61088
4b Average	784	865.66667	1158	1392.3333	1602.6667
4b Stnd. Dev.	662.21522	457.9152	580.01983	658.70049	539.20899
4c Average	877	719.5	1321.6667	1941.6667	1930
4c Stnd. Dev.	0	508.5	636.68857	1074.2022	790.08164
5a Average	678	1544.3333	2093.6667	2210.6667	2409.3333
5a Stnd. Dev.	202.64994	564.79406	727.58321	1191.3263	1095.144
5b Average	421	1053	1204.6667	935.66667	1801.3333
5b Stnd. Dev.	356.19657	35	358.43316	474.10161	1656.9615
5c Average	210.5	316	596.33333	1041	1076
5c Stnd. Dev.	70.5	281	540.34464	132.86083	123.43824
6a Average	1532.3333	1450.6667	1041.3333	982.66667	959.33333
6a Stnd. Dev.	620.27924	406.65014	353.31902	245.57144	302.30007
6b Average	1333.5	971	1333.3333	1041.3333	1918.3333
6b Stnd. Dev.	456.5	559.3237	930.50327	368.63849	1719.1196
6c Average	35	316	818.66667	1052.6667	1251.6667
6c Stnd. Dev.	0	0	1236.1069	509.91895	548.5411
7a Average	3041	3158.3333	2737	3111.3333	2409.3333
7a Stnd. Dev.	1390.9935	551.59526	312.04327	831.95693	752.66283
7b Average	1825	2152.3333	2199	1766	2772
7b Stnd. Dev.	807	591.66911	180.15826	214.39916	1175.8907
7c Average	1169.6667	1380.3333	1567.3333	947.33333	1181.3333
7c Stnd. Dev.	421.48468	545.2452	649.57858	355.75319	411.10137
8a Average	1532.3333	1976.6667	1427	1275	1403.6667
8a Stnd. Dev.	1176.585	1092.6813	690.01522	544.09926	961.23324
8b Average	772	994.33333	1122.6667	1357	1333.3333
8b Stnd. Dev.	526	107.47248	230.0442	123.43824	245.57144
8c Average	316	1041	1052.6667	1134.6667	1614

8c Stnd. Dev.	321.76233	674.15799	497.33925	272.82656	321.76233
9a Average	3602.3333	3462	1918	1894.6667	1988.3333
9b Stnd. Dev.	298.67094	1155.7366	1545.8845	1220.0223	294.42203
9a Average	1017.6667	1298.6667	1228	1614.3333	959.33333
9b Stnd. Dev.	809.3172	620.73934	425.34222	245.50017	358.64514
9a Average	1017.6667	1626	1871.3333	1497	1052.6667
9b Stnd. Dev.	920.55762	659.03794	870.9933	983.34277	529.94559

Table A3: Percent Exposed Bare Soil and Percent Cover

Site Id	Bare	Lichen	Litter	Rock	Vegetation
1a	23	0	0	77	0
1b	35	7	3	55	0
1c	13	62	5	20	0
2a	5	2	0	93	0
2b	22	20	0	50	8
2c	24	50	0	22	4
3a	60	0	0	40	0
3b	8	75	3	10	4
3c	4	63	8	15	10
4a	63	0	0	37	0
4b	35	8	2	20	35
4c	15	7	20	13	45
5a	85	0	0	15	0
5b	30	5	5	5	55
5c	22	5	28	10	35
6a	95	0	0	5	0
6b	35	4	3	20	38
6c	30	0	10	2	58
7a	95	0	0	5	0
7b	43	0	4	18	35
7c	8	0	47	0	45
8a	98	0	2	0	0
8b	20	0	13	4	63
8c	35	0	7.5	7.5	50
9a	93	0	5	2	0
9b	50	0	5	5	40
9c	40	0	25	0	35

Table 4A: Carbon and Nitrogen Contents and Ratios

Site ID	Carbon	Nitrogen	C:N
1a	0.9	0.08	10.8
1b	5.3	0.53	9.9
1c	6.4	0.68	9.5
2a	4.1	0.36	11.3
2b	17.6	1.01	17.4
2c	0.3	0.06	5.1
3a	1.6	0.15	10.6
3b	17.5	1.44	12.1
3c	27.6	2.28	12.1
4a	3.3	0.27	11.9
4b	3.0	0.26	11.6
4c	15.6	1.21	12.7
5a	4.3	0.37	11.7
5b	24.6	2.11	11.6
5c	28.6	2.32	12.3
6a	5.2	0.37	14.3
6b	5.3	0.43	12.2
6c	0.4	0.15	2.4
7a	2.6	0.14	18.9
7b	3.1	0.18	17.4
7c	43.7	0.75	58.4
8a	4.8	0.17	28.2
8b	5.5	0.24	22.6
8c	20.9	0.70	29.9
9a	5.3	0.19	28.1
9b	5.2	0.22	24.0
9c	24.1	0.72	33.7

Table 5A: Erosion Condition Classifications

Site ID	Erosion Condition Classification
1a (on trail)	moderate (59)
1b (adjacent to trail)	moderate (44)
1c (off trail)	slight (26)
2a (on trail)	moderate (43)
2b (adjacent to trail)	moderate (45)
2c (off trail)	stable (19)
3a (on trail)	moderate (53)
3b (adjacent to trail)	slight (35)
3c (off trail)	slight (21)
4a (on trail)	moderate (56)
4b (adjacent to trail)	moderate (41)
4c (off trail)	stable (19)
5a (on trail)	moderate (44)
5b (adjacent to trail)	slight (33)
5c (off trail)	stable (20)
6a (on trail)	slight (39)
6b (adjacent to trail)	slight (27)
6c (off trail)	stable (10)
7a (on trail)	slight (34)
7b (adjacent to trail)	slight (33)
7c (off trail)	stable (18)
8a (on trail)	slight (25)
8b (adjacent to trail)	slight (26)
8c (off trail)	slight (28)
9a (on trail)	slight (25)
9b (adjacent to trail)	slight (23)
9c (off trail)	slight (21)

Table A6: Soil Texture

Site ID	Soil Texture
1a (on trail)	loamy sand
1b (adjacent to trail)	loamy sand
1c (off trail)	sandy loam
2a (on trail)	loamy sand
2b (adjacent to trail)	loamy sand
2c (off trail)	loamy sand
3a (on trail)	sandy loam
3b (adjacent to trail)	sandy loam
3c (off trail)	loamy sand
4a (on trail)	loamy sand
4b (adjacent to trail)	loamy sand
4c (off trail)	sandy loam
5a (on trail)	loamy sand
5b (adjacent to trail)	sandy loam
5c (off trail)	sandy loam
6a (on trail)	sandy loam
6b (adjacent to trail)	silt loam
6c (off trail)	sandy loam
7a (on trail)	silt loam
7b (adjacent to trail)	silt loam
7c (off trail)	loamy sand
8a (on trail)	sandy loam
8b (adjacent to trail)	sandy loam
8c (off trail)	sandy loam
9a (on trail)	sandy loam
9b (adjacent to trail)	sandy loam
9c (off trail)	sandy loam