

A Review of Sequoia-Kings Canyon National Park Wilderness Solitude Monitoring



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PROJECT SUMMARY AND KEY TAKEAWAYS

This document provides a review of Sequoia-Kings Canyon National Park's (SEKI) trail-use monitoring program. We evaluate how SEKI monitors and quantifies wilderness encounter rates, which serve as a measure of impacts to visitors' opportunities for solitude. This review of SEKI's monitoring approach has three core objectives: (1) determine if SEKI's monitoring methodology aligns with established practices in the literature; (2) explore different trends in SEKI's monitoring data; and (3) provide opportunities for advancing both future monitoring protocol and future analyses.

For managers, these data and results can help guide opportunities for educating the public about trail use and encounter rates. Our findings suggest that, while sampling events more often occurred on non-holiday weekends, more people were encountered on high-use trails over holiday weekends. In other words, people disproportionately used high-use (standard 25 and 45) trails on holiday weekends. Given our findings, there is an opportunity to educate trail users who seek opportunities for solitude to explore trails that are longer in distance (require more time to travel along) or to avoid traveling on trails over holiday weekends.

Overall, with the extensive years and repeat trail segment surveys, SEKI has a robust data set for beginning to address questions regarding factors that influence encounter rates on trails across the National Parks. As a result, we were able to evaluate a few key factors that influence encounter rates - namely that holiday weekends increase encounter rates, especially on already heavily used trails.

INTRODUCTION

The report (1) begins with an overview of the scientific literature to identify current wilderness encounter and solitude monitoring practices. We use this literature overview to discuss how current practices in the literature align with SEKI's monitoring approach. Next, (2) we examine wilderness encounter data collected from 2012 to 2020 to first, identify if current survey practices meet sampling requirements for adequate data analyses; and second, to identify trends in wilderness encounter data across the survey period. SEKI currently organizes all trails in the National Park into analysis areas (networks of trails that are commonly grouped and accessed together) into four categories based on established encounter thresholds (i.e., number of people a visitor will encounter per hour on 90% of days). These thresholds are: 45 people/hour in Very High (VH) use areas, 25 people/hour in High (H) use areas, 15 people/hour in Medium (M) use areas, and 6 people/hour in Low (L) use areas. Additionally, (3) we provide valuable opportunities to update the current monitoring protocol and future analysis. Finally, at the end of this report, you will find (4) an Appendix with further detailed figures on general survey effort across years (Appendix A) as well as fine scale evaluation of a select few analysis areas and trail segments (Appendix B).

Overview of Wilderness Encountering and Solitude Monitoring

Broadly, SEKI's Wilderness Encounter and Solitude Monitoring protocol is well-aligned with existing wilderness encounter and solitude monitoring literature. Several technical reports from

the Forest Service and National Park Service (e.g., Landres et al., 2018; Landres et al., 2008; Forest Service, 2014; National Park Service, 2014; Forest Service, 2009), peer-reviewed journal articles (e.g., Watson et al., 1998), and theses (e.g., Macias, 2012; Lilly, 2018) discuss how land managers can best approach wilderness character monitoring. ‘Solitude’ is an important aspect of wilderness character monitoring, for which land managers can monitor rates of people encountered on trails as an indicator of a primary threat to outstanding opportunities for solitude. Previous reports and studies (Landres et al., 2018; Landres et al., 2008; Macias, 2012; Lilly, 2018; Watson et al., 1998) offer standardized approaches to help managers formulate monitoring protocols to examine opportunities for solitude by collecting data on encounter rates. Given SEKI’s alignment with standardized protocols for monitoring encounter rates and opportunities for solitude, we were able to evaluate these monitoring practices more thoroughly and identify trends in encounter rates as well as identify recommendations for future monitoring success and data analysis.

In this report, we find that, with the extensive years and repeat trail segment surveys, SEKI has a robust data set for addressing questions on factors that influence encounter rates on trails across SEKI. Below, we evaluate a few key factors that influence encounter rates. Results from these analyses can help managers develop educational opportunities on when and how visitors can best use trails to increase opportunities for solitude.

While we were able to explore some variables and their influence on encounter rates, we also highlight potential modifications to data collection protocols that (1) provide a more robust sampling approach for future analyses and (2) easier data collection applications for park employees conducting surveys.

METHODS

Field Monitoring Protocol

SEKI’s wilderness encounter monitoring protocol has been implemented since 2012. The purpose of this monitoring protocol is to assist SEKI managers in understanding the availability of outstanding opportunities for wilderness solitude within SEKI’s wilderness areas. SEKI managers are responsible for developing the monitoring protocol, and have made small adaptations to the methodology, though it has remained largely consistent since 2016. SEKI’s current monitoring protocol does the following:

1. Wilderness rangers and trailhead rangers conduct most monitoring as part of their regular duties, though other employees and volunteers assist when available.
2. Monitoring occurs from the Friday before Memorial Day through the third Thursday in September (SEKI’s wilderness permit quota season). During this season, monitoring includes:
 - a. Collecting data while traveling at the pace of an average visitor.
 - b. Collecting data multiple times throughout the season (i.e., different months of the season, different days of the week, different times of day).
3. Monitoring DOES count:

- a. People/stock within 25 feet of the observer, regardless of whether the person or stock is on or off the trail.
- b. People/stock previously seen, but not previously measured, during the sampling event, and people/stock seen during different measurements.
- c. People engaged in administrative duties.
- 4. Monitoring DOES NOT count:
 - a. People/stock greater than 25 feet away from the observer.
 - b. People/stock that are stationary at predetermined congregation points along the trail segment.
 - c. People already seen and counted during the measurement.

Designation of Trail Segments, Analysis Areas, and Standards by SEKI

SEKI categorizes their data into aggregated groups composed of trail segments that experience similar use; these are referred to as analysis areas. We analyzed wilderness encounters for each of the 72 trail segments, aggregated into the larger analysis areas that experience similar visitor use and are located near each other (see map below from Frenzel 2020 p 10). The 28 analysis areas are further grouped according to SEKI's standards.

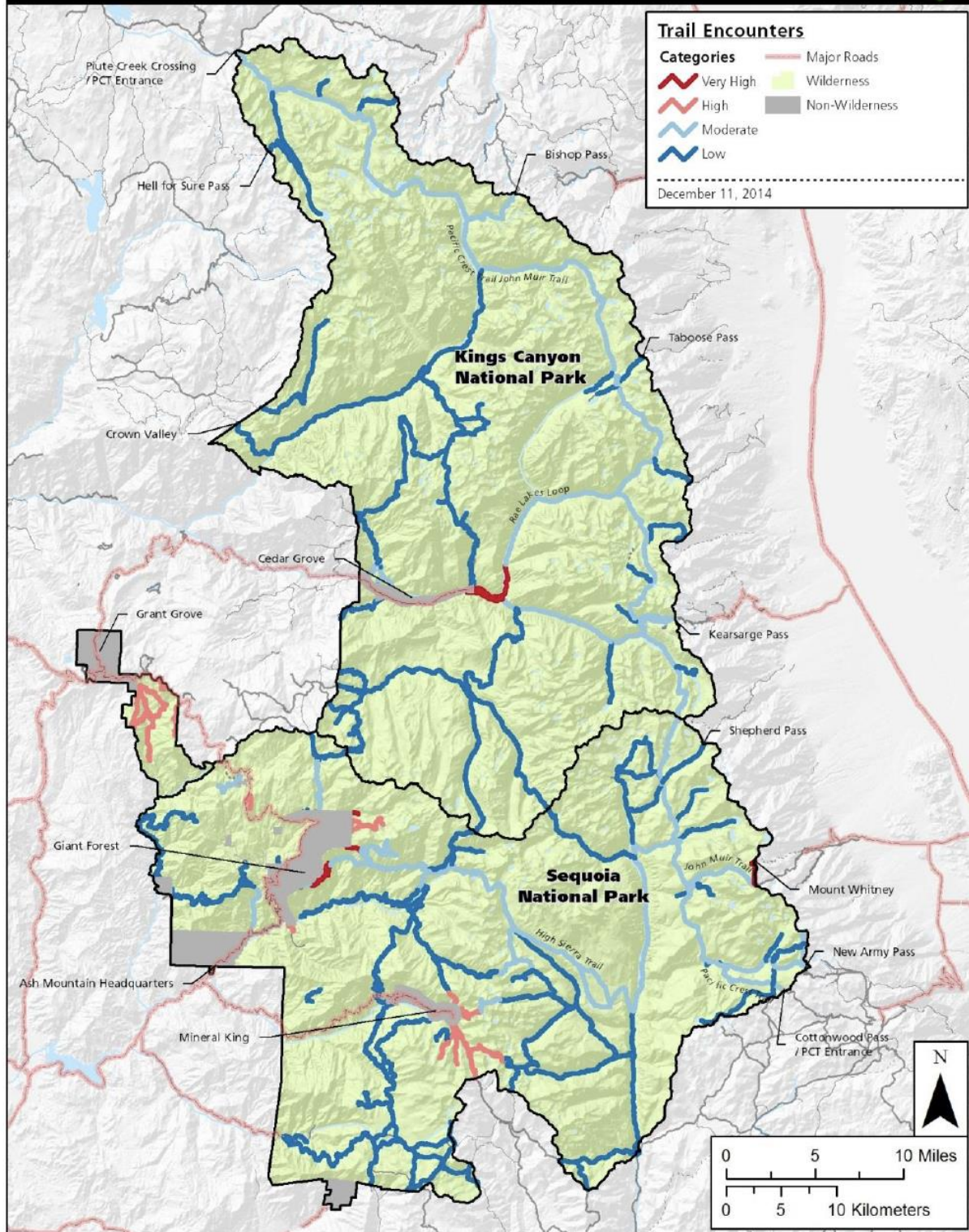
Standards for analysis areas are based upon pilot data and desired future conditions outlined in the 2015 Wilderness Stewardship Plan (Frenzel, 2020, p 1). These standards dictate that visitors on a given trail segment within analysis areas should not encounter a particular amount of people per hour on 90% of days during the hiking permit season. Depending on the standard, this amount of people is: 45 people/hour for VH use areas, 25 people/hour for H use areas, 15 people/hour for M use areas, and 6 people/hour for L use areas. Leading up to the analysis in this report, SEKI research staff used piecewise linear continuous functions in R to determine an estimated number of people encountered in an analysis area. The estimated number of people encountered were used to calculate the 90th percentile encounter rate, which was then compared to the standard (by bootstrapping a confidence interval; Hyndman and Fan 1996). The 90th percentile confidence interval around the estimated number of people encountered, allowed SEKI to determine if the analysis area's use for a given year was above, below, or within the standard on 90% of days (Frenzel, 2020, p 2-3). In this report, we compare results from trail surveys to determine how often trail surveys exceed standard.

Summarizing data

To analyze the existing data, we first evaluated the *number of surveys (sampling events)* across years and days of the week as well as across standard and analysis area (Figure 2 - 3; Appendix A). We then evaluated how *encounter rates* varied across years, standard and analysis area (Figure 4 -7). In our Data Analysis section, we connect factors influencing encounter rates using mixed-effects logistic regression models (Figure 8-11). *Note: a **sampling event** is defined as a survey of a designated trail segment (sample unit).*

Sequoia and Kings Canyon National Parks
California

National Park Service
U.S. Department of the Interior



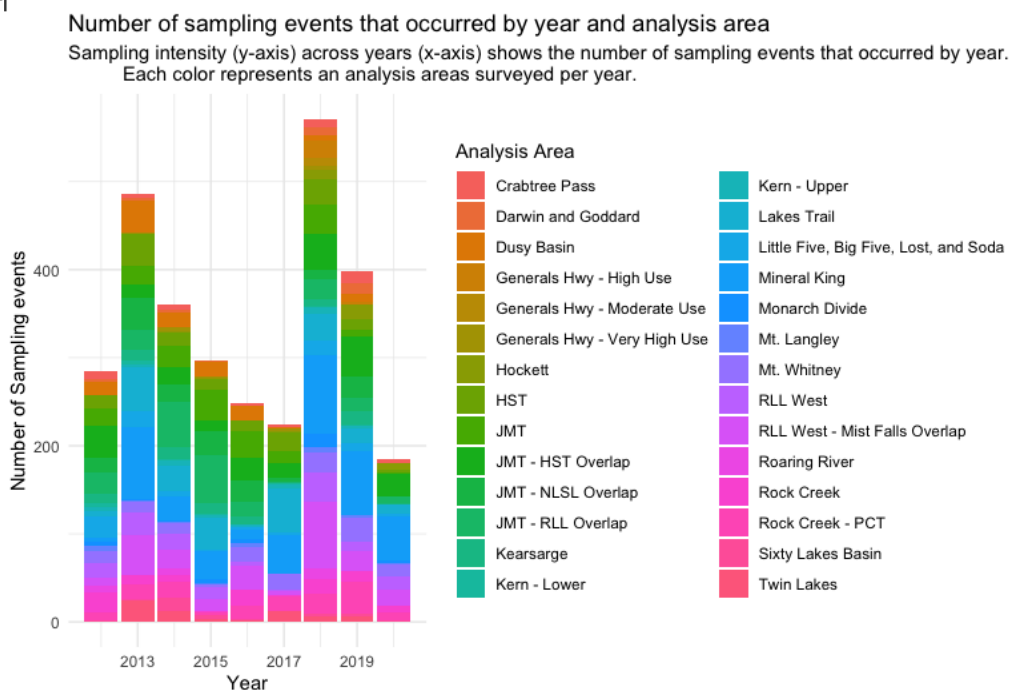
Overall SEKI sampling effort and descriptive statistics

Temporally, our analysis includes data collected from Memorial Day weekend through the first weekend in October and from 2012 to 2020. There are a total of 3,056 unique sampling events that occurred on 72 trail segments within 28 analysis areas in Sequoia-Kings National Park, California. Across the 9 years of data collection, 2013, 2014, 2018 and 2019 saw the most survey effort (Figure 1). Data were collected from 0500 – 2000 hours, with the majority of surveys occurring between 0900 – 1600 hours (See Appendix A). Data were generally collected equally across all days of the week with some increased sampling intensity on Saturdays and Sundays (see Appendix A). Finally, there was significant sampling variation across years. *Note: in this report, **sampling intensity** is defined by the quantity of trail segments (**sample units**) surveyed; with greater sampling intensity meaning more trail segments surveyed and lower sampling intensity meaning fewer trail segments surveyed.*

Sampling Effort

Overall, sampling intensity varied across years, while sampling effort was largely consistent across analysis areas and within years. Figure 1 below shows a histogram of sampling intensity (y-axis) across years (x-axis) and is meant to explore the number of sampling events that occurred by year. In Figure 1, each color within a bar represents an analysis area (see legend). In general, most analysis areas were surveyed every year that surveys were conducted.

