Recreational trail use on the Red Rock Ranger District of the Coconino National Forest: A 2023 estimate for Sedona and Village of Oak Creek Area, Arizona

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Abstract

The Red Rock Ranger District (RRRD) of the Coconino National Forest, Arizona, has several hundred miles of trail surrounding the City of Sedona and nearby Village of Oak Creek. This extensive trail system goes through land that is of great archeological, cultural, and ecological importance. A comprehensive study of trail usage across RRRD has not been conducted since 2015; in the following years, public lands near Sedona and Oak Creek have seen a significant increase in visitorship due to the COVID-19 pandemic and other factors, indicating that restudy is needed. The research presented here uses a trail count methodology to reassess trail visitation in the Sedona and Oak Creek area over a one-year period, providing the first update to trail use in the Sedona and Oak Creek area since that 2015 study. This effort blended both in-person and TRAFx automated trail count data to triangulate data across modes of collection, providing the most accurate estimate possible. Data collected and analyzed between June 2022 and May 2023 indicate that trail usage has increased from approximately 1.7 million users in 2015 to 2.2 million users over the study period. Updated trail usage figures will allow managers on the Ranger District make informed decisions based on reliable and up-to-date estimates, allowing them to work with partners more effectively at the non-profit, city, and county levels.

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1. Introduction

1.1 National Context

Millions of people benefit from recreation every year in the western United States. Public land users partaking in hiking, camping, and various other recreation activities outdoors see increased physical wellbeing and improved mental health. Members of the public not only seek health benefits, but also a place to relax, view scenery, and escape the stresses of everyday life when they look to recreate in public lands (Bawa, 2017). During the Sars-CoV-2 pandemic, people relied on the outdoors as a socially distanced replacement for other physical activities that were closed during that time such as going to the gym as well as seeking mental health benefits from being surrounded by nature (Yang, 2021). Aside from providing benefits to the individual, these natural areas provide economically for entire towns and regions within the Western United States (Bowker et al., 2009).

Despite an uptick in public land visitation, agencies responsible for overseeing these lands remain underfunded relative to the number of visitors and diversity of recreation activities they must manage for (McConnel, 2018). This has impacted their ability to protect natural resources, provide recreation opportunities, create jobs, and manage resources in an adaptive way as social and ecological conditions evolve (McConnel, 2018; Williamson, 2005). This challenge is particularly true for the US Forest Service (USFS); since the 1990s, the average national forest has seen an average increase of 800,000 or more visitors a year (U.S. Forest Service, 2018). USFS receives its funding through Congressional appropriations which determine the total amount of funding across all forests. This funding is then divided between regions, forests, and then split once more at the level districts (Congressional Research Service, 2022). Each forest receives its share of funding based in part on the total number of users annually. This use number is determined by the National Visitor Use Monitoring Program, an assessment that is conducted by surveying each forest across the nation once every five years (English et al., 2020). While this survey is an effective tool to estimate total *national* forest visitation numbers, it can be difficult for an individual forest or district to accurately estimate total visitation due to monetary and staffing constraints.

Increasing demand for public land recreation paired with limited budget availability for land management places great pressure on public land managers to make effective decisions based on use and resources available to both protect ecosystems and ensure positive human experiences. University researchers are well positioned to assist agencies like the USFS with more accurate visitor use data at the district level to provide deeper understandings of usership locally that can inform more granular decision making at smaller scales (e.g., individual trails) where broader efforts like the National Visitor Use Monitoring Program cannot.

1.2 Local context: Red Rock Ranger District, Coconino National Forest, Arizona

One of three administrative units on the Coconino National Forest, the Red Rock Ranger District (RRRD) is situated approximately twenty-five miles south of Flagstaff, AZ. RRRD surrounds the City of Sedona and the Village of Oak Creek, both of which have strong tourism-based economies that depend in large part on public land access. The Sedona and Oak Creek area have documented a significant increase in the number of visitors they received yearly over the past several decades (Koller, 2016). Popular scenic hikes experience very high levels of use compared to other trails across the RRRD and other districts on the Coconino. Staff on the Red Rock District have stated that they simply do not have the resources to deal with the current number of visitors they are seeing daily, particularly on high use trails such as Devil's Bridge (Shumaker, 2021). Some land managers ascribe the boom in tourism to social media, while others note that the US has experienced a population boom in many western states since 2010 (Peterson, 2022; Rotert, 2022). The number of visitors has increased even further since the 2020 COVID 19 pandemic began. Prior to the pandemic, RRRD received nearly 3 million visitors a year, and in 2020 they saw a 5% increase in the number of visitors (Pearson, 2022); this reflects national trends, as trail use increased 79% across the U.S. between March and July of 2020 alone (Ainsley, 2021).

Figure 1: A photo showing the location of Sedona on a map of the State of Arizona (Pulaski, 2019).

The RRRD occupies a very sensitive geological, ecological, and social landscape that can be disturbed by a sudden increase in the number of visitors (Koller, 2016). The RRRD draws its name from its unique geology, which features bright red rocks in the form of buttes, spires, and arches (Coconino National Forest, 2022). The soil in the area contains a high amount of potassium and is vulnerable to disturbance by user groups such as hikers, bikers, and horseback riders (see Appendix A for resource map of RRRD). Additionally, many of the areas near Sedona and Oak Creek contain large numbers of heritage sites and cultural artifacts of Sinagua, Yavapai, and Apache peoples (Stanislawski, 1963).

1.3 Development of a trail use study for RRRD

Given both the national and local contexts described above, RRRD could greatly benefit from an updated estimate of non-motorized trail use on national forest lands in the Sedona and

Village of Oak Creek areas. An estimate of the total number of trail users has not been conducted since 2015 and RRRD is in need of new and accurate information. The aim of this professional paper is to develop an updated trail use estimate for trails in the Sedona and Village of Oak Creek area within RRRD. This professional paper overviews the process of designing, conducting, and analyzing the results of a trail count survey to provide new use estimates for the RRRD, in partnership with both recreation staff on the district and volunteers from the Sedona chapter of Friends of the Forest, a local non-profit group. This project is intended to support RRRD as staff look to apply for additional funding through grants and public-private partnerships which will allow them to increase the number of trail maintenance workers they employ, replace broken equipment, and create conditions that allow for sustainable trail use (Sedona Red Rock Trail Fund, 2023). Simultaneously, provision of a new trail use estimate and subsequent modified management efforts can provide for improved visitor experiences while minimizing the impacts of recreation on fragile ecosystems and cultural sites.

2. Literature Review of Trail Use Estimation Methods

The trail use estimation literature presents six different methods for estimating the total number of trail users on a given trail or across a given area: in-person counts, infrared cameras, digital cameras, in-person surveys, multiple regression statistical modeling and digital data (e.g., social media geotags). All six methods rely on the successful collection of a representative data set and then extrapolating use over a larger time frame from the smaller data set. Even hypothetical estimates based on multiple regression models, which are designed to help predict the future use of trails given certain conditions, need some amount of primary data (Eliot et al., 2022).

In-person counts, which are used in this professional paper, entail an individual stationed at a given trail manually recording the number of trail users they are seeing in real time, either with pen and paper or on a tablet. They may also record trail user characteristics such as mode of transportation, group size, weather, and time of day (Watson et al., 2000; Wan et al., 2014). The literature on trail user count methodologies indicate that in-person counts are the most rigorous and accurate approach when it comes to collecting data in the field (Fisher et al., 2018). An additional benefit of in-person counts is that it can provide community members invested in certain trail systems an opportunity to become involved with data collection which increases overall community engagement and often boosts the number of donations received from volunteers by nonprofit groups affiliated with the trail system (Alta Planning + Design, 2016; Bergman et al., 2016).

In-person counts are often paired with surveys to collect additional data about trail users through random sampling. Often the random participant is chosen from the groups by asking who had the most recent birthday (English et al., 2020; Watson et al., 2000). This additional capacity to collect data is very helpful to agencies as it gives them a more complete picture of the recreationists and their priorities (English et al., 2020). The data collected allows land managers to employ the recreation opportunity spectrum approach to resource management. The Recreation Opportunity Spectrum (ROS) looks at recreation in the context of its setting, recreation activity type and the resulting experience (Buist & Hoots, 1982). ROS management gives agencies a framework for managing recreation experience and is a part of the legally required integrated land and resource management planning process (Buist & Hoots, 1982).

While in-person counts are the most accurate method of collecting data, they are also very time intensive and expensive because of the costs associated with sourcing, hiring, and training labor to conduct the count (Fisher et al., 2022; Zarnoch, 2011). Much of the literature agrees that infrared (IR) cameras are an adequate substitute for in-person observation when the location is very remote or data needs to be collected continuously (Bates, 2014; Pettebone et al., 2019). While the use of IR cameras can help reduce cost, it is still critical to calibrate them with in-person observations to make sure they are not being interfered with by vandalism, weather, or simple degradation due to exposure to the elements (Bates, 2014). For example, Bates (2014) calibrated the IR cameras used in their study three times over the course of a one-year study period. In some instances, digital cameras, similar to game cameras, have been used to augment IR camera data (Campbell, 2006). Digital game cameras in concert with infrared cameras can help determine direction, if the trail user is human, and the mode of transportation of the trail user. One study found that observers looking at video from digital cameras were better able to accurately count the number of bikes on the trail when compared to in-person counts and that they handled counting large groups more effectively (Arnberger et al., 2006). The limitations of the digital camera are that they need to be recharged more frequently than IR cameras, can take blurry photos and are more cost prohibitive than IR cameras (Campbell, 2006).

More recently, the use of digital data collected from cell phones and geotags on pictures posted to social media websites have been employed to determine trail user numbers with mixed results (Creany et al., Sonter et al., 2016; Wu et al., 2017). All of these articles agreed that digital data can be helpful in determining spatial use patterns. Sonter et al (2016) employed a multiple regression model that correlated a large database of geotagged images with user numbers and found that they correlated in a statistically significant way. However, Wu et al (2017) found that there was a very weak correlation between geotagged images and actual user numbers reported by IR cameras. Creany et al (2021) found that cellular tracking data was a good indicator of overall use and helped account for entry into natural areas through unofficial or social trails. They did however also note that this methodology can only be applied in areas with strong cell phone reception, and thus it limits the usefulness of this method on remote portions of public lands.

The use of multiple regression models designed to anticipate trail demand is rapidly increasing. This method is different in that it attempts to model projected trail use while the other methods described above assess real-time trail use. Eliot et al (2022) found that they could create a statistically significant estimate of trail users on urban trails if they were able to plug significant factors into the model such as: urban density, annual precipitation, proximity to water, tree cover, median income, share of population with vehicle, and leisure employment nearby (Eliot et al., 2022). This methodology may be more helpful in the development of new trails rather than the management of existing trails as it predicts anticipated trail use rather than estimating past trail use that has already occurred.

In summary, there are multiple approaches that can be taken when conducting a trail use estimation. In-person counts are often costly in terms of resources and time but result in the most accurate data collection in many instances while also allowing for the inclusion of other variables such as mode of transportation, direction, and group size to be recorded (Fisher et al., 2018; Wan et al., 2014). IR cameras and digital game cameras are more affordable than in-person counts, but still require human calibration to ensure accuracy (Bates, 2014). Both IR and digital cameras are a suitable option when continuous data is necessary, cost is a primary concern, or when the count location is remote (Bates, 2014; Pettebone et al., 2019). Estimation based on collection of data from social media sites can be useful in an urban context but there is mixed evidence as to whether estimations based on social media geotag data sets are accurate (Creany et al., Sonter et al., 2016; Wu et al., 2017). Lastly, multiple regressions models designed to anticipate future use can be especially useful to urban planners and land managers as they look to design new trails and associated facilities (Eliot et al., 2022). Research that combines two or more methods is most likely to ensure accurate and comprehensive trail user count measurements.