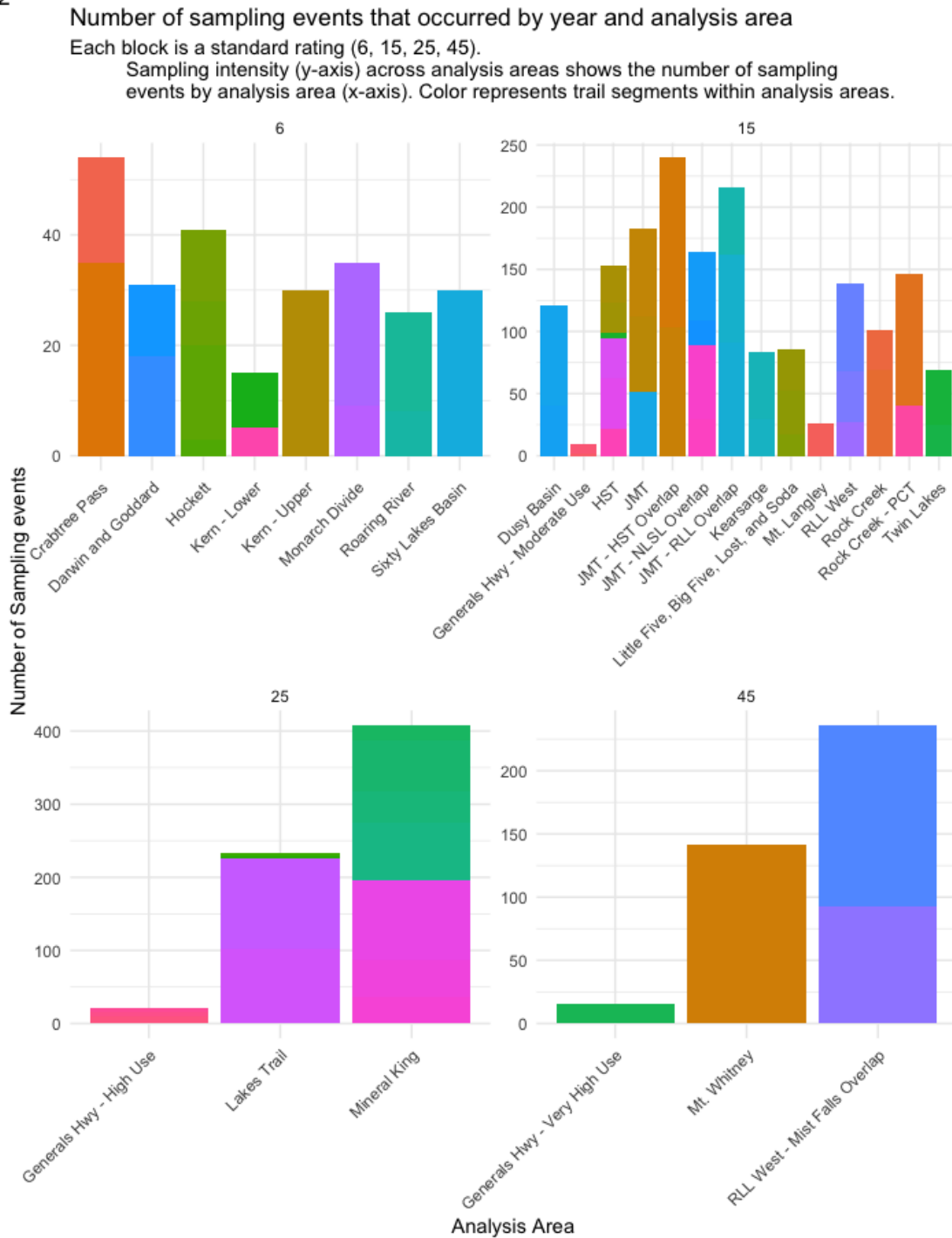
Figure 1



We observed the most variation in survey effort across trail segments (trailID). Most trails surveyed were classified as medium use (standard of 15). Further, we observed that some analysis areas and trail segments received greater survey effort than others, with the most surveys occurring in the JMT analysis areas, Mist Falls Overlap and Mount Whitney analysis areas (see Figure 2).

The data include surveys from all trail segments across SEKI and are therefore a representative sample of trail use across the SEKI trail segments. The following figure further breaks down overall sampling events by standard (labeled as 6, 15, 25, and 45 at the top of each panel) and analysis area (x-axis) and the number of trail segments within an analysis area (color). In general, most analysis areas and trail segments received adequate sampling efforts, however a few trail segments (i.e., all Generals Highway trail segments) did not receive substantial survey efforts. We suspect this is largely due to a change in trail segment classification.

Figure 2

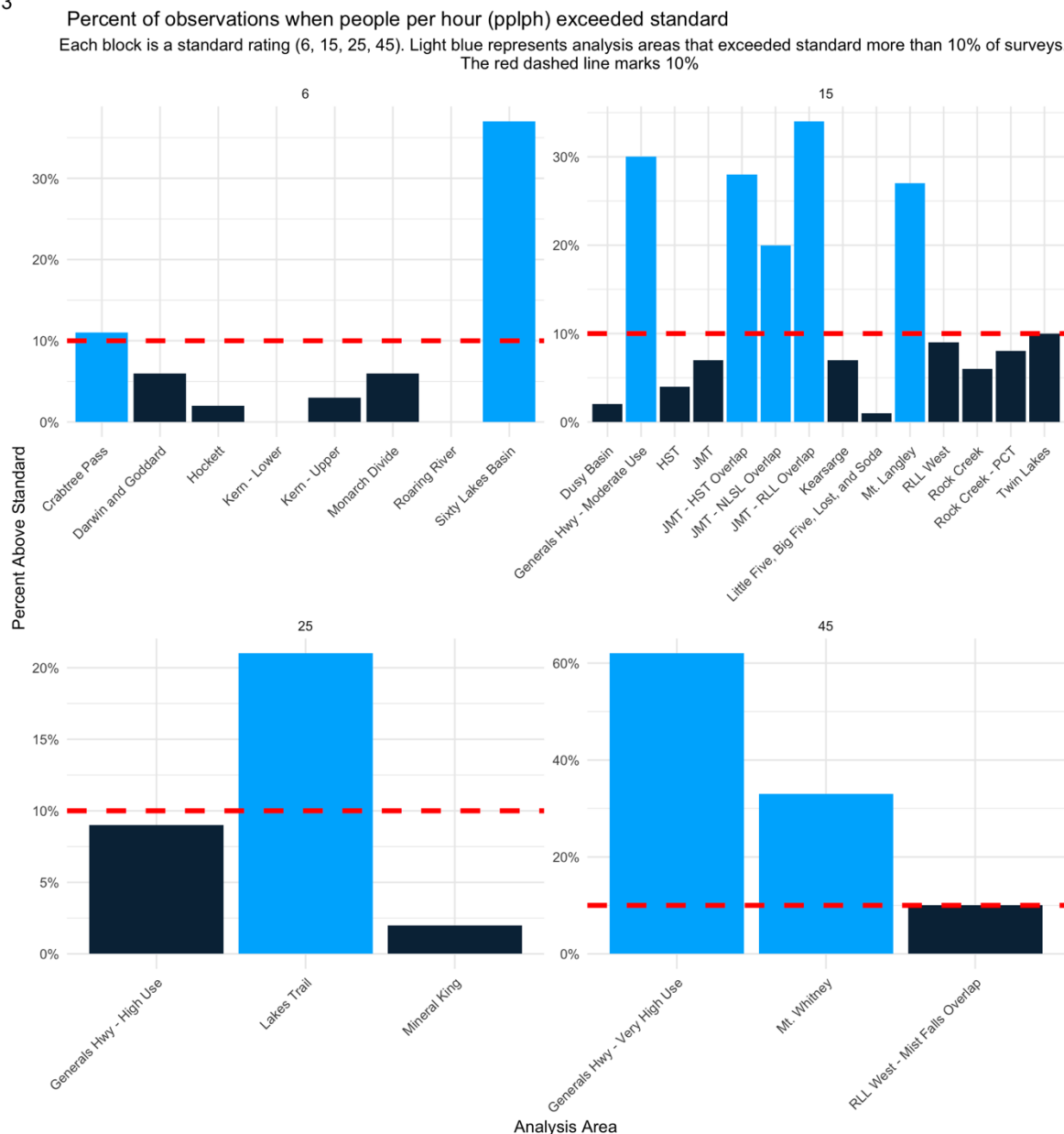


Descriptive Statistics

Identifying analysis areas in and out of standard: The subsequent figures break down encounter rates of people encountered per hour (pph; y-axis) by standard (each panel) and analysis area (x-axis) (Figure 3). In the preceding figures (Figure 4 – 8), the same figure is broken down by

standard. In these figures and the light blue bars are analysis areas (x-axis), are analysis areas that exceeded standard more than 10% of surveys for a given standard (6, 15, 25, 45). Dark blue bars represent surveys that exceeded standard less than 10% of surveys. If no bar is present, then no surveys exceeded standard. In general, we see sampling events that recorded encounter rates higher than 6, 15, 25, or 45 people per hour across all analysis areas above standard 15.

Figure 3



The subsequent figures provide more detailed information by standard on encounter rates by analysis area and across years.

Figure 4

Proportion of observations when people per hour (pplph) exceeded standard for Standard 6

Each block is an analysis area. Light blue represents analysis areas that exceeded standard more than 10% of surveys. The red dashed line marks 10%. Analysis areas with no values means that no trailsegment survey exceeded standard

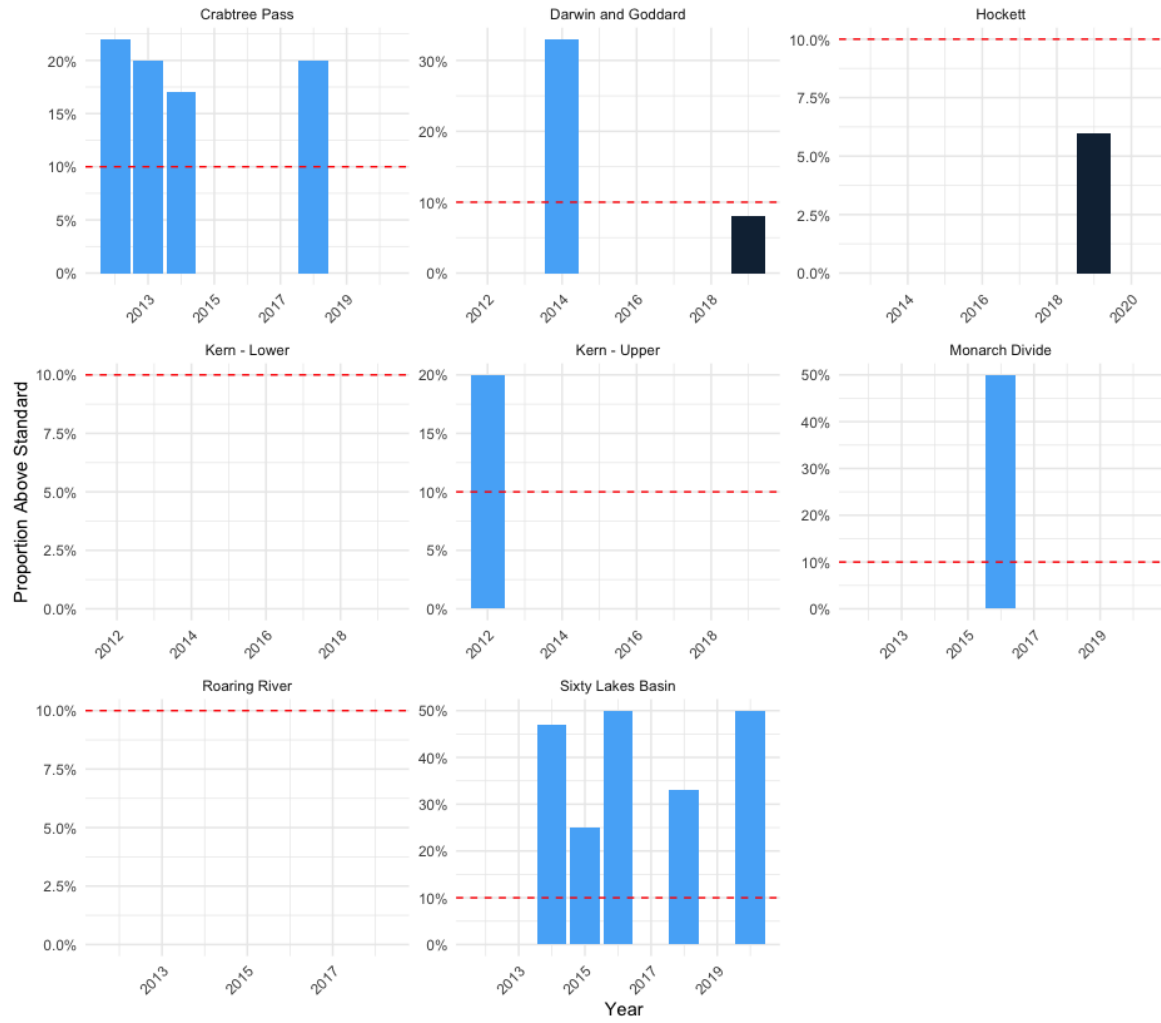


Figure 5

Proportion of observations when people per hour (pplph) exceeded standard for Standard 15

Each block is an analysis area. Light blue represents analysis areas that exceeded standard more than 10% of surveys. The red dashed line marks 10%. Analysis areas with no values means that no trailsegment survey exceeded standard

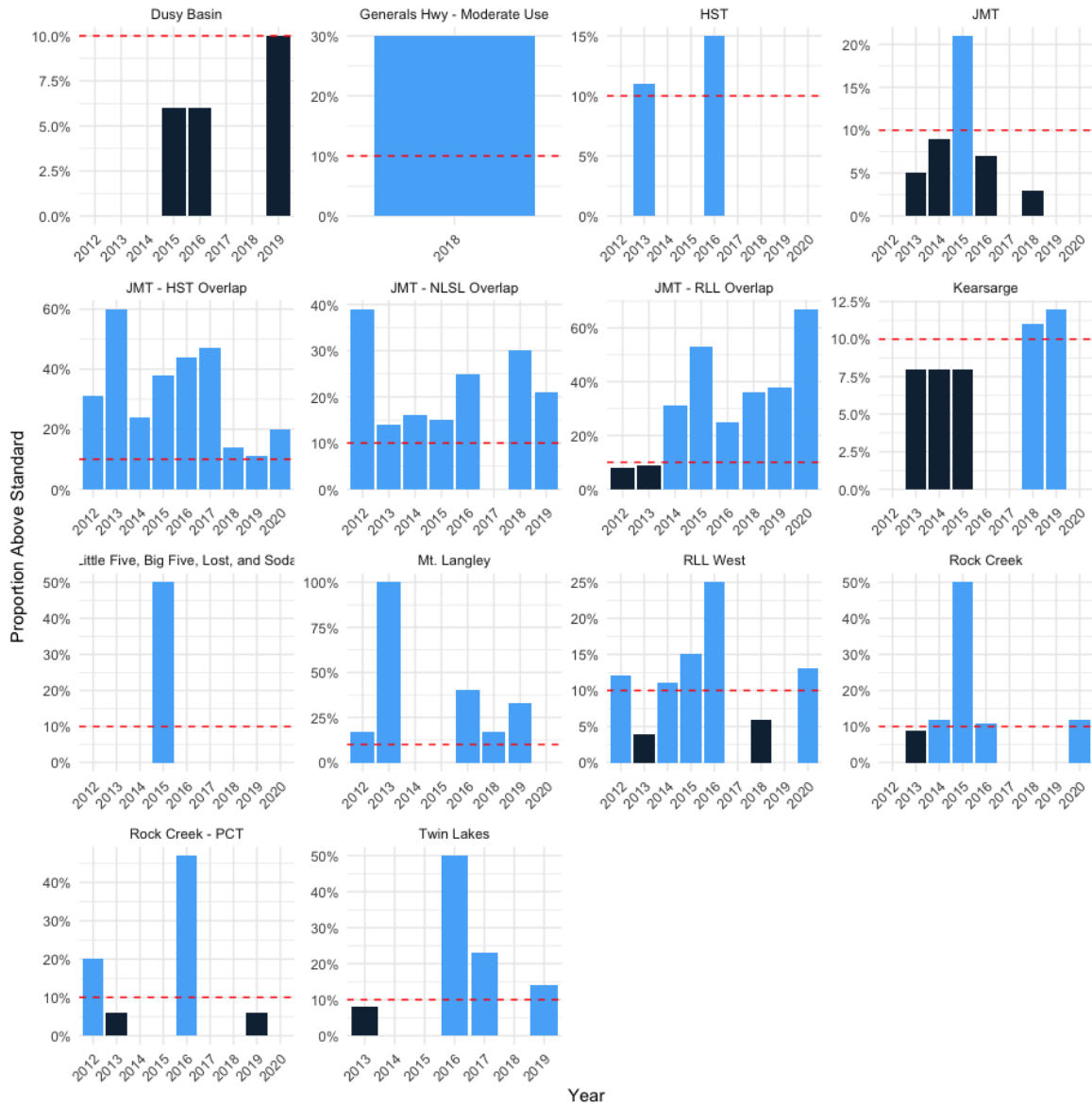


Figure 6

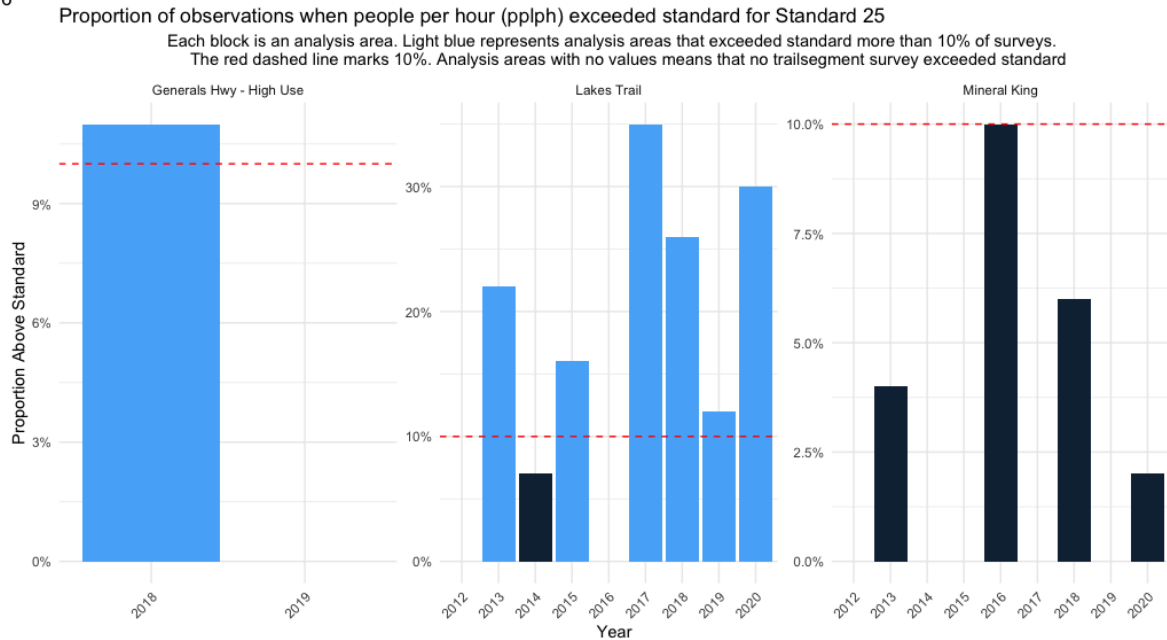
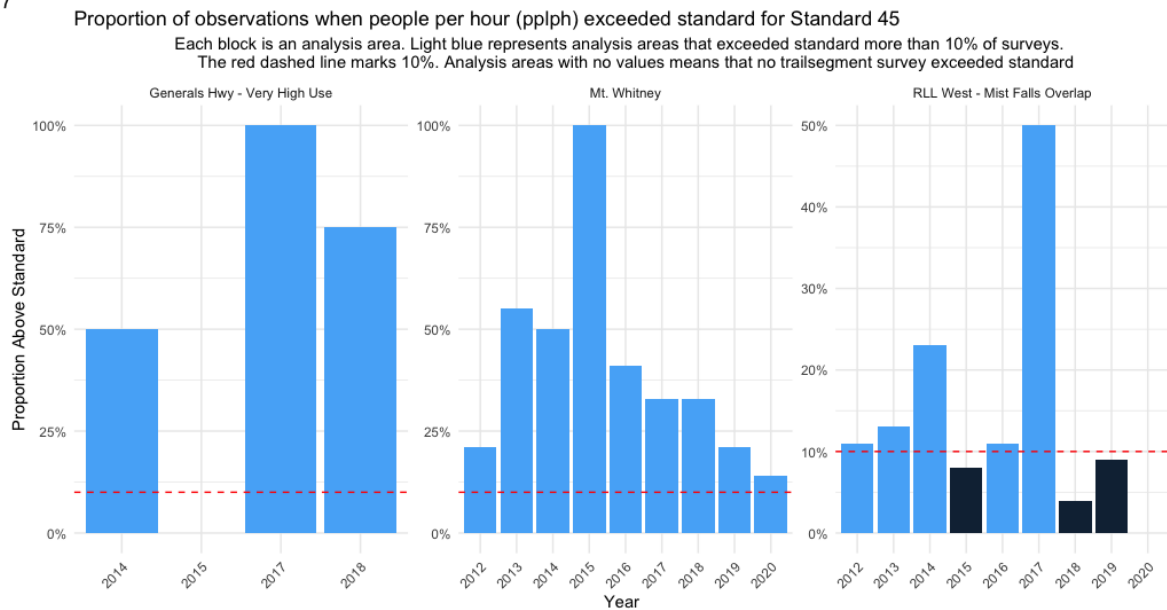


Figure 7



Analysis of factors influencing encounter rates

The following figures show 2 things: first, the distribution of sampling events for a given factor represented using bar plots; and second, the distribution of encounter rates for a given factor represented using box plots. Factors that presented as significant are:

1. whether the sampling events occurred over a holiday weekend (holiwnknd). *Note: Holiday weekend is defined as the Saturday, Sunday and respective federally recognized holiday*

(i.e., Memorial Day weekend includes surveys conducted on Saturday, Sunday, and Monday).

2. weather classification (note that while this variable ranked as an important variable to include in our models, it did not have significant influence in parameter estimates – see Table 1).
3. hours surveyed (the number of hours a trail segment was surveyed).

In general, while sampling events occurred more often on non-holiday weekends, more people were encountered on high-use trails over holidays weekends. In other words, people disproportionately used high-use (standard 25 and 45) trails on holiday weekends.

Figure 8

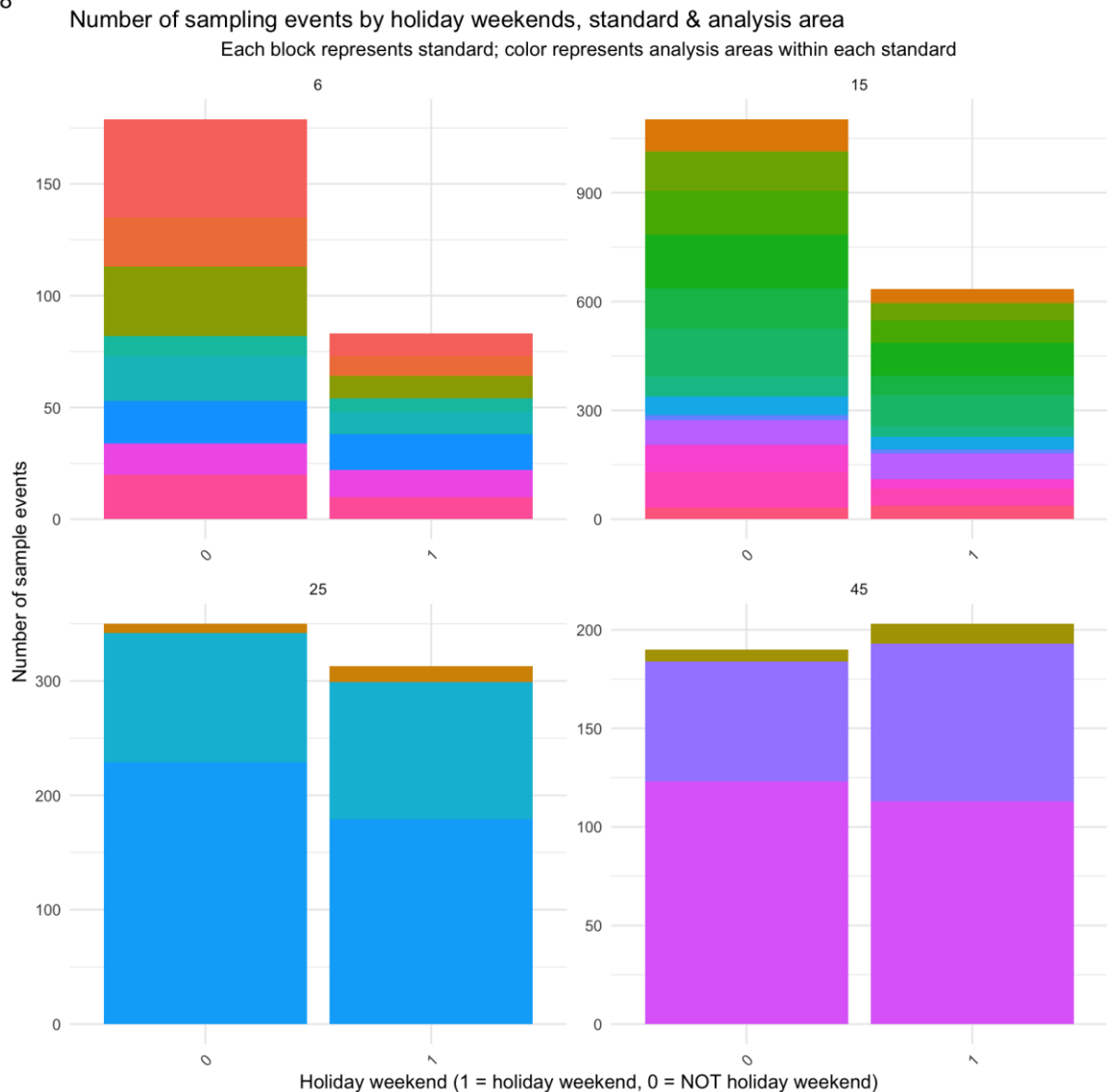
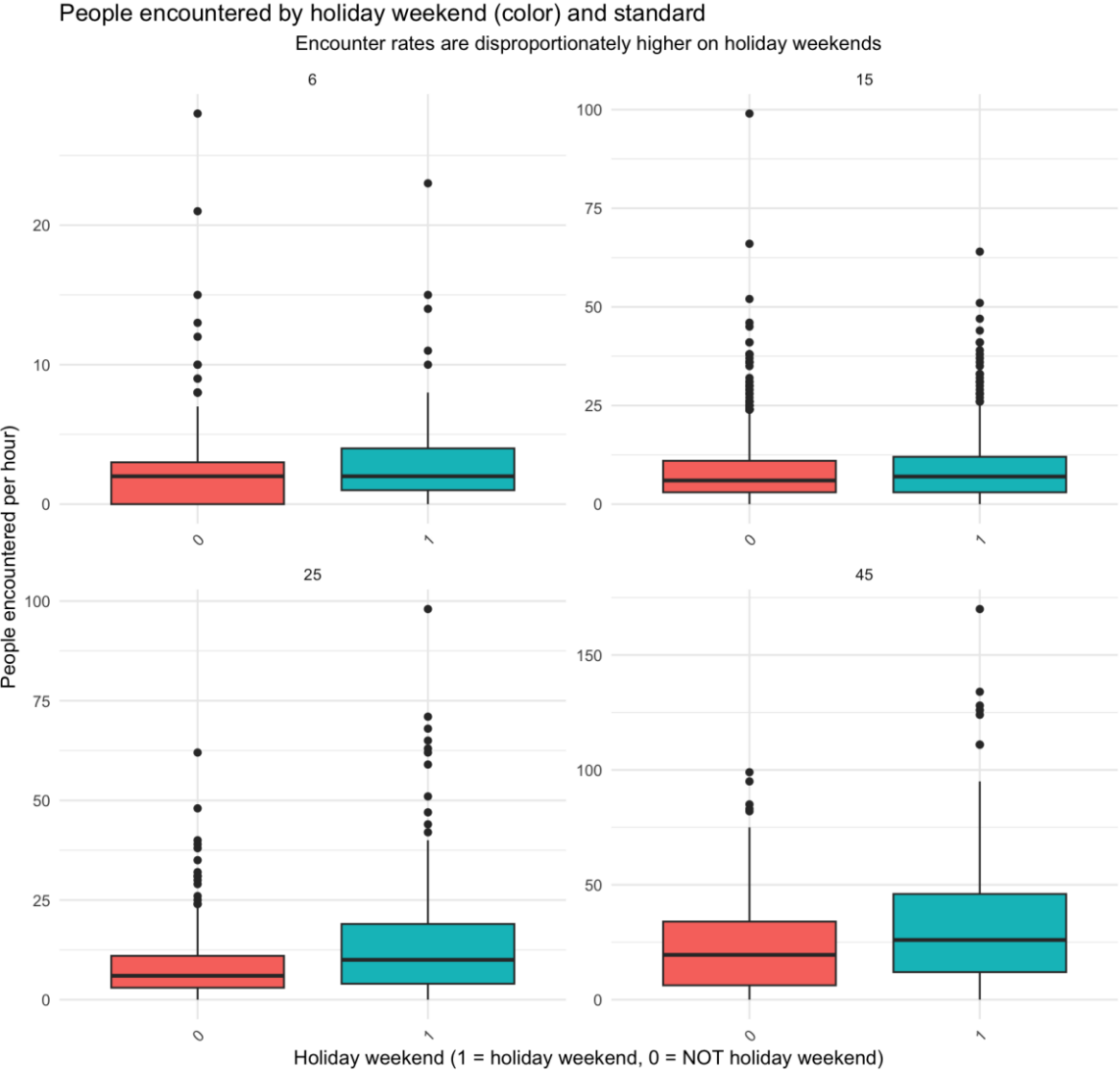