3. 2015 Red Rock Ranger District Trail Use Estimate

The last study conducted on trail use around Sedona and the Village of Oak Creek was undertaken by the RRRD in 2015 (Red Rock Ranger District, 2016). It is important to note that the 2015 study was ambitious in its scope. In addition to estimating the total number of trail users they estimated the total number of visitors to heritage sites, visitor centers, wilderness users, use at popular destinations, total day and campsite users, and total outfitter use (Red Rock Ranger District, 2016). Below, I summarize this study in order to provide context for the 2022-2023 trail survey and to clarify variations in methodology between both studies.

3.1 Methodology

The report on the RRRD 2015 study describes the methodology used to estimate trail use in a very limited capacity. In 2015, the RRRD calculated annual usage based on trailhead register data and data collected by TRAFx cameras. TRAFx cameras are a common type of IR camera, similar to the ones described above in the literature review (Bates, 2014). They collected data directly from six trails using TRAFx cameras. The remaining twenty-two trails within the sample calculated trail use based on trailhead registration. Trailhead registration is a method of data collection that relies on users to self-report trail use and has sometimes been criticized for its low level of accuracy (Shoji et al., 2008). Between 2006 and 2013, trailhead registers were in place at 28 trailheads for visitors to voluntarily log their visit (Red Rock Ranger District, 2016). RRRD used data collected at trailhead registers from 2006 to 2013 to calculate 2015 trail use estimates. They do not include the equations they used to determine yearly trail use or how they accounted for the fact that the data was not current.

The RRRD designated all trails in their 2015 sample frame as low, moderate, or high use based on employee observations of historic usage (Koller, 2022). Several representative trails were selected for the sample at each use level (Red Rock Ranger District, 2016). The trails used for the low use sample in the 2015 study are: Dogie, Loy, Secret Canyon, Woods Canyon. Trails used for the moderate use sample in the 2016 study were: Aerie, Bear Mountain, Cockscomb, Bull Pen, Long Canyon, Sycamore Canyon, Vultee Arch, and Wilson Mountain. Trails used for the high use sample were Adobe Jack, Broken Arrow, Chuckwagon, Devil's Bridge, Doe Mountain, Fay Canyon, Fossil Creek, Little Horse, Mescal, and Soldiers Pass (Red Rock Ranger District, 2016).

At six of the sample trails, RRRD collected data using TRAFx cameras. These trails were: Bell Rock Pathway, Broken Arrow, Cathedral Rock, Devil's Bridge, Fay Canyon, and West Fork. They did not specify the period in which data was collected at each trail. All other trail use numbers were calculated off data collected from trailhead registers. Based on their data collected at each trail they calculated a yearly use estimate for each individual trail in the sample. The methodology for calculating the total number of annual users was not included within the report. They then calculated an average use number based on the individual estimates for each use strata: low, moderate, and high. The average use number was assigned to each trail of the same use strata for all trails that were not within the sample. The 2015 study report does not document the total number of trails within their sample frame – only that they extrapolated out to the total number of trails from the twenty-eight trails they collected data from.

To supplement the information available within the 2016 report, I reached out to Jennifer Burns, the recreation lead at the time the study was conducted. She informed us that they modified the total number of users who self-reported their visit using a trailhead register by a factor of five, because they had seen low levels of self-reporting at trailhead registration boxes in the past (Burns, 2022). In the study they also report the total percentage of user types divided into three categories: cyclists, equestrian users, and hikers. It is not stated how they collected this data. It may have been determined from trailhead registration data, as TRAFx cameras do not collect this type of data. They do not include the calculation they used to extrapolated user type data on the entire trail system from their sample. However, Jennifer informed me they reached out to a statistician to produce the percentages they used in their final report (Burns, 2022). Additionally, the RRRD acknowledged that the report they created was closer to an approximation of use, rather than an exact number. This is understandable as this project was conducted primarily for internal use, and there are significant financial and time constraints associated with the production of such data.

I also reached out to Laura Koller, who is listed as the lead author on the study. She informed me that use level categories for each trail were determined by Red Rock Ranger District Staff at the time and explained that they relied more heavily on TRAFx data than self-registration to calculate the averages they used for each trail use level group (Koller, 2022). However, it is unclear as to how they did this given the fact that TRAFx cameras were only in place at high use trails.

3.2 Key findings from the 2015 RRRD trail use study

In the 2015 study the authors determined that there were 1,727,714 annual trail users (Red Rock Ranger District, 2016). Even then the RRRD was seeing a dramatic increase in the number of visitors to the area. Visitor use in the district had tripled in the previous ten years, and no single use group had grown more than trail use. The other use groups included in the report are special permit uses, day site uses, visits to heritage sites, trips to visitor centers, use of scenic vistas, and visits to Fossil Creek (Red Rock Ranger District, 2016). At that time trail users accounted for 61% of all visitors to the district (Red Rock Ranger District, 2016). They estimated that 82% of all users were hikers, 17% were mountain bikers and 1% were equestrian users (Red Rock Ranger District, 2016).

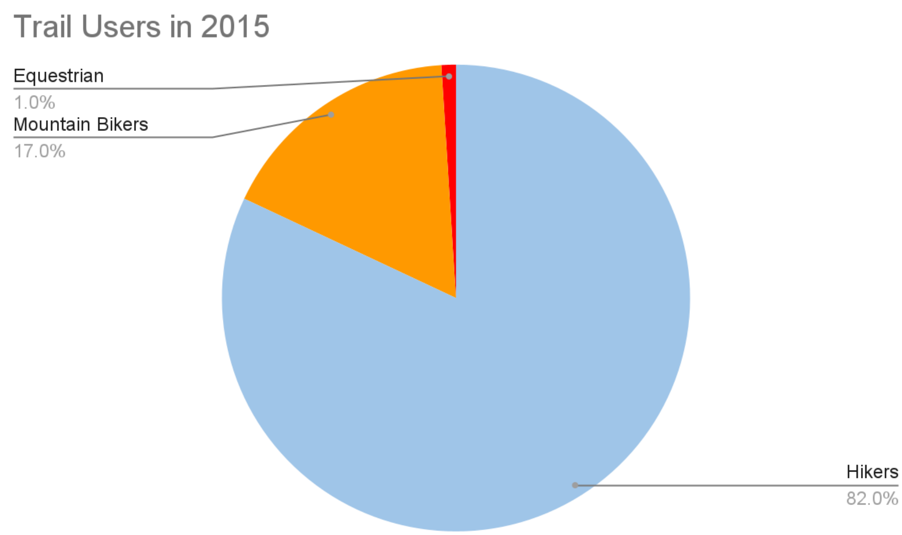


Figure 2: A pie chart showing percentages of different user types on the trail during the 2015 study conducted by Red Rock Ranger District.

4. 2022-2023 study objective

The primary objective of this study was to generate an updated estimate of the total number of trail users annually on RRRD trails around Sedona and Oak Creek from June 1st, 2022, to May 31st, 2023. I also sought to provide supplemental information to the RRRD to inform implementation of adaptive management strategies based on current usage, including the average number of trail users per group and how many dogs accompany visitors each year. This information can improve access to funding and resources to advance trail management so that RRRD can continue to undertake comprehensive land management measures, while allowing the public to reap the benefits of public land use with minimal ecological and cultural impact.

5. Methodology

5.1 Study area trail population

This study took place in the Sedona and Oak Creek area within the RRRD. Our sample population consisted of 118 nonmotorized trails on USFS land, spanning a total of 199 miles of trail. For a full list of trails included in this study, see Appendix B. Many of these trails are loops and intersect with one another or are accessible by multiple trail heads. Some of the trails within the study area connect to federally designated wilderness areas and therefore can only be accessed legally by foot or by horse (Coconino National Forest, 2022). Only twelve of the trails within the sample (approximately 10%) were classified as wilderness trails. The study area and 118 trails that are the focus of this research do not include all trails located on the RRRD; only those adjacent to or in close proximity to Sedona and Oak Creek where the majority of visitation occurs.

5.2 Sampling Strategy and Equipment

I employed a proportionate random stratified sampling method when selecting our trail for inclusion in the study sample. Proportionate random stratified sampling involves taking random samples from groups that have been defined by a descriptive characteristic (Swenson, 1978). In this study, the variable used to define groupings was level of trail use. Trails were classified as low, moderate, and high use based on the 2015 study and input from current staff on the RRRD, and then verified by independent local experts nominated by those staff. In total, there were twenty-five high use trails, 62 moderate use trails, and 31 low use trails within our sample population. This meant that 21% of the trails in our study would need to be high use, 53% of the trails would need to be moderate use, and 26% of the trails would need to be low use. This is important because I wanted our trail sample frame to be representative of the entire trail system to more accurately reflect current use conditions (Grafström & Schelin, 2014). Collecting data at all the trails within the trail system was not feasible due to funding and time constraints. See Appendix B for a complete table of trails and their use levels within our sample.

A subset of twenty trails was determined as appropriate to collect data that could be extrapolated to the entire trail population given the time and resources available. With a sample size of 20, I was able to calculate a yearly use estimate with a confidence interval of 95% and a margin of error of 20%, given the original sample population of 118 trails.

Two data collection efforts were conducted and merged in this study: (1) in-person trail counts, and (2) TRAFx camera data. Timing of in-person data collection was based on my availability to conduct field research, ensuring that data collection spanned both peak and off-peak seasons as is recommended by several other studies on trail use estimation (Alta Planning + Design, 2016, Bergman et al. 2016, Watson et al., 2000). I used continuous data from 2018 to 2021 collected by TRAFx cameras to determine the timing of high use seasons to support the most accurate extrapolations of field data to achieve an annual estimate. There are currently eleven TRAFx cameras in place at trailheads across the RRRD, but only two had continuous coverage over the three years leading up to and including our data collection effort due to weather conditions or vandalism. Using the TRAFx data from Bell Rock Pathway and Broken Arrow, it was determined that Spring and Fall have the greatest number of trail users (Figure 3). For the purposes of this study, I defined spring as March through May, summer as June to

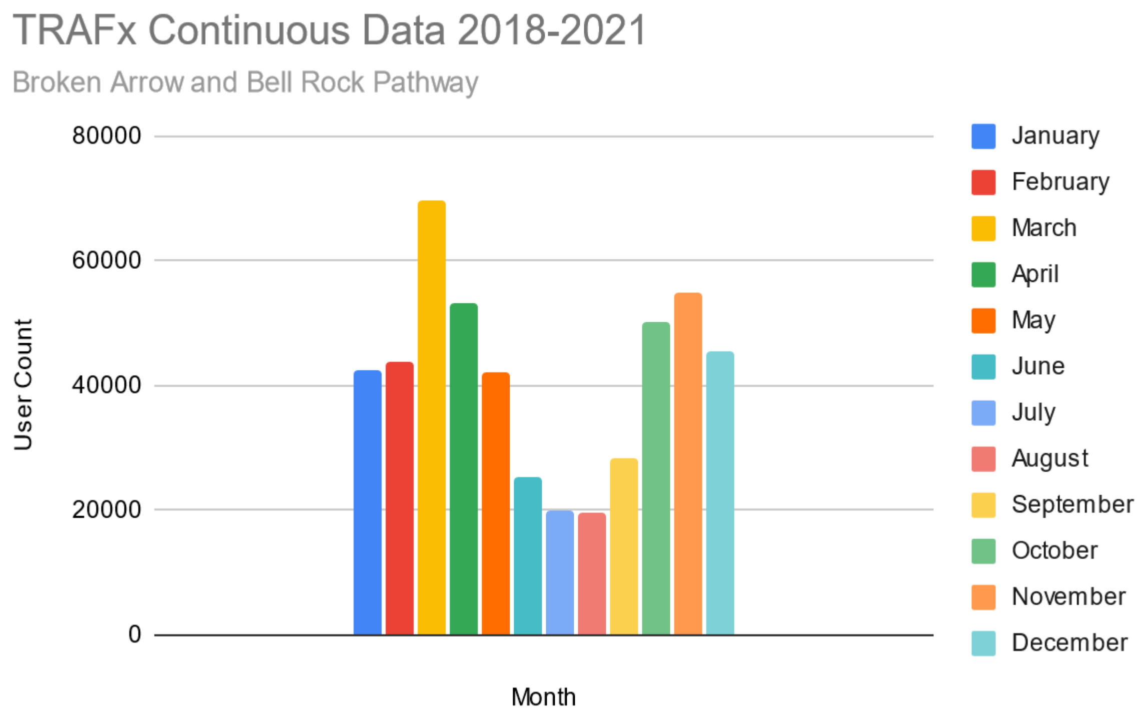


Figure 3: A graph illustrating trail use trends at Broken Arrow and Bell Rock Pathway using TRAFx data 2018-2021.