Figure 9



In general, weather does not significantly influence encountered rates on trails as there were a disproportionate number of sampling events that occurred on sunny days and encounter rates were generally equal across recorder weather conditions.

Figure 10

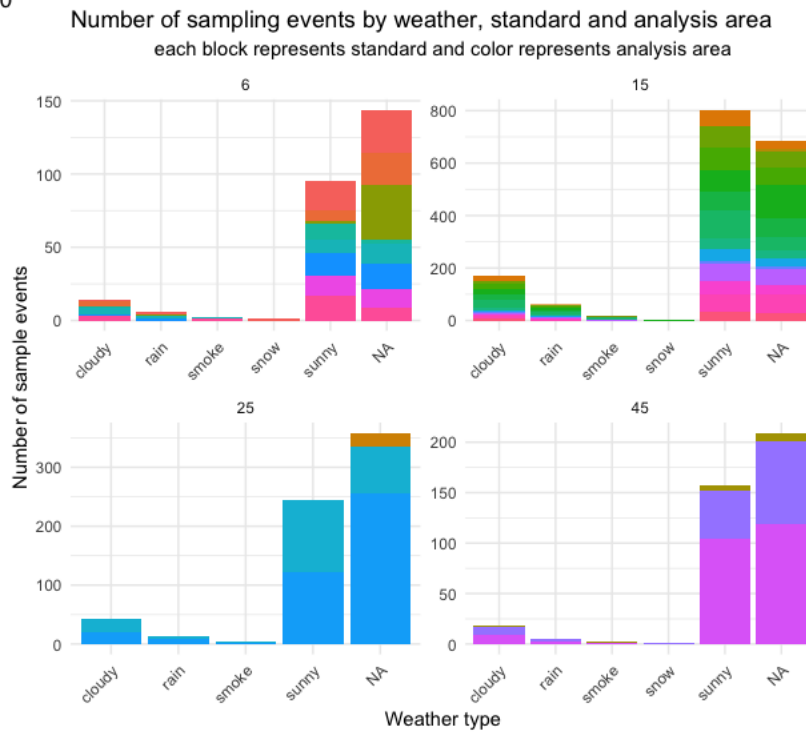


Figure 11

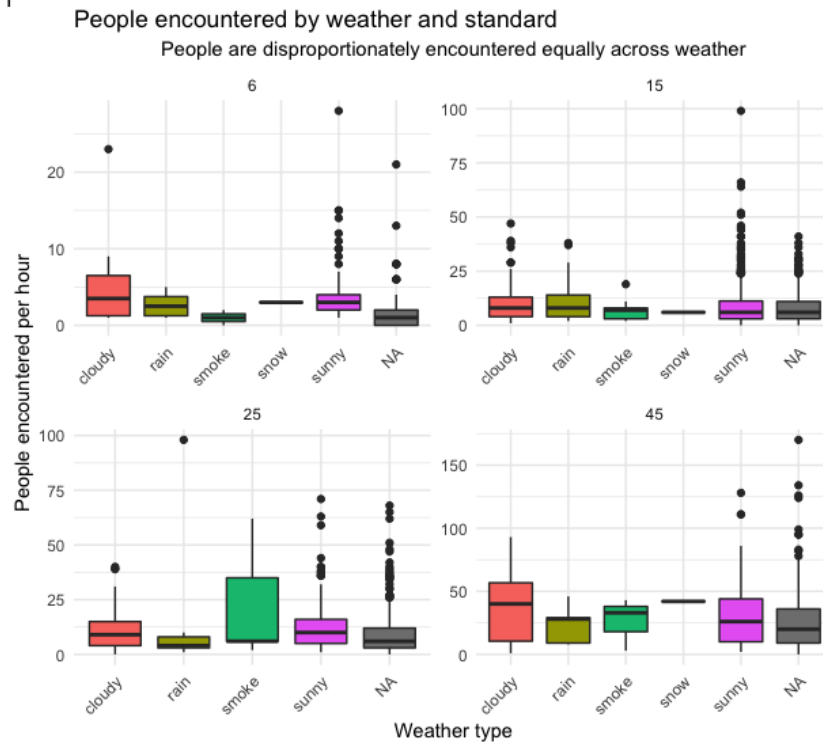


Figure 10

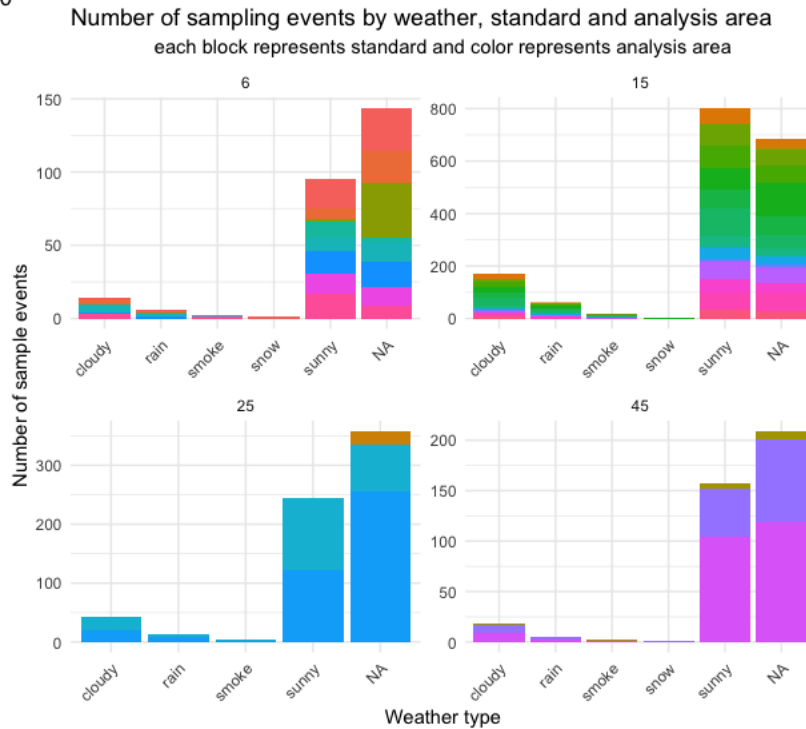
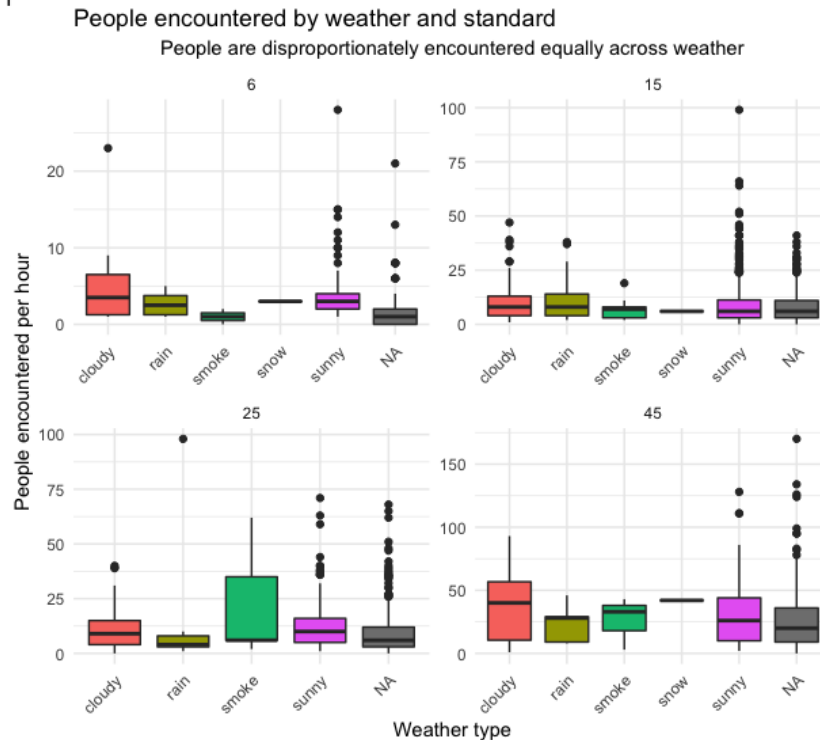


Figure 11



DATA ANALYSIS: FACTORS INFLUENCING ENCOUNTER RATES

In this section, we describe analyses used to assess factors influencing encounter rates of people (calculated as people per hour [pplph]) on trails in SEKI National Park. These analyses, which constitute basic predictive models, can support wilderness and national park managers to better

understand what factors influence encounter rates and, thus, what characteristics (e.g., time of day, time of year) influence opportunities for solitude.

Analytical Methods

We use regression to analyze trail encounter data from 2012 – 2020 with data collected from Memorial Day weekend to the first weekend in October (for distribution of surveys by month and year see Figure 3). We collected data between 0600 – 2200 (time of day) and on all days of the week, including holidays (Figure 1; Figure 2; Figure 4).

To evaluate the factors influencing the people encountered on a trail segment (pplph), we employ negative binomial regression. This model is appropriate because our response variable is made up of count data (numbers of people) and was chosen because the variance (variation in pplph in the data) is greater than the mean (average number of people encountered per hour) – which makes sense given that there are specific times (i.e., holiday weekends) when the number of people on trails greatly increases. Negative binomial regression analyses calculate an incident rate ratio (IRR; see Results for more information) which represent the multiplicative effect of a one-unit change in the predictor on the number of people encountered

In our analyses, we built a series of models that estimate the log of the expected people encountered per hour (pplph) as our response variable to measure wilderness encounter rates.

Pplph is modeled as a function of several predictor variables, including

- Direction of travel (dot; classified as e-w, w-e, n-s, s-n)
- Time of day (tod)
- Day of the week (dow)
- Month (mon)
- Year
- Weather (wxnew; we classified weather into 4 categories: sunny, rainy, snowy, smokey)
- Hours surveyed (tothr; number of hours it took to survey a trail segment)
- Holiday weekend (holiwknd)

We then grouped analyses and fit random effects by analysis area (aa), trail segment ID (trailID) and standard.

An important assumption of independence of observations: Each observation (e.g., trail encounters) is assumed to be independent of the others. This means that the number of people encountered on one trail visit is not influenced by the number of people encountered on a different visit. This is an important assumption and is likely violated because encounters may not be independent, and because trail segments were sampled conveniently (rather than randomly), which may influence our interpretation – see Conclusions.

RESULTS

Our top model was a mixed effects model that fit a random effect (grouping variable) on trail segment (trailID) and included fixed effects on total hours surveyed (tothr), weather conditions (wxnew; snow, smoke, rain, sunny), and holiday weekends (holiwknd). By including TrailID as

a random intercept, we allowed for baseline differences in encounter rates across trails while estimating the average effect of hours surveyed, weather, and weekends across all trails.

$$\text{Encounter Rates (pplph)} \sim \beta_0 + \gamma_{\text{trailID}} + \beta_1 * \text{holiwnknd} + \beta_2 * \text{wx} + \beta_3 * \text{tothr}$$

When interpreting model results, we evaluate the expected number of people encountered for a one-unit change in the predictor variable. Specifically, a predictor value greater than 1 suggests an increase in the number of people encountered, while a value of less than 1 indicates a decrease (See Table 1 and Figure 13). Specifically, we estimate a negative effect of *total hours surveyed* (tothr; IRR = 0.834, $p = <0.001$), which means that for every additional hour of surveying, the expected number of people encountered decreased by 17%. Additionally, we found that the effect of rainy weather is 1.11, which indicates that encountering people is 11% more likely on rainy days. Additionally, we found that the effect of snowy weather is 0.62, which means that hikers are 38% less likely to encounter people on snowy days - holding other variables constant. Finally, and unsurprisingly, there is a strong positive effect of holiday weekends on people encountered across all trails. In estimating an IRR of 1.24 ($p = <0.005$), which means that encountering people is 24% more likely on holiday weekends.

In fitting a random effect on trail segment (trailID), we are accounting for the fact that encounters might vary across different trails due to factors not captured by the fixed effects (e.g., trail popularity, trailhead location). Using a random intercept allows each trail to have its own baseline encounter rate, while estimating an average influence of hours surveyed, weather, and holiday weekends (the fixed effects) across all trails. For example, one trail might inherently have more people due to its location or popularity, while another trail might have fewer people.

Our top model estimated the variance for the random effect TrailID as 0.426, which means that the variation in the data can be explained by trail segments, suggesting that encounter rates (people per hour) differ moderately between trails due to unobserved trail-specific factors.

Our top model shows that 46% of the variation in the data can be explained by trail segments. Holiday weekends was the strongest variable for predicting encounter rates (pplph). Unsurprisingly, there is a strong positive relationship between holiday weekends and increased encounter rates across all trails. The second factor influencing encounter rates is the number of hours that a trail segment was surveyed. There is a strong negative relationship between total hours surveyed (tothr) and encounter rates (pplph). This likely means that the longer it takes to survey a trail, the fewer people were encountered across trail segments. This could be an opportunity for educating the public on how to create more opportunities for solitude. While weather was included in the top model, it did not have significant influence on encounter rates as all coefficient estimate confidence intervals overlapped 0 (Figure 13) and p values were high (Table 1).

Table 1: Top model results show IRR estimates from our top model (p-values).

variable	estimate	std.error	conf.low	conf.high	p.value
(Intercept)	11.754	0.087	9.903	13.95	<0.005
Hours surveyed (tothr)	0.834	0.011	0.815	0.852	<0.005
Holiday weekend (holiwknd)	1.239	0.014	1.206	1.272	<0.005
Rainy (wxrain)	1.114	0.031	1.049	1.184	<0.005
Smokey (wxsmoke)	1.058	0.054	0.951	1.177	0.296
Snowy (wxsnow)	0.616	0.116	0.491	0.772	<0.005
Sunny (wxunny)	0.981	0.018	0.947	1.015	0.272
TrailID - random effect	0.426				

Figure 12: Top model coefficient estimates for trail segments. This figure demonstrates that encounter rates vary a lot by trail segment. Each dot is a mean encounter rate estimate for each trail segment with each line representing the 95% confidence interval. The variation demonstrates that it is important to consider all explanatory variables within the context of each trail segment. It is worth noting that trail segment ranked as a stronger influence in measuring encounter rates over analysis area and standard.

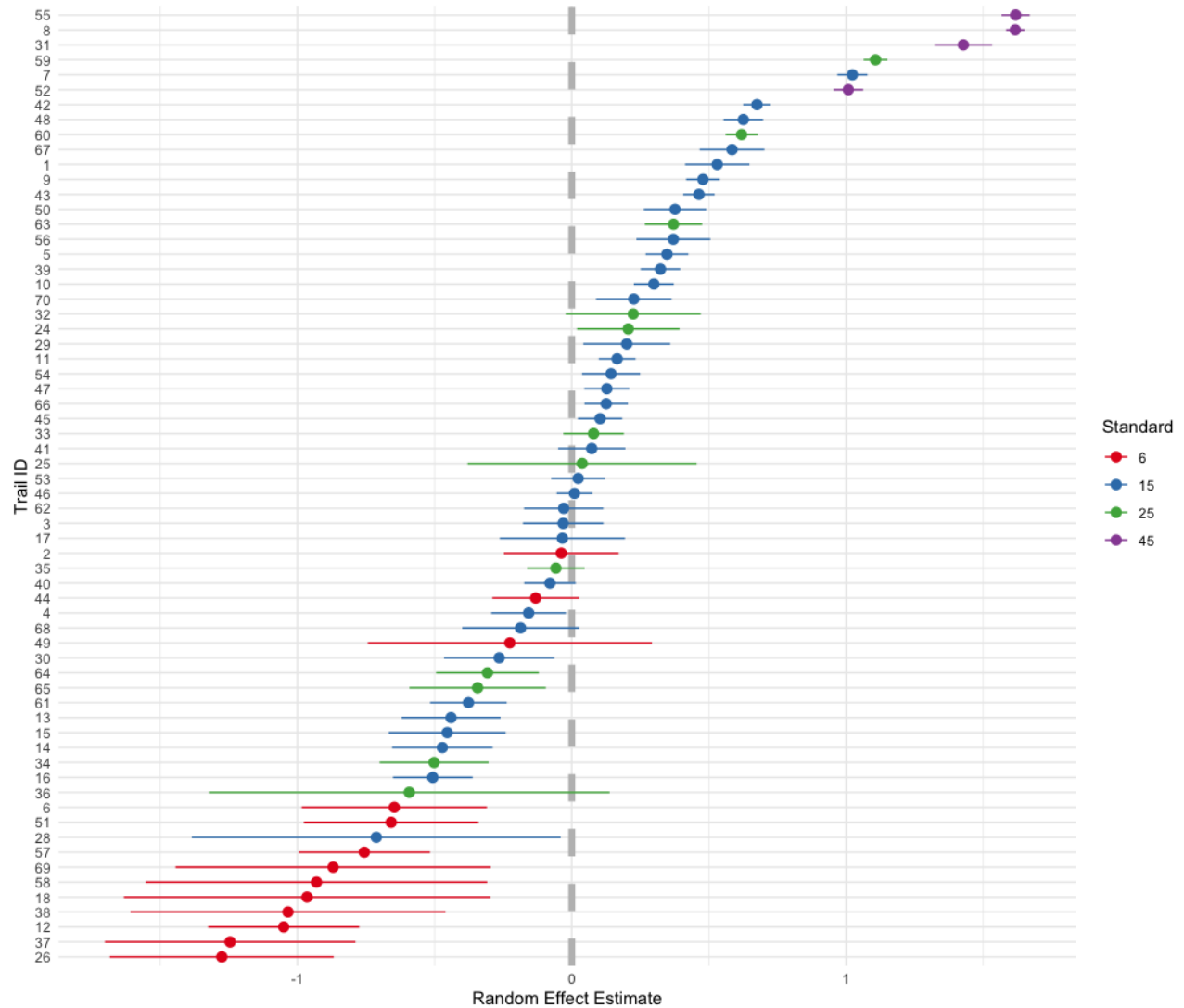
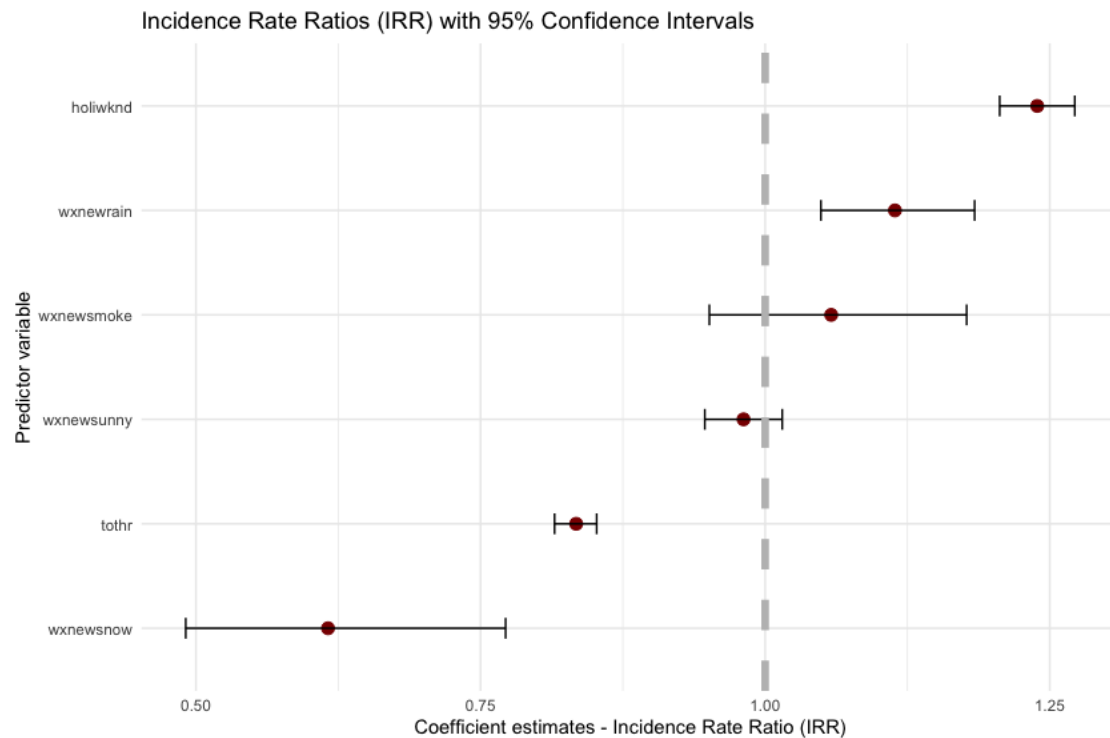


Figure 13: Coefficient estimates for explanatory variables included in the top model. Holiday weekends (holiwknd) and total hours surveyed (tothr) were the strongest predictors of encounter rates across all trails with p-values well below 0.05. Holiday weekends have a strong positive relationship with encounter rates (pplph), while survey hours (tothr) had a strong negative relationship with encounter rates (pplph). Rain has a significant positive effect on encounter rates, while snow has a significant negative effect on encounter rates.



CONCLUSION

Overall, with the extensive years and repeat trail segment surveys, SEKI has a robust dataset for addressing questions of factors influencing encounter rates (and thus opportunities for solitude) on trails across the National Parks. As a result, we were able to evaluate a few key factors that influence encounter rates - namely that holiday weekends increase encounter rates by 24% especially on already heavily used trails.

For managers, these data and results can help guide opportunities for educating the public about trail use, and expected encounter rates. For example, given our findings, managers could encourage trail users who seek opportunities for solitude by exploring trails that are longer in distance (require more time to travel along) or to avoid traveling on trails over holiday weekends.

While we were able to leverage a robust trail survey dataset to explore a variety of variables and their influence on encounter rates (and opportunities for solitude), there are important statistical

assumptions to consider when interpreting our results. Most statistical models (ours analyses included) assume that each survey and trail segment is independent of other surveys and trail segments— in other words we assume that the people encountered on each survey and trail segment is not correlated with some other factor (e.g., weather, trail location, time of day). It is possible that we do not meet this important assumption as trail surveys were conducted using convenient sampling rather than random sampling. This assumption can be met by employing a random sample to determine when and which trail segments to survey. We account for some of this assumption by fitting a random effect to trailID. However, this does not address the lack of independence in surveys. Thus, we must interpret our results with some caution.

In the future, modifications to data collection protocols that employ random sampling would offer a more robust sampling design for stronger inferences and a deeper understanding of factors influencing encounter rates. For example, trail segments could be randomly selected each year and repeatedly surveyed within each year. We highlight additional opportunities for future SEKI managers to consider when adapting their survey protocols.

DISCUSSION

Opportunities for advancing SEKI's monitoring approach

When compared to standards outlined in the existing literature, SEKI's wilderness encounter monitoring protocol is consistent with best practices. However, the literature on the topic is limited, and our analysis highlights several opportunities that may be available for adding rigor to the current methodological approaches for SEKI and in the literature. We consider the potential opportunities available to augment SEKI's monitoring approach, while also recognizing that practical constraints for change may exist (e.g., available staff and funding resources for monitoring).

Consistency of monitoring: Current monitoring protocols include sampling trail segments on different days, at different times, and in each month of the monitoring season. However, the existing data for the trail areas analyzed in this report indicate that there are large fluctuations each year in how often samples are taken in a month and on which days. For example, the Lakes Trail analysis area had 54 samples (unevenly distributed across months) in 2017, but only 32 samples in 2018. This analysis area also had no data for May in 2012, 2013, and 2015-2019; only 5 of the 9 monitoring years had any data collected in September. This may be caused by employing convenience sampling methods, which is beneficial when staff availability and funding is potentially limited but leads to data gaps.

Considerations: Implementing an annual random sample of trail segments to survey each year is an excellent way to decrease survey effort and increase information gain and data collection rigor. Especially if additional funding is unavailable to expand capacity for monitoring, it may be helpful to reduce the number of trail segments and analysis areas that wilderness and trailhead rangers are expected to monitor each season. Instead of attempting to collect data for 28 analysis areas each year, prioritizing certain segments/areas based on long-term data trends may be valuable. For example, if there is consistent data and numbers across a series of years, that segment/trail area may be put on a rotational basis for monitoring, while other sites with less data

or inconsistent data, could be monitored more regularly. In conclusion, SEKI could consider surveying a random sample drawn from all trail segments to reduce survey efforts and survey time. In surveying a random sample of all trail segments, stratifying by standard rating (low, medium, high, very high) or by day of the week given the importance of holiday weekends in our findings, managers would survey fewer trail segments each year, yet still extrapolate across all trails. Managers could then create a schedule that standardizes which trails are surveyed across years. Additionally, should managers have priority areas of interest/concern (e.g., perceived crowding and overuse of the John Muir Trail), these areas could be included in each year's survey in order to maintain fine scale understandings of factors impacting encounter rates and opportunities for solitude.

Additionally, different monitoring techniques can be used on segments/areas depending on levels of use. For VH and H categorized analysis areas, indirect observation methods could be used, such as infrared trail counters, to gauge how many people use the trail per hour. Using indirect measurements has been shown to be an effective method to estimate encounters (e.g., Watson et al., 1998, p. 20). Overall, trail counters can provide accurate counts of use to complement the solitude/encounter monitoring. In using both methods, we could estimate a probability of detecting hikers during a survey – which could further increase the precision around our encounter estimates.

Encounters vs. People: In 2016, there was a deliberate choice to change data collection to the total number of people recorded during an entire survey rather recording the time and number of people at each encounter. Because the standards in the 2015 plan were defined in a way that did not make use of the additional detail (i.e., timestamps with each group encountered, which was time-consuming to collect), SEKI managers elected to simplify the protocol with the goal of reducing the workload of the monitoring effort and in hopes of getting a greater number of observations. This change to the protocol had some potential implications for how the data could be analyzed. Originally, several individual encounters (e.g., 3 separate encounters while hiking with 12, 4, and 9 people per encounter) were included in the total number of people encountered during the hike (e.g., the 9/13/2019 sampling event at Cedar Grove-1 recorded 25 people listed for 1 encounter). Since all trail segments in this analysis area are reported to take ~45 minutes, for analyses, we grouped these data into hourly rates of people encountered (lumping everyone seen on the trail within a survey hour, rather than the number of people seen at individual moments on the trail). This approach, while more time efficient during monitoring, may mask finer scale understanding of factors impacting solitude experience. For example, hikers will experience a trail differently if they encounter 10 groups totaling 25 people than one group of 25 people.