August, fall as September through November, and winter as December through February (Trenberth, 1983). In-person trail count data was collected from March through May 2023. Additionally, I ran a pilot trail survey in the field during December 2022 to test our data collection method and make adjustments as necessary to ensure data were collected in a rigorous and comprehensive fashion.

5.3 Data Collection

In-person trail counts were conducted by researchers from Northern Arizona University and volunteers from the Sedona Chapter of Friends of the Forest. In total, 320 hours were spent in the field collecting trail use data for this project. This was a very intensive way of collecting data, but the recreation literature consistently demonstrates that in-person data collection is the most accurate technique (Wan et al., 2014). All data was collected within 100 yards of each selected trailhead in order to capture the majority of trail users, based on recommendations provided by Watson et al. (2000). Trail users were only counted while entering the trail to avoid counting the same individual multiple times. This is adequate for creating a total user estimate as this study was not focused on how much of the trail an individual user completes. Given that many of the trails are accessible by multiple trail heads, I determined that I would only count trail users as they entered the trail, which is also in line with the procedures established by Watson et al., (2000). For a map of all data collection sites please see Figure 4.

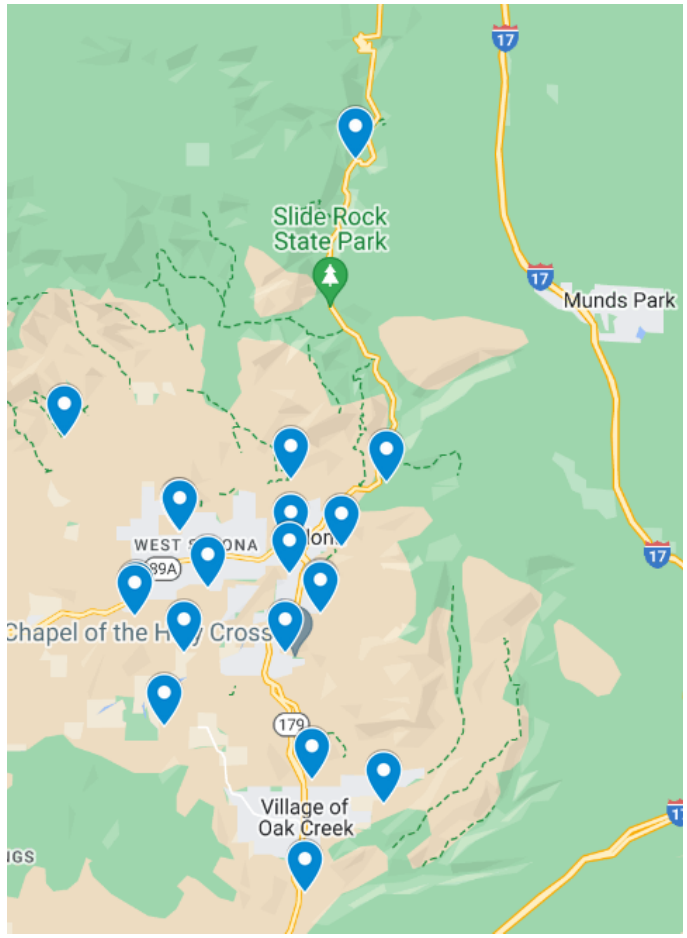


Figure 4: A map with the location of data collection sites in the Sedona and Village of Oak Creek Area.

In-person trail count data was collected for each trail on one weekday and one weekend day. This is based on a modified version of the sampling techniques provided by Watson et al. (2000), in which any previous weekday can stand in for the same weekday the week before the sample is taken, or the week after. Due to the large nature of the sample and time constraints, in our data collection period any weekday stands in for any weekday in the season at that trail and any weekend day stands in for any weekend day within that season. I defined the week as Monday to Friday and the weekend as Saturday and Sunday. I ensured that data collection occurred on different weekdays and weekends, as I expected there would be wider variation between trail use on a Monday and a Friday than on the weekend.

At each trailhead location, the following data was collected: size of group, time entered trail, mode of transportation, and number of dogs with each group. Mode of transportation was reported as one of the following categories: hikers, bikers, equestrians, or other. See Appendix D for the sheet I used to collect data in the field, based on a template from Waton et al. (2000). Once the field data had been collected it was added into a master data sheet. Data collection took place on selected days from 8:00 am to 4:00 pm in order to capture the largest number of users in an eight-hour window and maintain consistency in data collection across trails and data collectors. This peak use window was determined by examining available TRAFx camera data from March of 2021 (see Appendix E). It was determined that visitation was minimal outside of the sample window.

5.4 Estimating Trail Use

In order to calculate our twelve-month use figure from June 1st, 2022, to May 31st, 2023, I began by estimating the total weekly use for each trail based on the weekday count and weekend count that I collected in the field. This was done by multiplying the weekend number by two and the weekday number by five to create a seven-day use figure. I then calculated the spring season total for each trail in the sample by multiplying the weekly figure by twelve, as there are twelve weeks in each season as defined above.

The next step was to identify what percentage of trail users during the spring season were on high, medium, and low use trails so that I could extrapolate these numbers from our twenty sample trails to all 118 trails in the Sedona-Village of Oak Creek area. This stratification of site use levels is common practice in trail use estimates as it is a helpful tool when differing site types receive vastly differing numbers of users (Alta Planning + Design, 2016; Watson et al., 2000). This extrapolation first required us to identify the use levels of our twenty trails as a ratio of the 118 total trails in the study area. For example, our sample of high use trails consisted of four of the twenty-five total high use trails on the RRRD. This means to calculate at our total figure I

$$\left.\begin{array}{r}\text{Week Day} - \text{Result} \times 5\\ \text{Weekend} - \text{Result} \ \times 2\end{array}\right\} 1 \text{ Week}(\times 12 = 1 \text{ Season})$$

$$n = 118$$

$$\text{Sample} = 20$$

$$\text{High Use } \frac{4}{25}$$

$$\text{Moderate Use } \frac{11}{62}$$

$$\text{Low Use } \frac{5}{31}$$

$$\text{High Use Example}$$

$$\text{Trail 1 Week } ((\text{WD} \times 5) + (\text{WE} \times 2)) = \text{Week Total}$$

Figure 5: Example of equation used to calculate weekly and seasonal use.

multiplied the high use strata seasonal data from our sample by 6.25 to arrive at total high strata trail use. These same steps were repeated for moderate and low use strata as well. See Appendix F for a full table of daily, weekly, and seasonal use by strata, and Figure 5 for the full calculation to establish annual use. This provided us with an estimate of trail use for all trails during the spring season.

Next, I sought to extrapolate this single season of data to the three other seasons. I used the continuous TRAFx data collected from Bell Rock Pathway and Broken Arrow from June 1st, 2022, to May 31st, 2023, to determine what percentage of year-round visitation occurred in our spring window. I found that 35% of annual visitation to these trails occurred in the spring and considered this to be representative of all trails in the RRRD. This meant I needed to extrapolate our spring estimate upwards by 65% to generate a total annual use number. I did not adjust the annual figure to account for users outside of the 8 am to 4 pm window because I provided a +/- 20% total use estimate range and a relatively small number of users would have been captured outside of our data collection window based on TRAFx data (see Appendix E for hourly TRAFx data).

6. Results

6.1. Annual trail use estimate for 2022-2023

The total annual trail use in the study area of National Forest surrounding Sedona and Village of Oak Creek from June 1st, 2022, to May 31st, 2023, was estimated to be 2,223,804. This figure was adjusted upwards and downwards by 20% to account for our margin of error. Taking into account the margin of error, our range of estimates for the total number of trail users

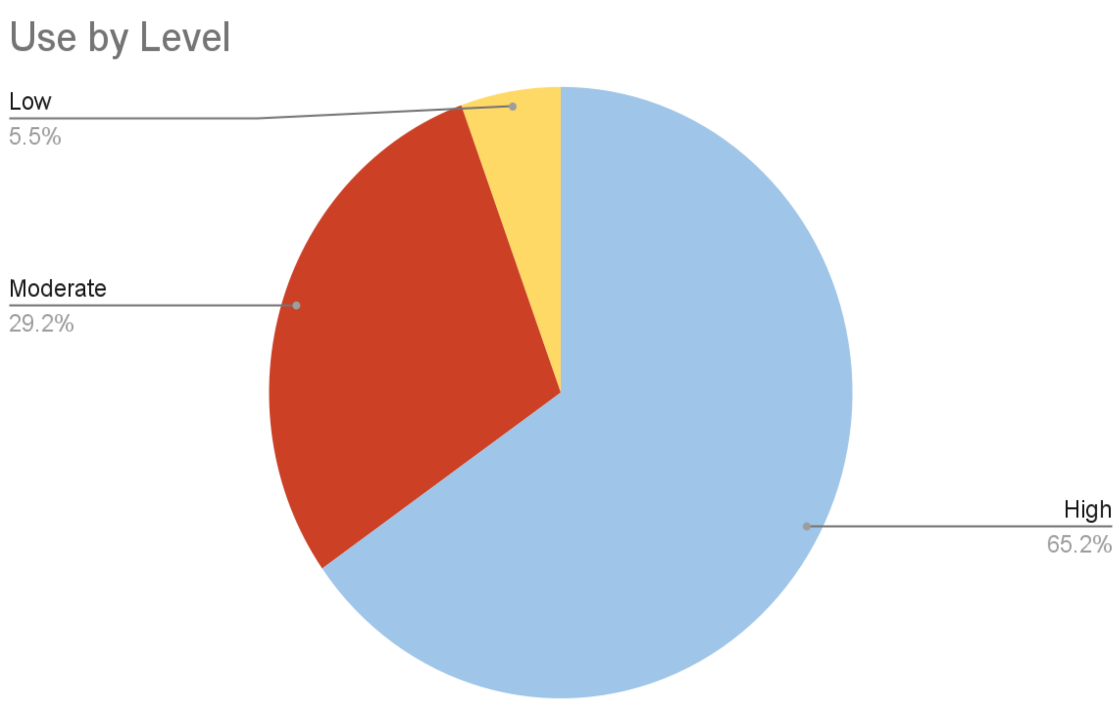


Figure 6: Percentage of yearly trail use by trail strata from June 1st, 2022, to May 31st, 2023.

for this twelve-month period is between 1,779,043 and 2,668,564. I estimated that, high use trails accounted for approximately 1,449,920 trail users annually. Moderate use trails accounted for 649,350 users annually, and low use trails accounted for 122,309 trail users annually. Approximately 65.2% of trail use was accounted for on high use trails alone.