Considerations: In general, SEKI has delineated trail segments in a way that captures the way people travel along the trails (e.g., new trail segment begins at a trail junction). To gain further statistical power in future analyses, SEKI could consider integrating a standardized data collection process employed across all trails. For example, surveyors could record the total number of people encountered every 1 mile – this would likely change the response variable to people per mile and would offer inference to *spatial* variation in encounter rates. Alternatively, surveyors could record the total number of people encountered every half hour – this would keep the response variable to a people per hour or half hour as we employ here, and offers inference to

temporal variation in encounter rates. Under either example, if the location and time stamp of each encounter is recorded along a trail, then both temporal and spatial variation could be considered in future analyses. For the most comprehensive analyses, we highlight the value of reinstating a time stamp and coordinates for each person/group encountered. That way, for analysis, we can then evaluate more accurate factors that influence people-encountered across time. If reducing survey effort is a priority, surveyors could record total people encountered every mile (or half mile per local knowledge recommendation; these could be called trail subsegments) along with recording start time and time at each mile when surveyors stop to record people encountered.

Distance of trail segment missing: Per our previous discussion, this is an additional area for improvement for SEKI data collection. Distance length for each trail segment will help quantify survey effort with distance rather than with time of surveys. Additionally, recording location of encounters and length of trail could help identify spatially where most encounters occur. Currently the only measure of effort is the number of sampling events and hours sampled, which makes our inference temporal in nature. Despite our findings suggesting that survey hours had a strong negative relationship with encounter rates, using a temporal measure to standardize our response variable (pplph) could bias results for shorter and busier trail segments. This is possible because as more people encountered are likely to cause longer time required to sample a trail segment, and thus creating more available time to encounter more people. Regardless, as long as researchers and managers adequately acknowledging statistical assumptions required during analyses, these data are extensive enough that they can continue to be included in future analyses to further understanding of trail use across SEKI.

Considerations: Record one-way distance of a trail segment and record direction of travel. Direction of travel was expressed as a possible important factor influencing encounter rates. While this may be true, we found the travel direction was recorded inconsistently with many options for classifying direction, rather than only 2 options (i.e., I should either be traveling north to south or south to north). An area for improvement for SEKI data collection would be to create a data collection app. In this case, we could offer auto-filled fields for direction of travel that are dependent on trail segments. It could be possible too, to consult with managers with extensive trail knowledge and determine if we could address these inconsistencies in the data.

Final Consideration: To streamline data collection processes, SEKI could leverage data collection apps (i.e., Survey123, Collector). These data apps can reduce data entry errors by including required fields and autofill values. Two examples that stand out are (1) direction of travel and (2) encounter time. For direction of travel, if a surveyor records which trail segment they are sampling, there will be only 2 options for direction of travel – therefore, reducing the surveyor's interpretation and data entry. For encounter time, the surveyor could simply record the number of people encountered as they are hiking, and the app will autofill the time stamp – requiring minimal time taken to record information.

Data to record in data collection app:

1. Trail segment ID
2. Analysis area (this should auto fill in a data collection app, once trail segment ID is recorded)

3. Distance of each trail segment (this is the sampling unit; this should auto fill in a data collection app, once trail segment ID is recorded)
4. Date/time (this should auto fill in a data collection app one survey starts)
5. Start and end time (this should auto fill in a data collection app one survey starts)
6. Number of people encountered at time of encounter
7. Time of encounter of each person (this should auto fill in a data collection app, once number is recorded)
8. Record 0's
9. Weather (choose from a drop-down menu in data collection app)

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Useful Resources

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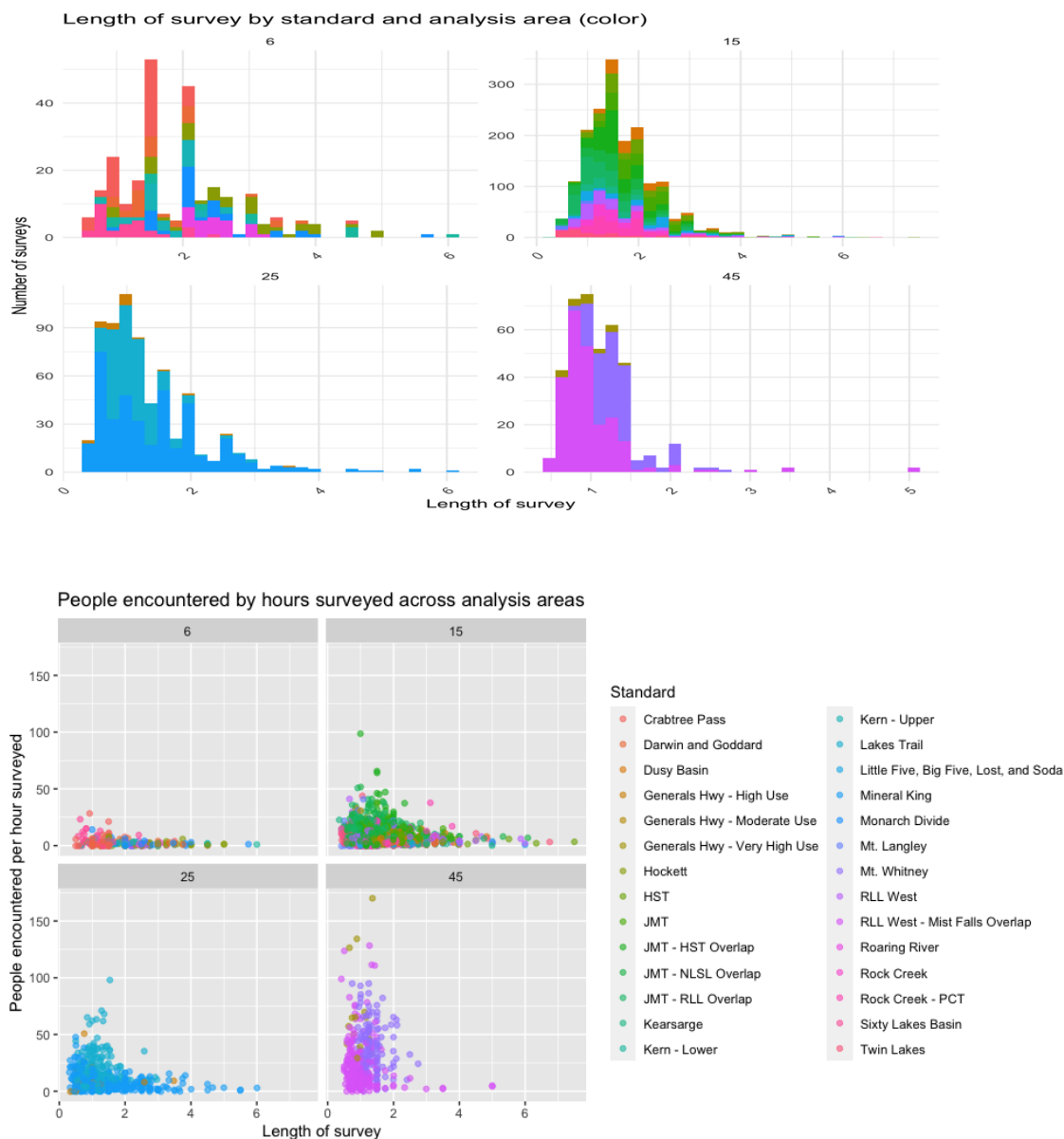
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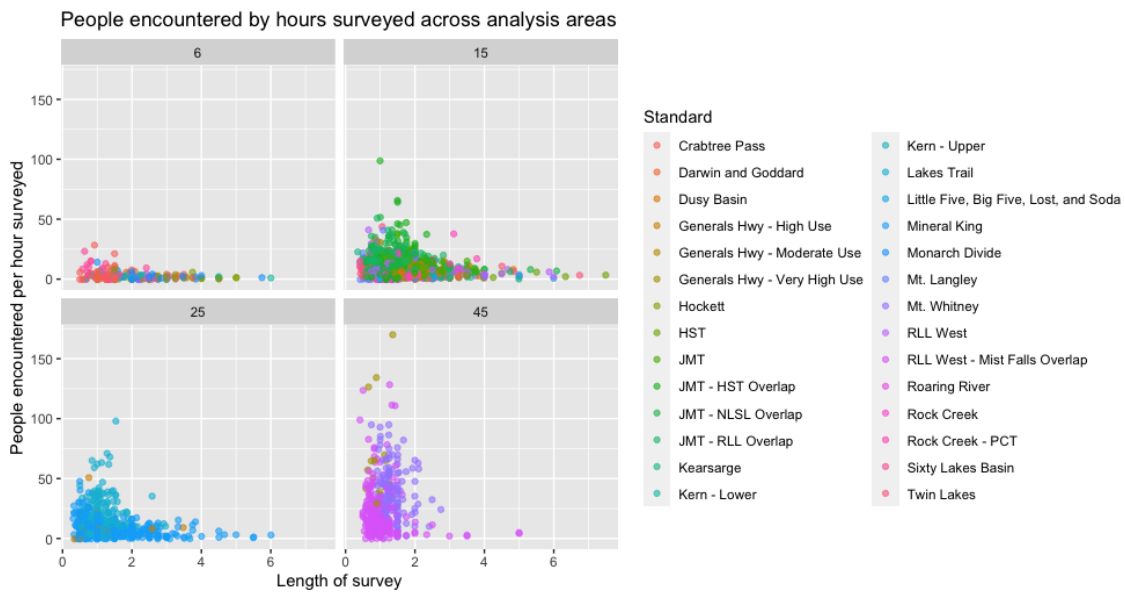
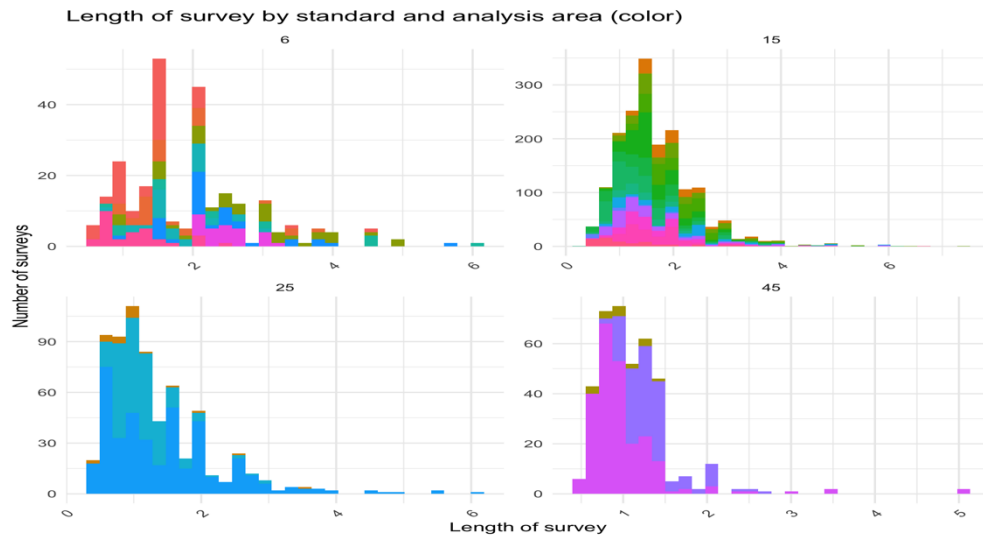
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APPENDIX

APPENDIX (A)

Sampling intensity and people encountered by analysis area and length of survey: The figures below show number of surveys (1. y-axis = number of surveys) and encounter rates (2. y-axis = people encountered per hour) in response to the number of hours surveyed (x-axis = length of survey). Each panel is a standard; color is analysis area. In the second figure, each point is a sampling event. In general, we see similar patterns across surveys of survey length across standards. However, we see that shorter surveys encounter higher people per hour. This makes sense if shorter trail segments (thus requiring less survey time) are likely easier trail likely to encounter more people.

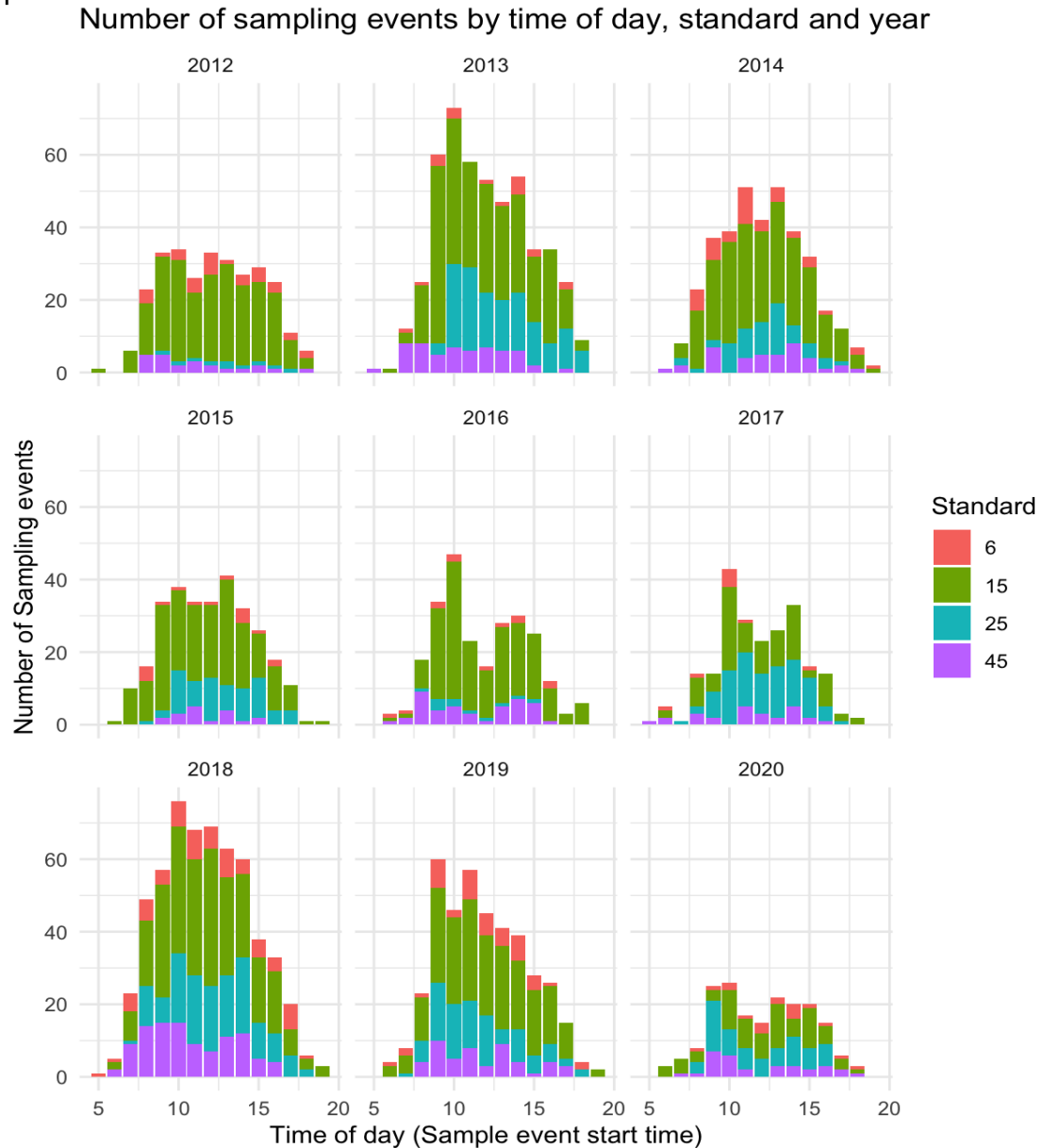




Breakdown of sampling effort across years, standard and analysis areas:

The figure below demonstrate that 2013 and 2018 saw the most sampling intensity across all years of data collection. The x-axis shows *time of day (measured from start of sampling event)* ranging from 0500 – 2000 hours; the y-axis shows the number of sampling events for each time period; colors represent standard; each panel is a year of sampling events.

Figure 1



The subsequent figures are broken out by standard (see labels) then further broken-down sampling events by year in each block, time of day on the x-axis, number of sampling events on the y-axis and analysis areas by color in the vertical bars.

Figure 1a



Figure 1b

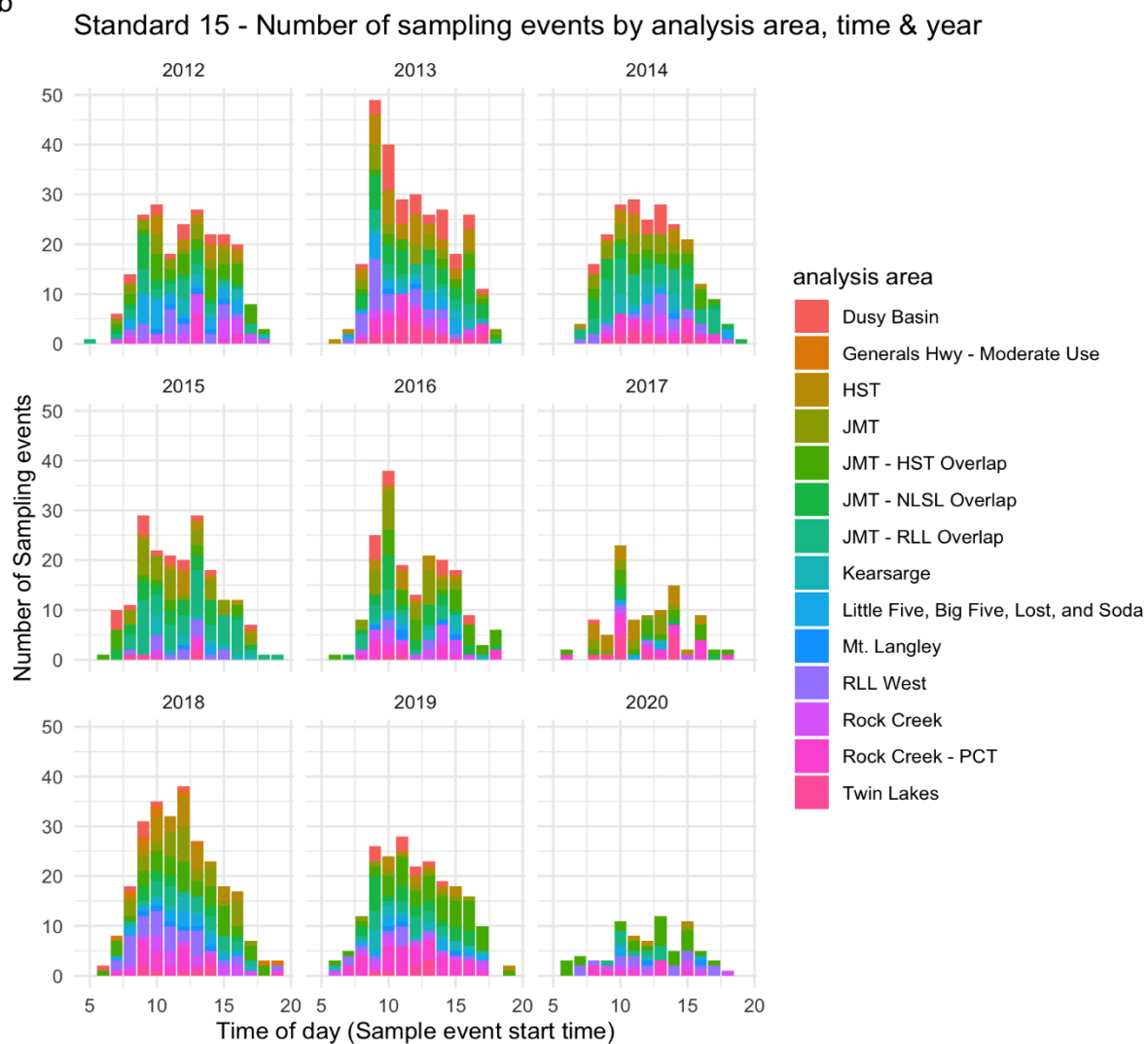


Figure 1c

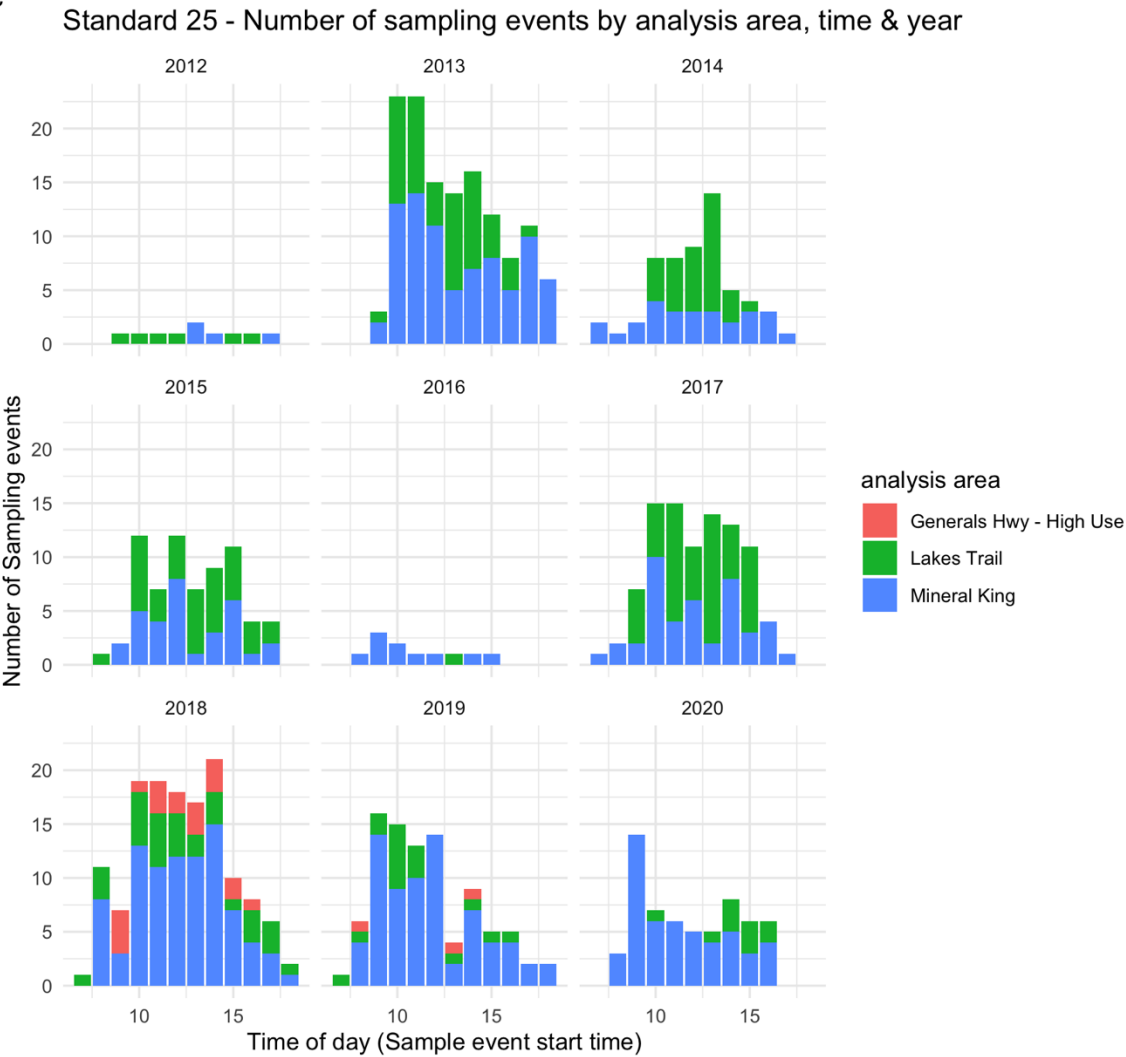


Figure 1d

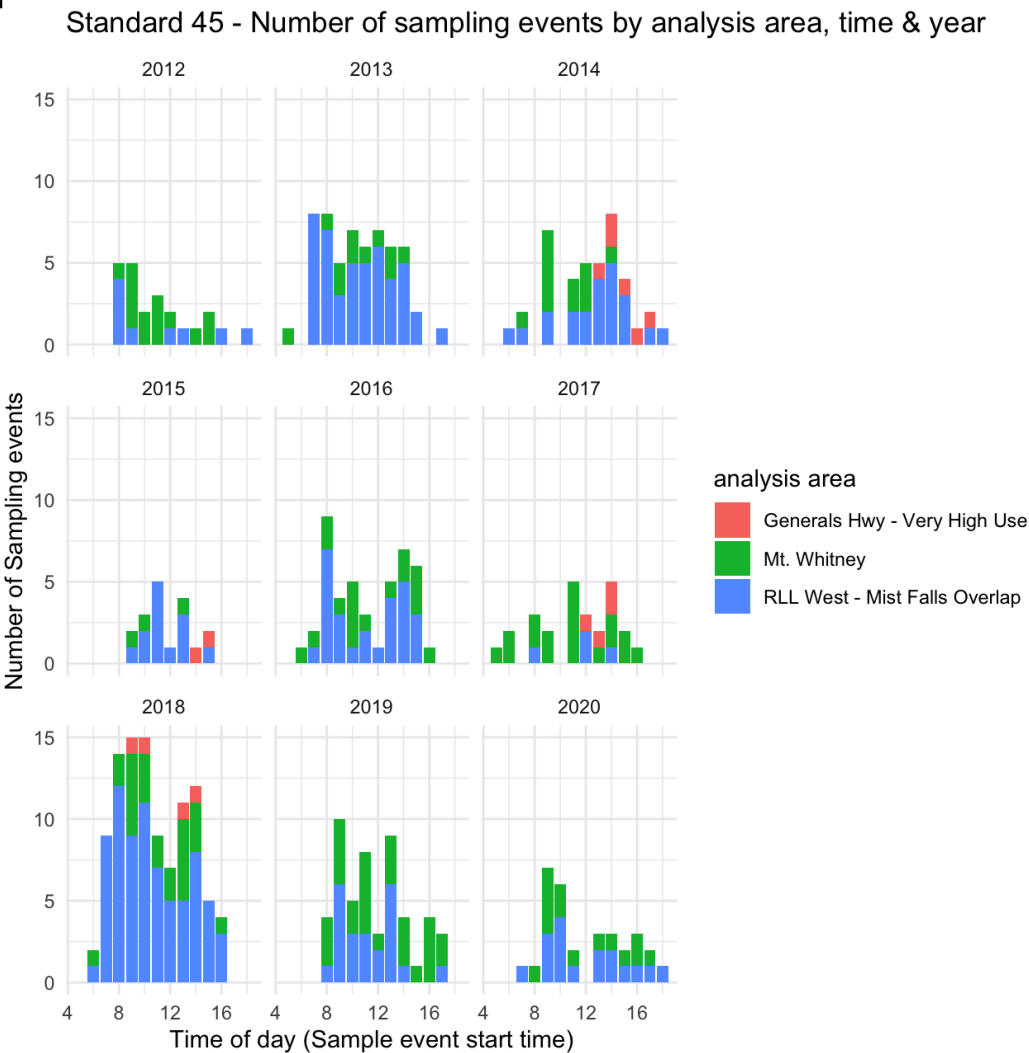
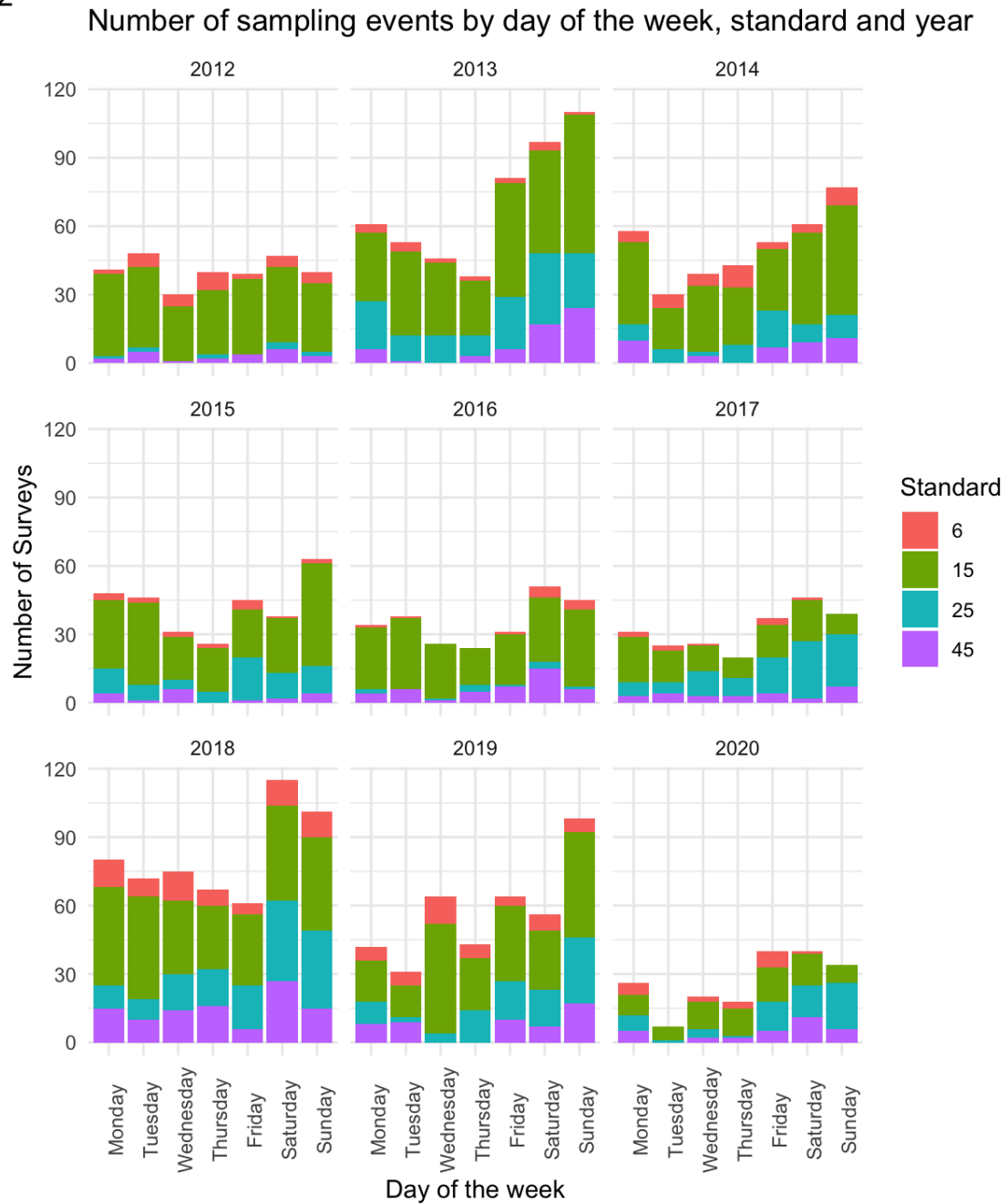