6.2. A profile of trail usership

In-person trailhead count data collected between March and May of 2023 indicates that hikers accounted for the vast majority of trail users at 94%, while bikers accounted for 6% and equestrian users accounted for less than 1% of users. I note that these data are to some degree a product of our random sample approach to trail selection, and that some variation is likely to occur on other trails with more distinct usership outside of our sample.

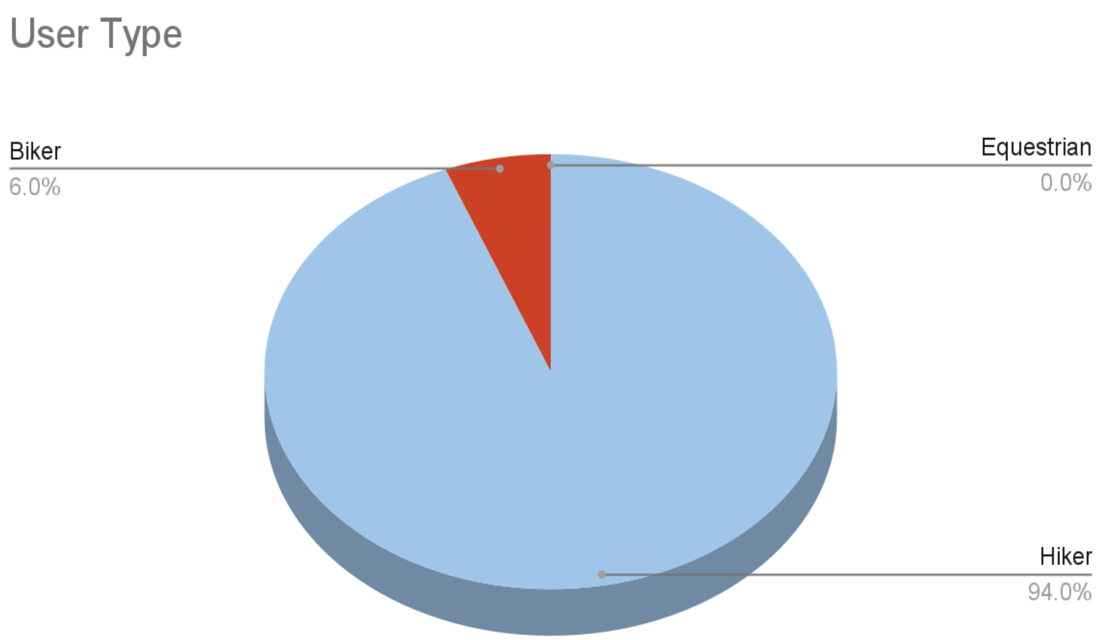


Figure 7: Percentage of different user types on the trail from June 1st, 2022, to May 31st, 2023.

Field data also indicates that 9 am to 11 am is the highest visitation window to trail heads, with the majority of users arriving between 10AM-11AM.

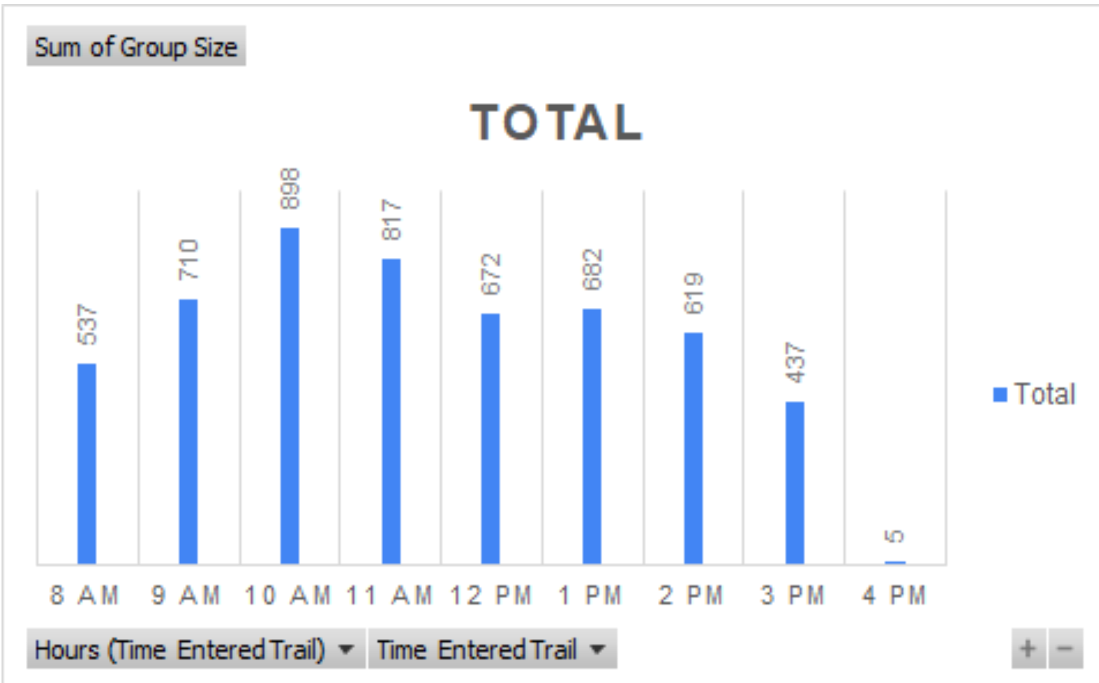


Figure 8: Sum of hourly totals across all trails from in-person count.

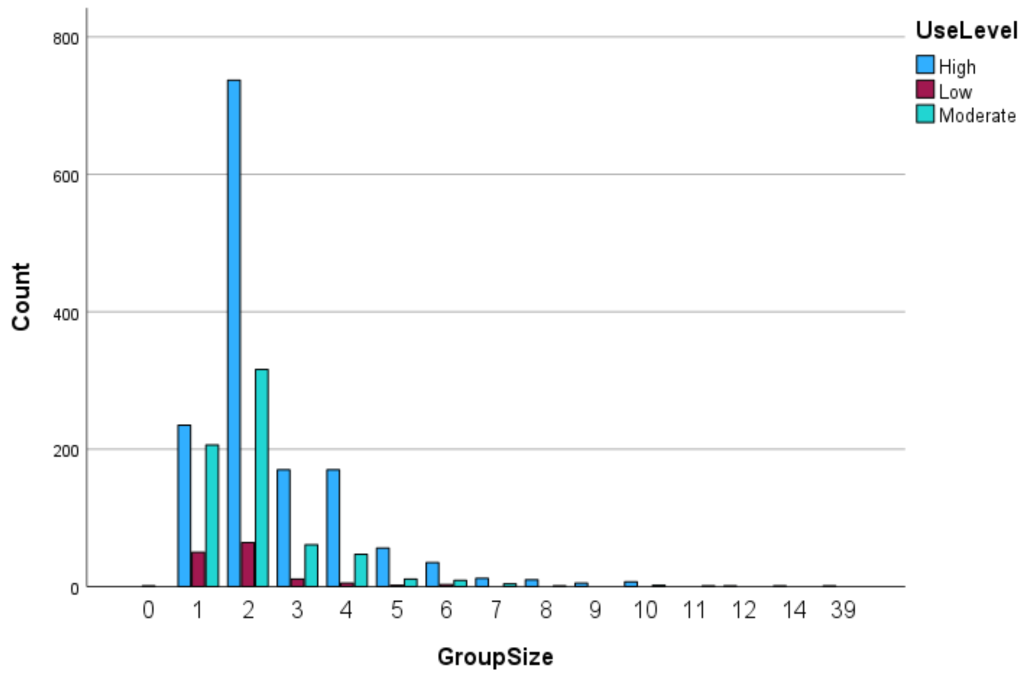


Figure 9: Total count of group size recorded in-person by trail use strata.

The average group size within our data set was 2.4. The single largest group in our data set was 39 trail users. I ran an ANOVA test and a chi square test in quantitative analysis software IBM SPSS (2021) and determined there was no correlation between time of day and group size. However, I did determine that there was a significant relationship between trail level use and group size; high use trails see larger group sizes when compared to moderate and low use trails.

The results were significant to p=<.001.

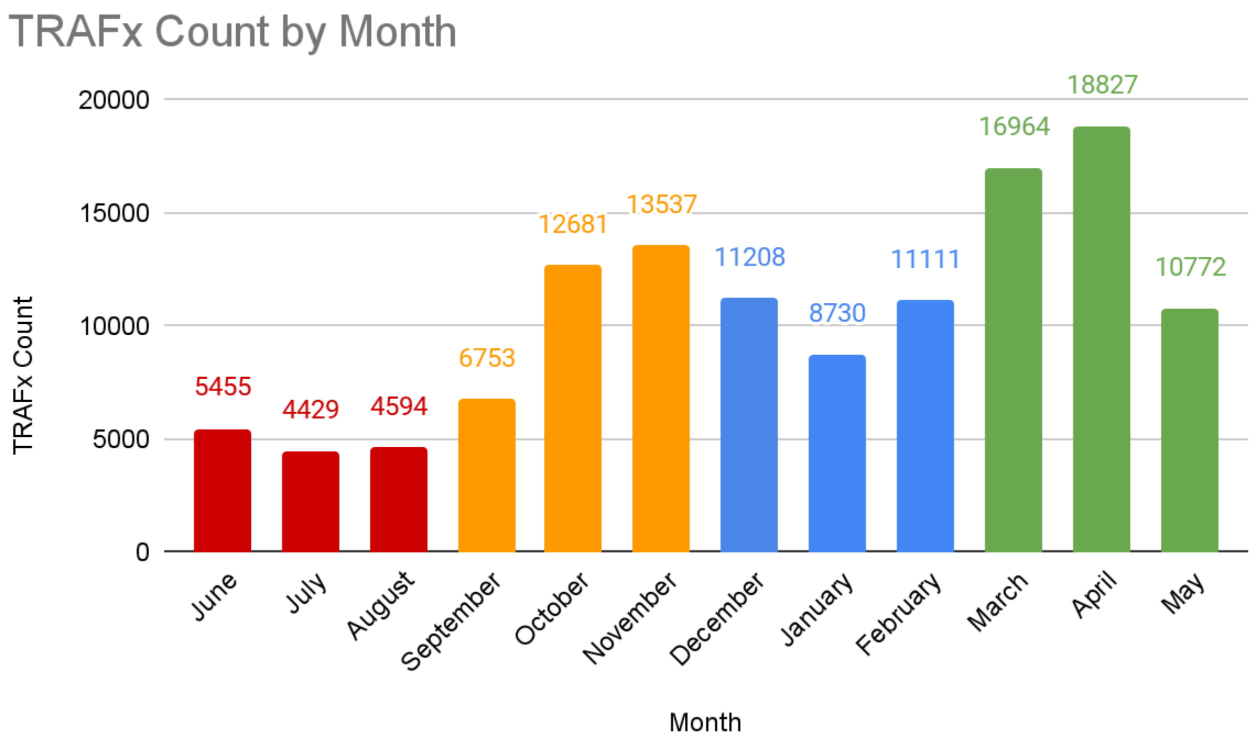


Figure 10: Monthly counts from TRAFx cameras at Bell Rock Pathway and Broken Arrow from June 2022 to May 2023. The months are color coded by season. Red bars indicate summer, orange indicates fall, blue indicates winter, and green represents spring.

Data gathered continuously from TRAFx cameras at Bell Rock Pathway and Broken Arrow during our data collection period shows similar seasonality to the continuous data gathered from 2018 to 2021. Winter and fall show similar levels of trail use. There is a significant decrease in trail use during the summer months and a pronounced increase in trail use during the spring. April is the month with the highest trail use and July is the month with the lowest overall trail use.

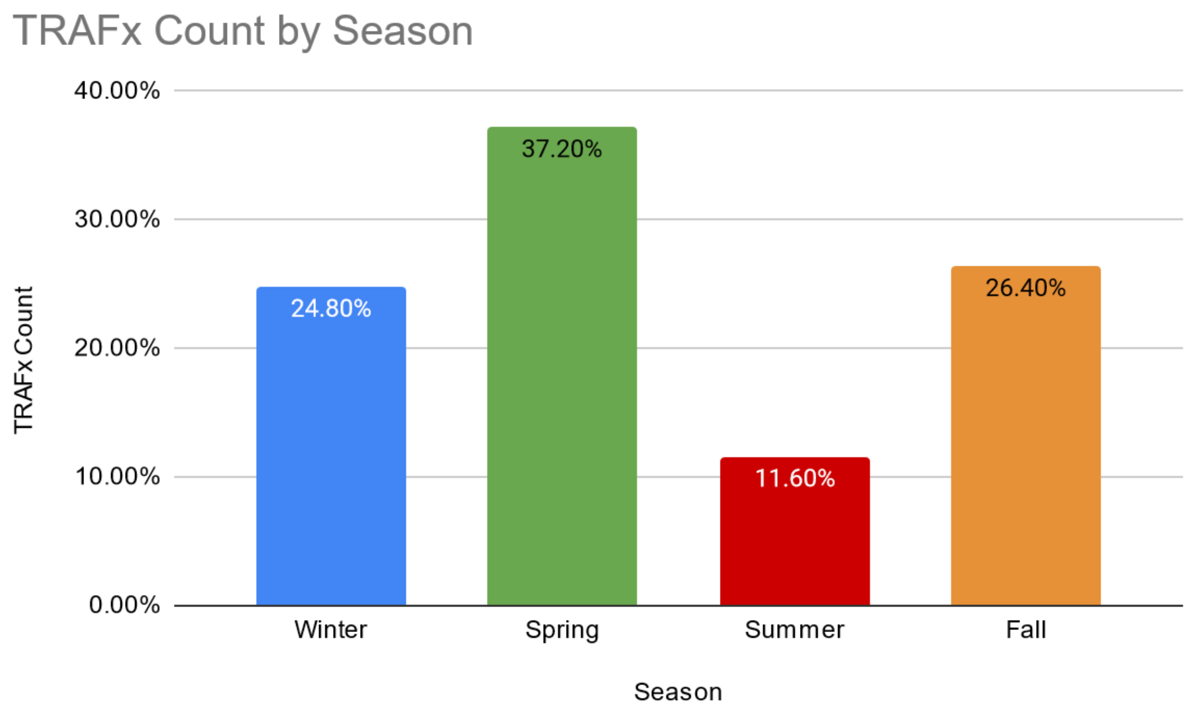


Figure 12: Percentage of total use by season from TRAFx data collected at Broken Arrow and Bell Rock Pathway from 2018 to 2022.

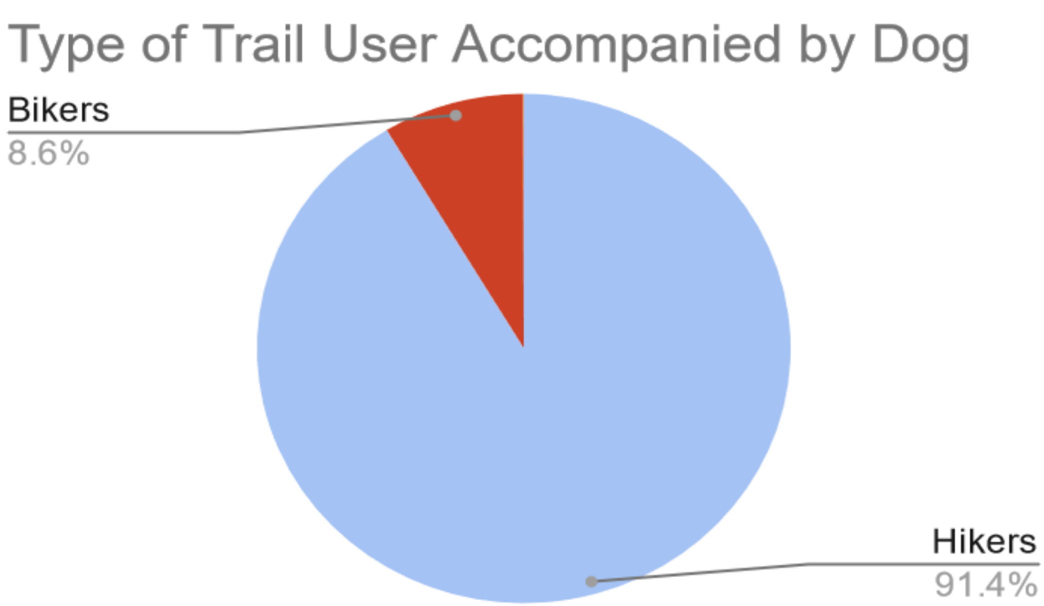


Figure 11: Percentage of user types that were accompanied by a dog on the trail.

Lastly, I calculated the total number of dogs on the trail annually based on data collected in the field. For every twenty people on the trail there was one dog recorded. The estimated number of dogs on trails annually is 111,190 with a range of 88,952 to 133,428 when accounting for a 20% margin of error.

7. Comparison to 2015 Study

7.1 Increase in Trail Use

There has been a significant increase in trail use since the 2015 study was conducted by the RRRD. In the 2015 study, the authors state that total visitation in 2006 was approximately 750,500 people, of which 401,621 were trail users (Koller, 2016). They reported that in 2015 there were a total of 1,727,714 trail users in the Sedona and Village of Oak Creek Area (Koller, 2016). Trail use appears to have increased by approximately half a million people between 2015 and 2022-2023 in our study.

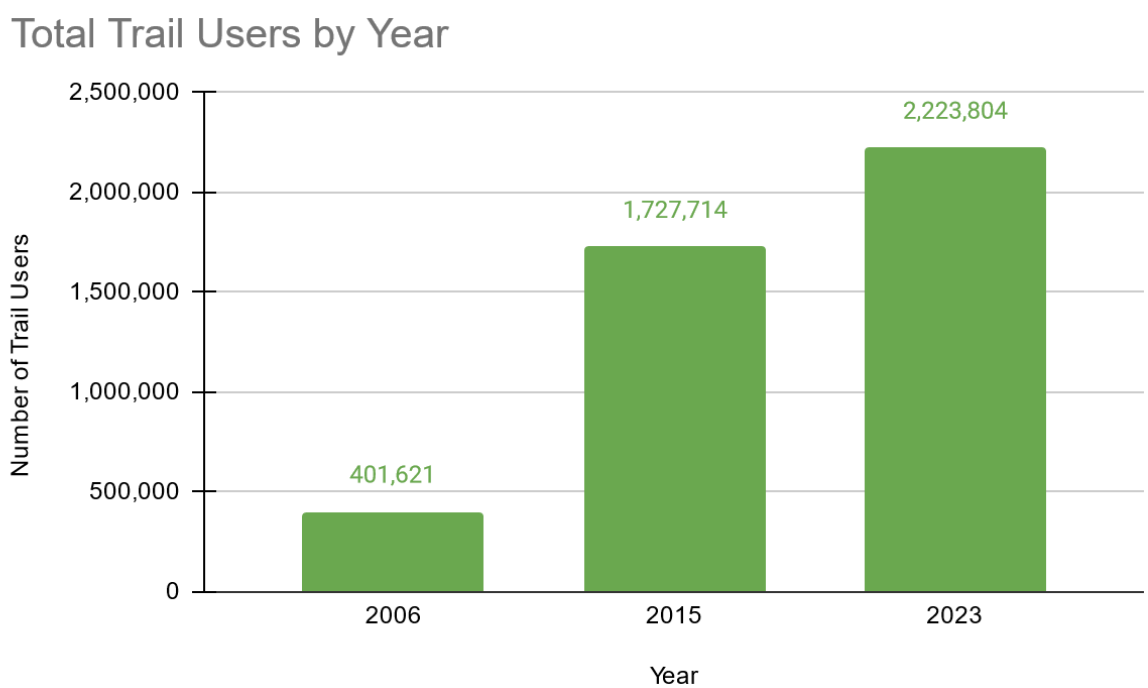


Figure 13: Graph showing total number of trail users estimated across three studies completed in 2006, 2015, and 2023.

From 2006 to 2015 there was a 232% increase in trail use or 1,326,093 more trail users. From 2015 to 2023 there was a 28.7% growth in the number of trail users or 496,090 more people on the trail. These findings align with existing recreation research describing a significant increase in total number of trail users in recent years (Bawa, 2017; and Yang, 2021). There is a significant jump in the number of trail users counted from 2014 to 2015 within the RRRD's data that to appears to be a direct result of changes to the trail count methodology that depends more heavily on TRAFx cameras than self-reporting at trails heads. This may mean that in 2006, the number of trail users could be significantly underestimated (Koller, 2016).

There are some visitors to National Forest land around Sedona and Village of Oak Creek, who do not use the trails, that may not captured within our trail sample population. In the 2015 study, trail use accounted for 61% of district wide usership. If this percentage of total use is still accurate, that means that there was a total of 3,645,580 visitors to the RRRD from 2022-2023 during the time of the most recent study. This would indicate an additional 1,421,776 visitors not accounted for within the scope of our study who did not use USFS trails.

7.2 Trail User Type

There are significant differences in the 2015 study and our current study when it comes to mode of transportation of trail users. The 2015 study found that hikers accounted for 82% of trail users, mountain bikers were 17% of trail users, and equestrians were 1% of trail users (Koller, 2015). In our study I found that 94% of trail users were hikers, 6% were mountain bikers, and less than 1% were equestrians.

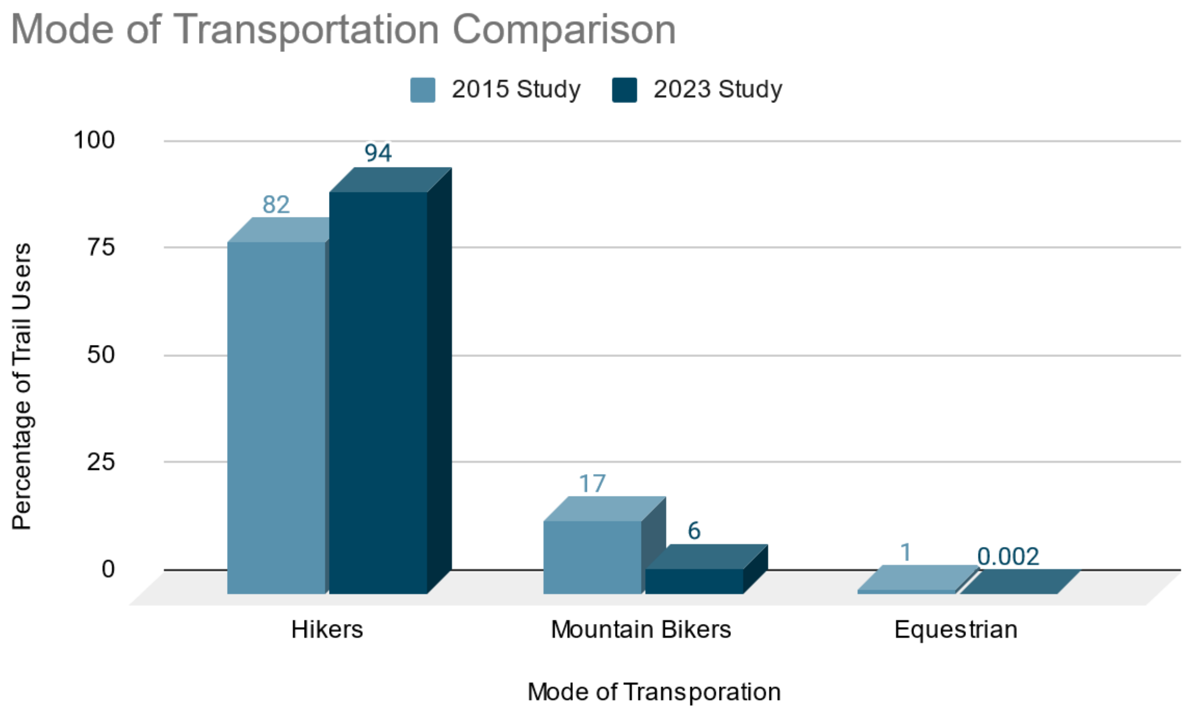


Figure 14: A comparison of transportation mode of trail users in the 2015 and 2023 studies.

It is important to note that the difference in these results may be a result of different data collection approaches rather than an accurate reflection of change in mode of transportation of trail users. I selected our trails through random stratified sampling, based on the level of usership of trails. In future studies it may be helpful to conduct additional stratification by choosing trails based on common user types and stratifying them that way as well. In conversations with professionals and residents familiar with the area and within the in-person trail count data, it became apparent that some trails are more popular with certain user groups, and that our trail sample frame may not have reflected that. However, it is also possible that an increase in hikers lead to a decrease in percentage of mountain bikers and equestrians as these uses can conflict with one another at times (Moore, 1994).

7.3 Wilderness Use

A total of twelve of the 118 trails within this study's sample population were considered wilderness trails. This designation was assigned when a majority of the trail was inside of a legally designated wilderness area. Within our sample, four of the twenty trails were wilderness trails with at least one wilderness trail inside of each use strata.

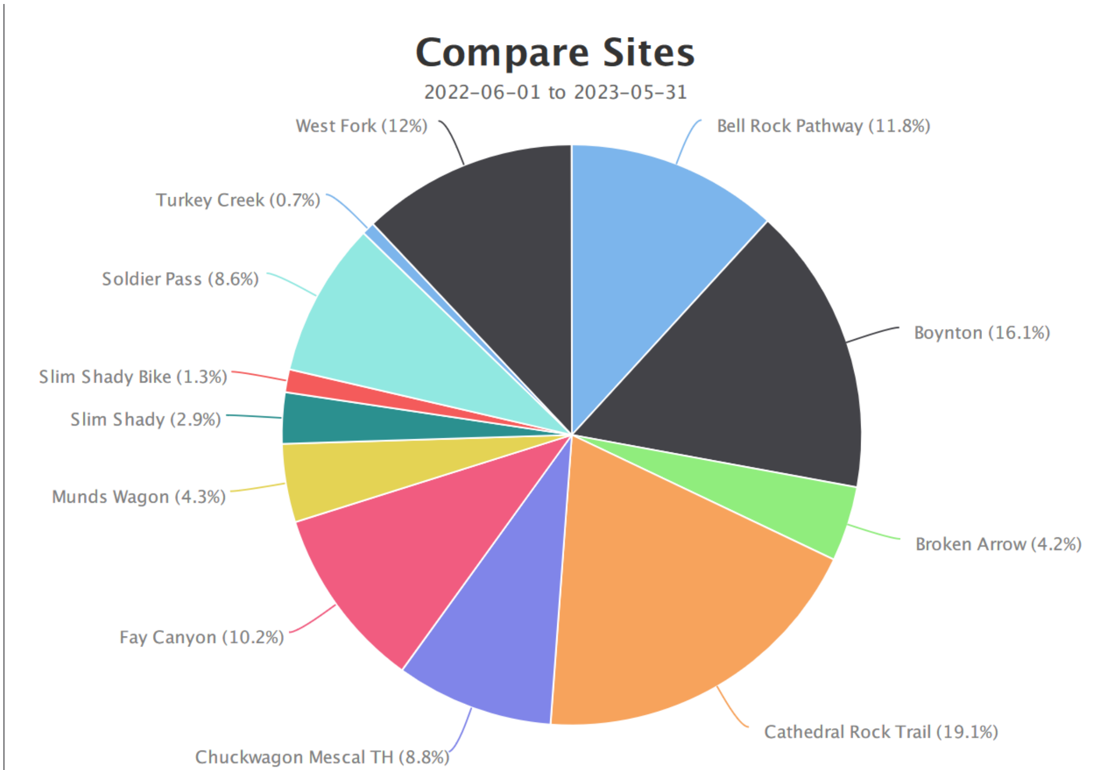
Table 1: Wilderness trails in our study and their use level strata.

Wilderness Trails	
Fay Canyon	High Use
West Fork	High Use
Margs Draw	Moderate Use
Jacks Canyon	Low Use

Wilderness trails accounted for 36% of total trail users during in-person trail counts. This is likely because high use trails account for the vast majority of trail use in the area and of our four high use trails within the sample, two were wilderness trails. This would mean that there were 800,569 trail users on wilderness trails from June 1st, 2022, to May 31st, 2023. Our estimate is in line with the use estimate established in the 2015 study, which found that 35% of all trail use in the Sedona and Oak Creek area took place in wilderness (Koller, 2016).

7.4 Most Visited Trails

Using data provided from TRAFx cameras at the busiest sites in the Sedona and Village of Oak Creek area, I found that the top 5 most trafficked trails based on average daily use are as follows: 1. Cathedral Rock, 2. Boynton Canyon, 3. West Fork, 4. Bell Rock Pathway, and 5. Fay Canyon.



Site Name		Daily Average
Bell Rock Pathway		256.5 (11.8%)
Boynton		349.5 (16.1%)
Broken Arrow		90.5 (4.2%)
Cathedral Rock Trail		415.4 (19.1%)
Chuckwagon Mescal TH		191 (8.8%)
Fay Canyon		221.3 (10.2%)
Munds Wagon		94.4 (4.3%)
Slim Shady		62 (2.9%)
Slim Shady Bike		27.6 (1.3%)
Soldier Pass		187.3 (8.6%)
Turkey Creek		15.5 (0.7%)
West Fork		261.5 (12.0%)

(D) = divide by 2 applied

Figure 15: TRAFx camera data during our sample period showing daily average use.

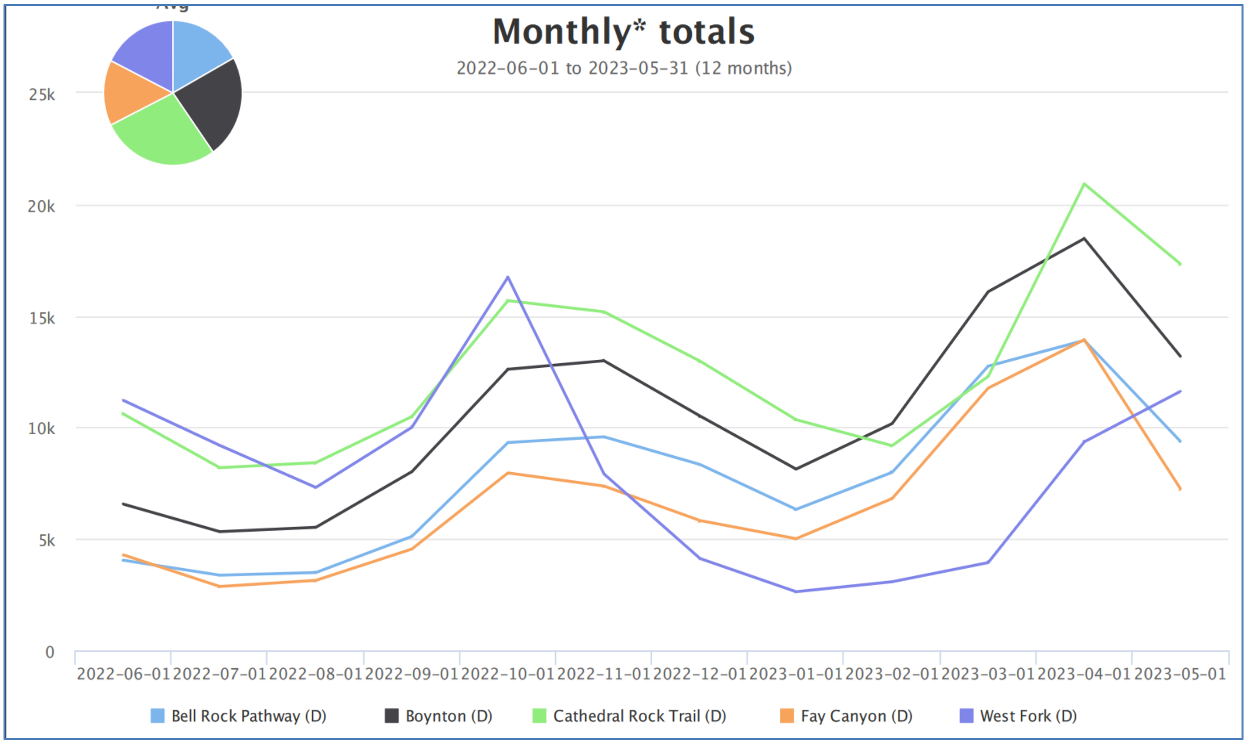


Figure 16: Monthly use totals at the five most used trails within our sample period based on TRAFx data.

Figure 16 demonstrates that the top five most popular trails follow typical seasonal use patterns except for West Fork Trail. This is likely due to the fact that West Fork has a substantial number of creek crossings, and the fact that it is further north and at higher elevation than many of the trails within our sample frame.

In the 2015 study the top five most used trails were: 1. Bell Rock Pathway, 2. Cathedral Rock, 3. West Fork, 4. Devils Bridge, and 5. Broken Arow (Koller, 2016). Table 2 shows a side-by-side comparison of the most visited trails in both the 2015 and 2023 studies. It is important to note that the 2015 and 2023 studies did not use the same subset of trails, which means they are not directly comparable.

Use rank	2015	2023
1	Bell Rock Pathway	Cathedral Rock
2	Cathedral Rock	Boynton Canyon
3	West Fork	West Fork
4	Devils Bridge	Bell Rock Pathway
5	Broken Arow	Fay Canyon

Table 2: Comparison of most used trails in 2015 and 2023.

8. Discussion

8.1 Overview of findings

A 28.7% increase in the annual number of trail users has occurred between 2015 and 2023. These data also suggest that there may be shifts in the types of trail users in the Sedona and Village of Oak Creek area towards a more hiker-dominated recreation environment. This study also shows that there are clear temporal and seasonal factors to consider when it comes to trail use. The greatest number of people access trails from 9AM to 11AM. It can also be seen that there is clear seasonality of use, with more trail use occurring during spring months. There is a significant dip in usership in the summer, likely due to the heat. High temperatures can drastically affect recreation behavior (Pröbstl-Haider et al., 2021).

Additionally, I was able to show that there is a correlation between group size and the use level of trails. High use trails saw larger group sizes on average than moderate and low use trails. This is important because it suggests that high use trails may have significantly different needs when it comes to parking management. Further research could explore the average number of people per vehicle at parking lots near high use trails.

Lastly, I estimated that there were between 88,952 to 133,428 dogs on the trail within our sample period. I did not differentiate between dogs on and off leash. Dogs off leash can have significant impacts on wildlife communities and future studies should collect data on this topic to better inform land managers of the extent to which these impacts are occurring (Forrest & St Clair, 2006).

8.2 Future Research Questions

This study has laid the groundwork for future research based on an accurate trail use estimate. Another study using a similar methodology to the one used in this study should be conducted five years from now to continue to track changes in overall trail use in the area. Future research should seek to expand upon and provide more in-depth information based on this study in order to provide up to date information for land managers. This includes efforts to better understand the spatial extent of trail use on national forest land in the Sedona and Village of Oak Creek area. Researchers may also look to ask questions through either surveys or interviews that can help create a more comprehensive profile of trail users in the Sedona and Village of Oak Creek area. Questions asked might ask similar questions asked by the National Visitor Use Monitoring Survey and expand upon those themes. Possible lines of questioning include:

- Where are visitors traveling from?
- How frequently do trail users use trails within the sample frame?
- How do trail users perceive the level of solitude on the trail?
- Did trail users find the level of parking at the trail head adequate?
- What trails would trail users consider hiking on, if the trail they are on now were to close temporarily?

- What percentage of total use within the trail system takes place at the five most used trails?
- How does Recreation Opportunity Spectrum classification affect trail use?

Additionally, researchers could examine whether a correlation exists between temperature and trail use. By installing thermometers alongside TRAFx cameras or using online weather databases if accurate enough, continuous data could be collected to determine the temperatures, both high and low, at which trail user numbers significantly decline. This data could be helpful in determining possible impacts on trail user numbers due to increased temperatures as a result of climate change.

8.3 Implications

Given the number of recreationists on trails in our high use strata, RRRD may want to consider permits based on peak use times and seasonality to disperse users from the highest use trails. The district could consider implementing a permit at a subset of the busiest trails, either year-round or during periods of peak use. They could also consider an increased parking fee at the peak use window of 9 am to 11 am. RRRD might also consider providing information about trails with lower use on social media and at visitors centers to disperse trail use to moderate and low use trails. These efforts could also be accompanied by an ecological impact study at high use trails, in order to better understand the ecological impacts of high recreational use. Additionally, if the trail is within a designated wilderness area, solitude monitoring could be helpful as well.

Lastly, RRRD could consider installing more TRAFx cameras across different use level strata (moderate and low use, rather than just high use) for a more complete picture of trail use at any given time if funding is available. In this study, I have demonstrated that a sample size of twenty trails is sufficient to estimate trail use in the area with a relatively high level of accuracy.

Expansion of TRAFx camera use would provide continuous data that better reflects overall trail use levels in the area at any given time. Using TRAFx data is likely to more affordable than an in-person count, such as the one conducted in this study (Bates, 2014).

9. Conclusion

This study documents an increase of 496,090 annual trail users for the period of June 1st, 2022, to May 31st, 2023, when compared to the 2015 study (Red Rock Rangers District, 2015). That is a 28.7% percent increase in trail use. This marks a significant increase in local trail use and places these data in line with other research that has noted increased visitation on federal and state lands in the past decade (Bawa, 2017). This could be due to the continued growth of western cities such as Phoenix, Sedona, and Flagstaff (Bowker et al., 2009), a general increase in interest in outdoor recreation (Bawa, 2017), or social media (Peterson, 2022). Leveraging these findings to access additional staff and financial support could allow the district to continue to manage national forest lands in a sustainable way well into the future.

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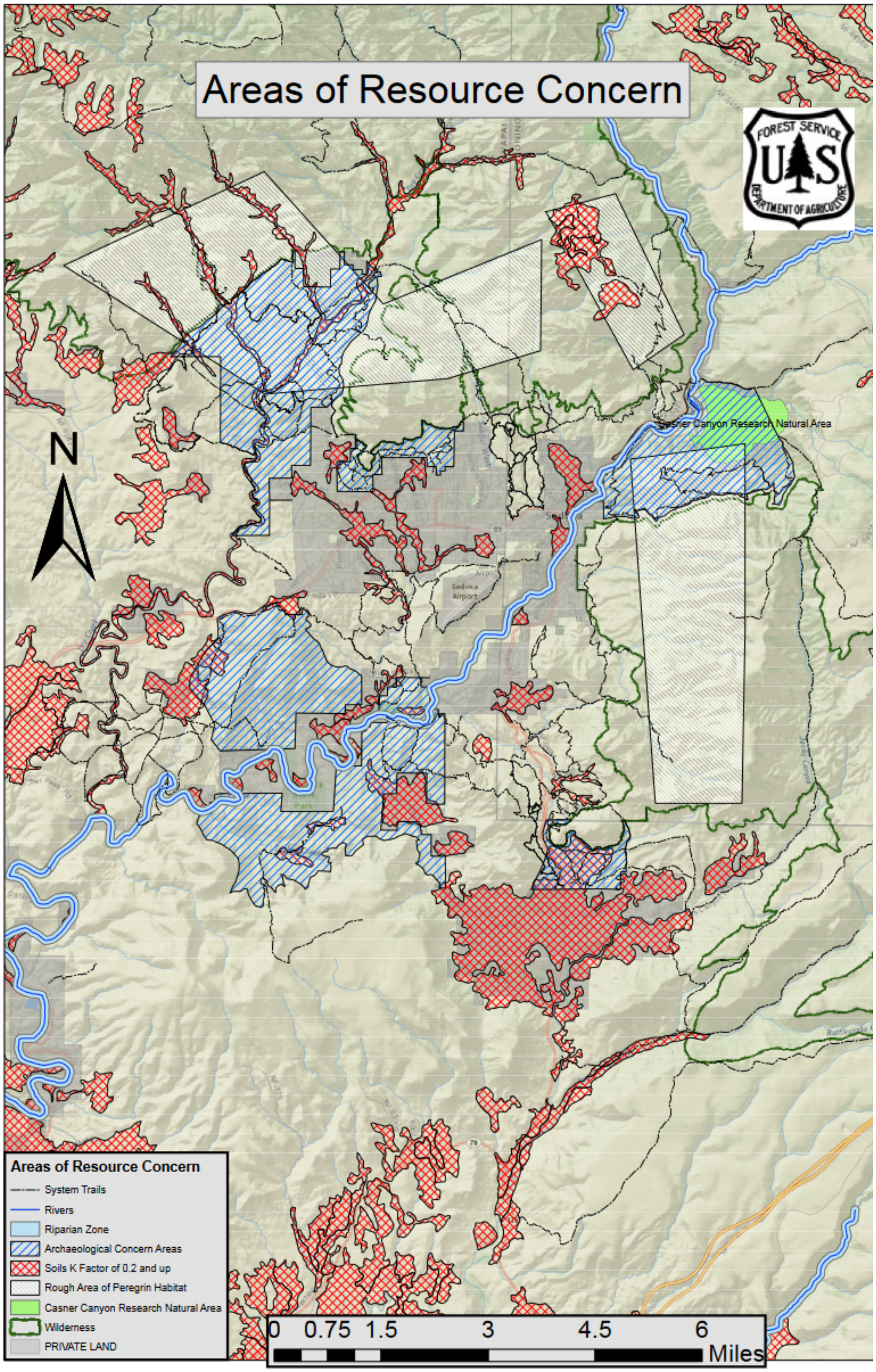
Appendix A: Area of Resource Concern Map from Red Rock Ranger District



(Red Rock Ranger District, 2015)

Appendix B:Trails Within Sample Frame and Use Level

High (4 of 20)	Moderate (11 of 20)	Low (5 of 20)
Bell Rock Pathway*	Thunder Mountain	Schuerman Mt #56
Fay Canyon*	Grand Central	Bandit
West Fork*	Allen's Bend	Woods Canyon
Broken Arrow #125*	Huckaby #161	Jacks Canyon #55 W
	Lower Chimney Rock	Old Post
	Scorpion	
	Brewer	
	Margs Draw	
	Jim Thompson	
	Turkey Creek #92	
	Mystic	
High:25	Moderate:62	Low: 31
21%	53%	26.00%
4	11	5
Population Total: 118		*Indicates TRAFx

Appendix C:List of Trails within Study Area and Classifications

Trail Name	Usage	Mileage	TRAFx Counter	2015 Study	Wilderness
Adobe Jack	High	2	No	Yes	No
Airport Loop	High	3.3	No	Yes	No
Baby Bell	High	0.2	No	Yes	No
Baldwin	High	2	No	Yes	No
Basalt	High	0.1	No	Yes	No
Bell Rock Pathway	High	3.7	Yes	Yes	No
Bell Rock Singletrack Bypass	High	0.7	Yes	Yes	No
Boynton Canyon	High	2.8	Yes	Yes	Yes
Boynton Spire (Vista)	High	0.2	No	Yes	Yes
Brins Mesa	High	3.7	No	Yes	Yes
Broken Arrow #125	High	1.5	Yes	Yes	No
Chuckwagon	High	5.2	Yes	Yes	No
Coconino #172b	High	0.4	No	Yes	No
Deadman’s Pass	High	1.4	No	Yes	No
Doe Mtn Trail #60	High	0.7	No	Yes	No
Little Horse	High	1.5	No	Yes	No
Mescal	High	2.6	No	Yes	No
Phone #96A	High	0.5	No	Yes	No
Slim Shady	High	2.5	Yes	Yes	No
Soldiers Pass	High	2	Yes	Yes	Yes
Submarine Rock	High	0.5	No	Yes	No
Templeton	High	3.5	No	Yes	No
West Fork	High	3	Yes	Yes	Yes
Cathedral Rock #170	High	0.7	Yes	Yes	No
Fay Canyon	High	1.2	Yes	Yes	Yes
Bandit	Low	0.5	No	Yes	No
Bolo	Low	0.5	No	No	No
Canyon of Fools	Low	1.2	No	Yes	No
Carroll Canyon	Low	1.8	No	Yes	No
Centennial	Low	0.3	No	Yes	No
Crusty	Low	0.4	No	Yes	No
Dairy Springs (Rabbit Ears)	Low	2	No	Yes	No
Ground Control	Low	0.8	No	No	No
Herkenham	Low	1.1	No	Yes	No
Hotloop #94	Low	9	No	Yes	Yes
Jacks Canyon #55 W	Low	6.5	No	Yes	Yes
Last Frontier	Low	2.8	No	No	No
Ledge - N- Airy	Low	0.8	No	No	No

Trail Name	Usage	Mileage	TRAFx Counter	2015 Study	Wilderness
Lime Kiln #82	Low	8	No	Yes	No
Oak Creek	Low	0.2	No	No	No
Old Post	Low	2.7	No	Yes	No
Outer Limits	Low	6.1	No	No	No
Over Easy	Low	0.2	No	No	No
Pine Valley (Little Rock)	Low	1.2	No	Yes	No
Red Rock Loop	Low	1.4	No	Yes	No
Ridge	Low	2	No	Yes	No
Saddle Up	Low	1.2	No	No	No
Schnebly Hill #158	Low	1.7	No	Yes	Yes
Schuerman Mt #56	Low	2	No	Yes	No
Sketch	Low	1	No	No	No
Snake	Low	0.4	No	Yes	No
Stirrup	Low	1.4	No	No	No
Table Top	Low	0.5	No	Yes	No
Two Fences	Low	0.7	No	Yes	No
Woods Canyon #93	Low	2	Broken	Yes	No
Yucca	Low	0.3	No	Yes	No
Andante	Moderate	0.6	No	Yes	No
Anthill	Moderate	0.6	No	Yes	No
Arizona Cypress	Moderate	1.6	No	Yes	No
Axis	Moderate	3.4	No	No	No
Bail	Moderate	0.4	No	Yes	No
Big Park	Moderate	1	No	Yes	No
Bottom Out	Moderate	1.2	No	No	No
Brewer	Moderate	0.6	No	Yes	No
Cow Pies	Moderate	0.5	No	Yes	No
Coyote	Moderate	0.3	No	Yes	No
Dawa	Moderate	2	No	Yes	No
Easy Breeezy	Moderate	1.2	No	Yes	No
Girdner #162	Moderate	5	No	Yes	No
H.T.	Moderate	0.8	No	Yes	No
Hangover	Moderate	3.3	No	Yes	No
High on the Hog	Moderate	1.7	No	Yes	No
Hiline	Moderate	3.1	No	Yes	No
Hog Heaven	Moderate	1.2	No	Yes	No
Hog Wash	Moderate	1.6	No	Yes	No
Honaki	Moderate	0.2	No	No	No
Huckaby #161	Moderate	2.6	No	Yes	No
Javelina	Moderate	1.2	No	Yes	No

Trail Name	Usage	Mileage	TRAFx Counter	2015 Study	Wilderness
Jim Thompson #124	Moderate	3	No	Yes	No
Jordan	Moderate	1.5	No	Yes	No
Kaibab #172A	Moderate	0.2	No	Yes	No
Lasso	Moderate	0.2	No	No	No
Lower Chimney Rock	Moderate	1	No	Yes	No
Made in the Shade	Moderate	1.2	No	Yes	No
Margs Draw #163	Moderate	3.2	No	Yes	Yes
Munds Wagon #78	Moderate	4	Yes	Yes	Yes
Mystic	Moderate	1	No	Yes	No
OK	Moderate	0.5	No	Yes	No
Palatki	Moderate	0.2	No	No	No
Peccary #125B	Moderate	0.5	No	Yes	No
Pigtail	Moderate	0.6	No	Yes	No
Powerline Plunge	Moderate	0.2	No	Yes	No
Pyramid	Moderate	1.2	No	No	No
Ramshead	Moderate	1.1	No	Yes	No
Remnant	Moderate	0.7	No	No	No
Roundabout	Moderate	1.7	No	No	No
Rover	Moderate	0.6	No	No	No
Rupp	Moderate	2.8	No	Yes	No
Scorpion	Moderate	2	No	No	No
Secret Slickrock	Moderate	0.4	No	Yes	No
Skywalker	Moderate	1.9	No	No	No
Sugarloaf Loop	Moderate	0.5	No	Yes	No
Sugarloaf Summit	Moderate	0.2	No	Yes	No
Teacup	Moderate	2	No	Yes	No
Thunder Mountain	Moderate	1	No	Yes	No
Turkey Creek #92	Moderate	3	Yes	Yes	No
Twin Buttes	Moderate	0.6	No	Yes	No
Aerie	Moderate	2.7	No	Yes	No
Allen's Bend	Moderate	1	No	Yes	No
Anaconda	Moderate	1.6	No	Yes	No
Chapel	Moderate	1	No	Yes	No
Cockscomb	Moderate	3.5	No	Yes	No
Grand Central	Moderate	2.1	No	Yes	No
Hermit #172E	Moderate	0.3	No	Yes	No
Lizard Head	Moderate	1.4	No	Yes	No
Llama	Moderate	2.7	No	Yes	No
Long Canyon #122 W	Moderate	2.9	No	Yes	Yes
Transept	Moderate	3.1	No	No	No
	Total Mileage:	199			

	Low: 31	Moderate: 62	High:25		

Appendix D: In-person trail use count data collection sheet

Red Rock Ranger District

Trail Count Record Sheet

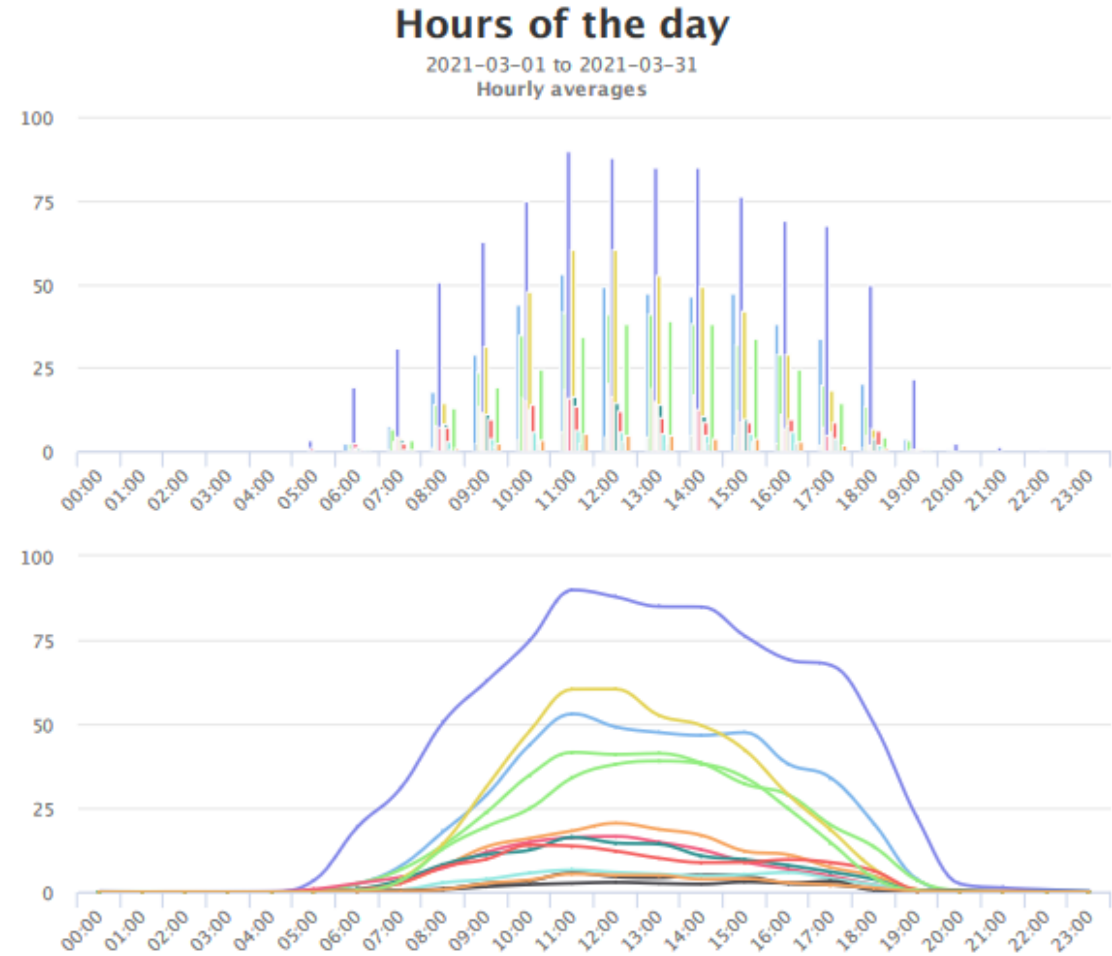
Page: _____ of ______

Date: __________ Location: ____________________ Observer: _______________

Group Size	Time Entered Trail	Mode of Transportation*	Number of Dogs

*(1) Hiking or Walking (2) Biking (3) Horseback (4) Other

Appendix E: Hourly use across all sample frame trails with TRAFx Cameras during March 2021



Site Name	Average	Median	STDV	Min	Max
Bell Rock Pathway (D)	19.2	7.7	20.4	0.0	53.0
Bell Trail (D)	2.3	2.3	1.9	0.0	5.7
Boynton (D)	16.3	13.4	16.1	0.0	41.5
Broken Arrow (D)	7.9	7.3	7.4	0.0	20.5
Cathedral Rock Trail (D)	39.9	40.4	34.8	0.0	89.9
Chuckwagon Mescal TH (D)	7.3	6.8	5.9	0.0	16.5
Fay Canyon (D)	24.6	18.4	22.6	0.0	60.4
Munds Wagon (D)	6.3	6.0	5.6	0.0	16.2
Slim Shady (D)	5.7	6.8	5.0	0.0	13.9
Slim Shady Bike (D)	3.3	3.9	2.4	0.0	6.5
Soldier Pass (D)	0.0	0	0.0	0.0	0.0
Turkey Creek (D)	1.5	1.9	1.2	0.0	3.2
West Fork (D)	19.2	19.5	14.7	0.0	39.0
Woods Canyon (D)	2.6	2.6	1.8	0.1	5.3

(D) = divide by 2 applied

Appendix F: Total seasonal use figures for 2022-2023

Trail Name	Weekday Single Day Total	Weekday Total	Weekend Single Day Total	Weekend Total	Week Total	Season Total	Season Total for all Trails in Sample Frame
Bell Rock Pathway	387	774	487	2435	3696	44352	
Fay Canyon	371	742	399	1995	3136	37632	
West Fork	241	482	471	2355	3308	39696	
Broken Arrow	150	300	214	1070	1584	19008	
		0				140688	879300

Trail Name	Weekday Single Day Total	Weekday Total	Weekend Single Day Total	Weekend Total	Week Total	Season Total	Season Total for all Trails in Sample Frame
Thunder Mountain	119	238	123	615	976	11712	
Mystic	95	190	122	610	922	11064	
Grand Central	51	102	30	150	282	3384	
Allen's Bend	33	66	55	275	396	4752	
Huckaby #161	56	112	43	215	370	4440	
Lower Chimney Rock	88	176	176	880	1232	14784	
Scorpion	44	88	63	315	466	5592	
Brewer	38	76	56	280	412	4944	
Margs Draw	19	38	37	185	260	3120	
Jim Thompson	25	50	36	180	266	3192	
Turkey Creek #92	13	26	35	175	236	2832	
						69816	393762.24

Trail Name	Weekday Single Day Total	Weekday Total	Weekend Single Day Total	Weekend Total	Week Total	Season Total	Season Total for all Trails in Sample Frame
Schuerman Mt #56	17	34	11	55	100	1200	
Bandit	12	24	14	70	108	1296	
Woods Canyon	25	50	84	420	554	6648	
Jacks Canyon #55 W	5	10	13	65	88	1056	
Old Post	26	52	17	85	154	1848	
	1815		2486			12048	74697.6
			4301				1347759.84
							2223803.736
							444,760.75
					1,779,043	2,223,804	2,668,564

Caption: Seasonal totals within our sample were multiplied by their proportion of the entire strata within the sample frame. High use trails were multiplied by a factor of 6.25, moderate use 5.64, and low use by 6.2.