Figure 2 shows similar results to Figure 1 with respect in interannual variation in sampling events. However, in this figure, the x-axis shows day of the week; the y-axis show the number of sampling events for each day of the week; each color represents standard; each panel is a year of sampling events.

Figure 2



The subsequent figures are broken out by standard (see labels) then further broken-down by sampling events by year in each block, day of the week on the x-axis, number of sampling events on the y-axis and analysis areas by color in the vertical bars.

Figure 2a

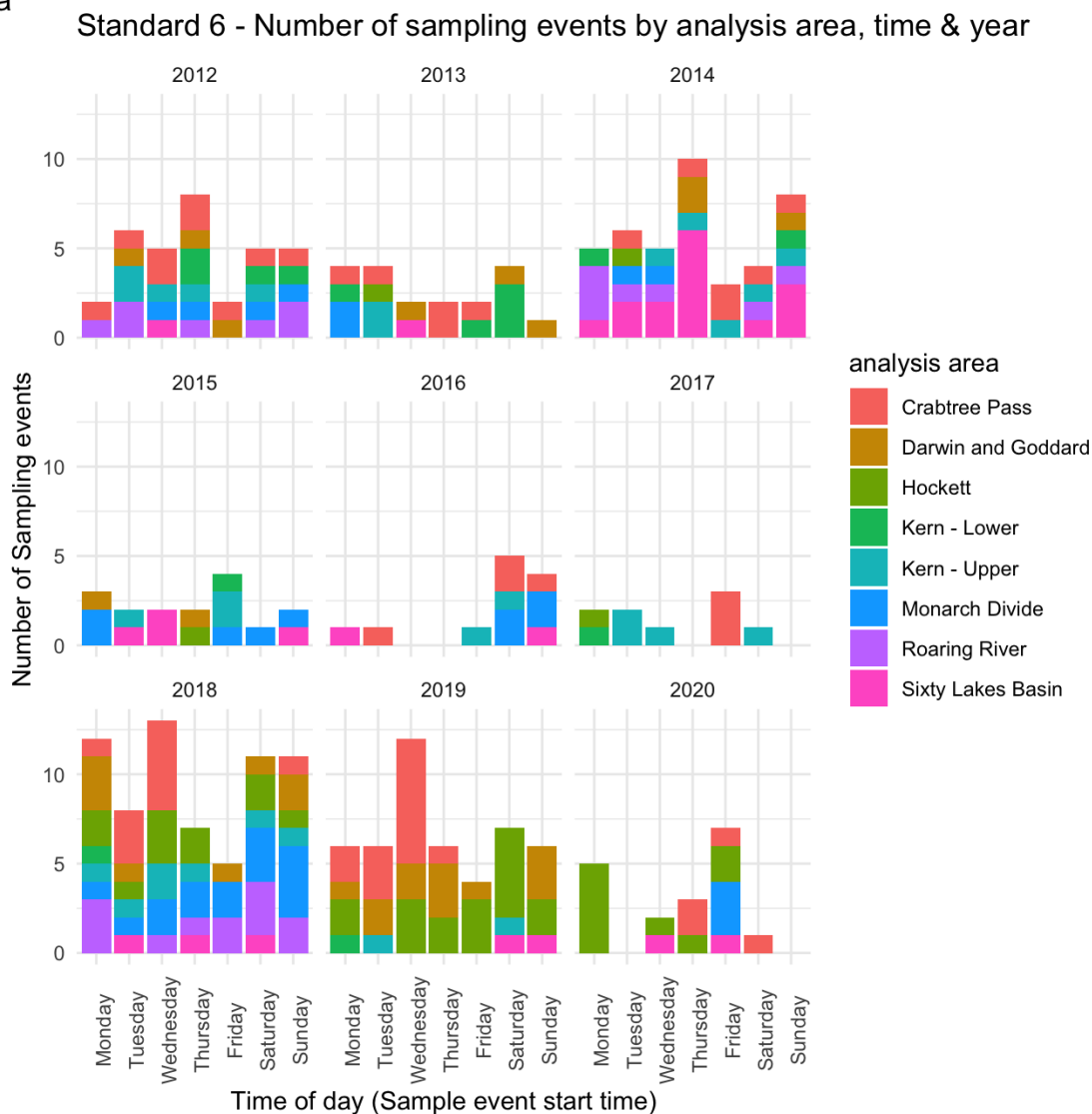


Figure 2b

Standard 15 - Number of sampling events by analysis area, time & year

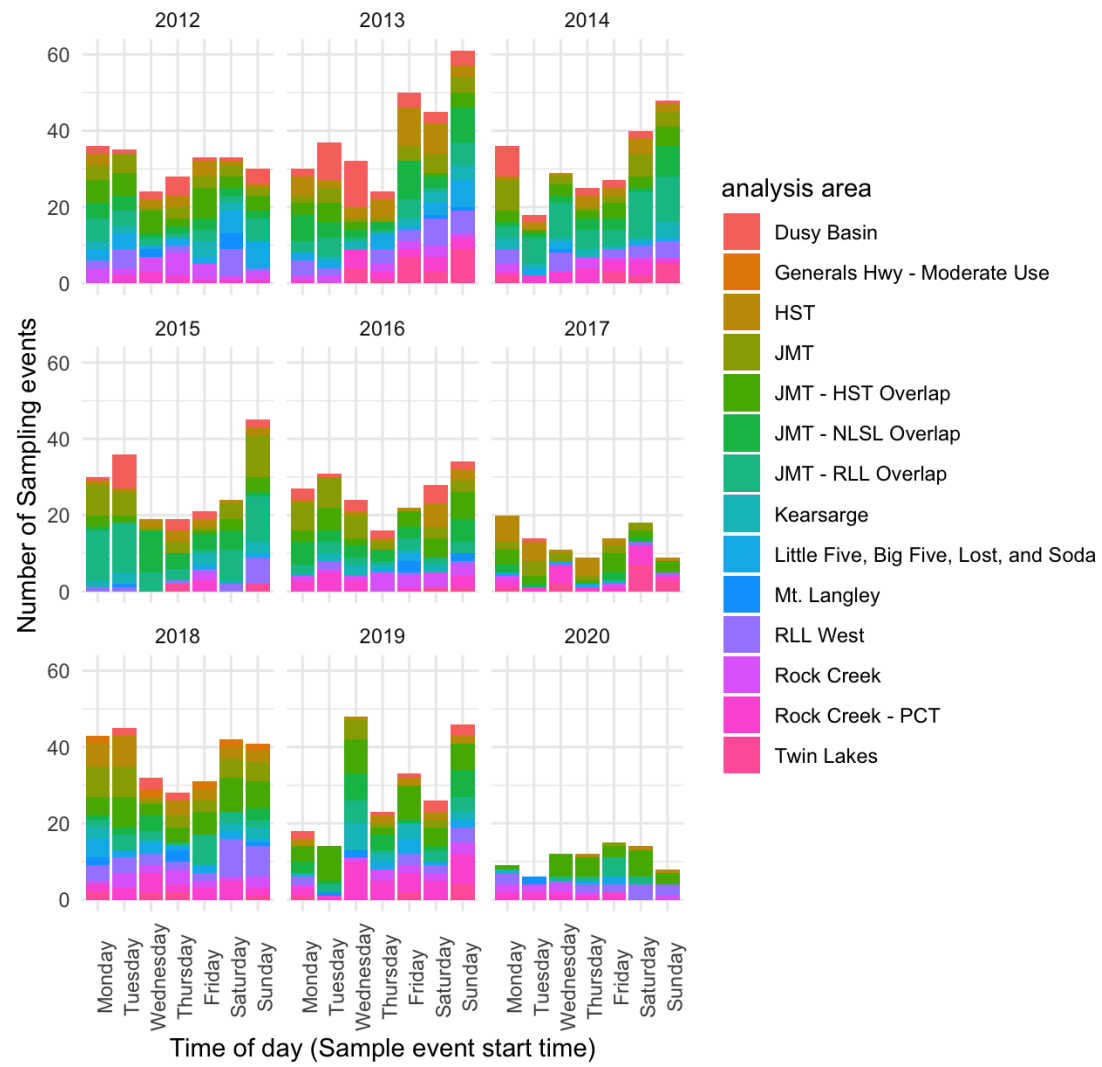


Figure 2c

Standard 25 - Number of sampling events by analysis area, time & year

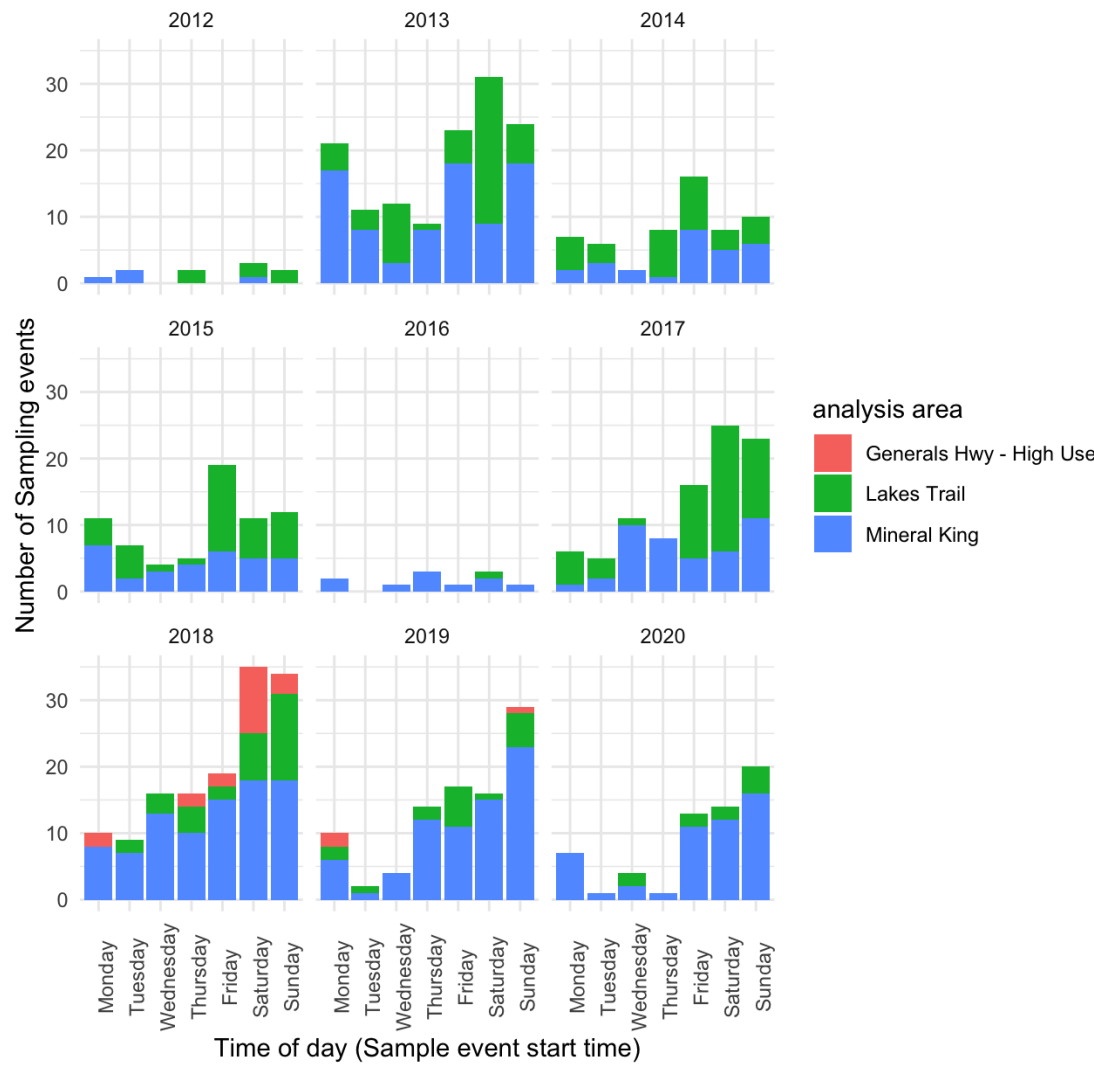
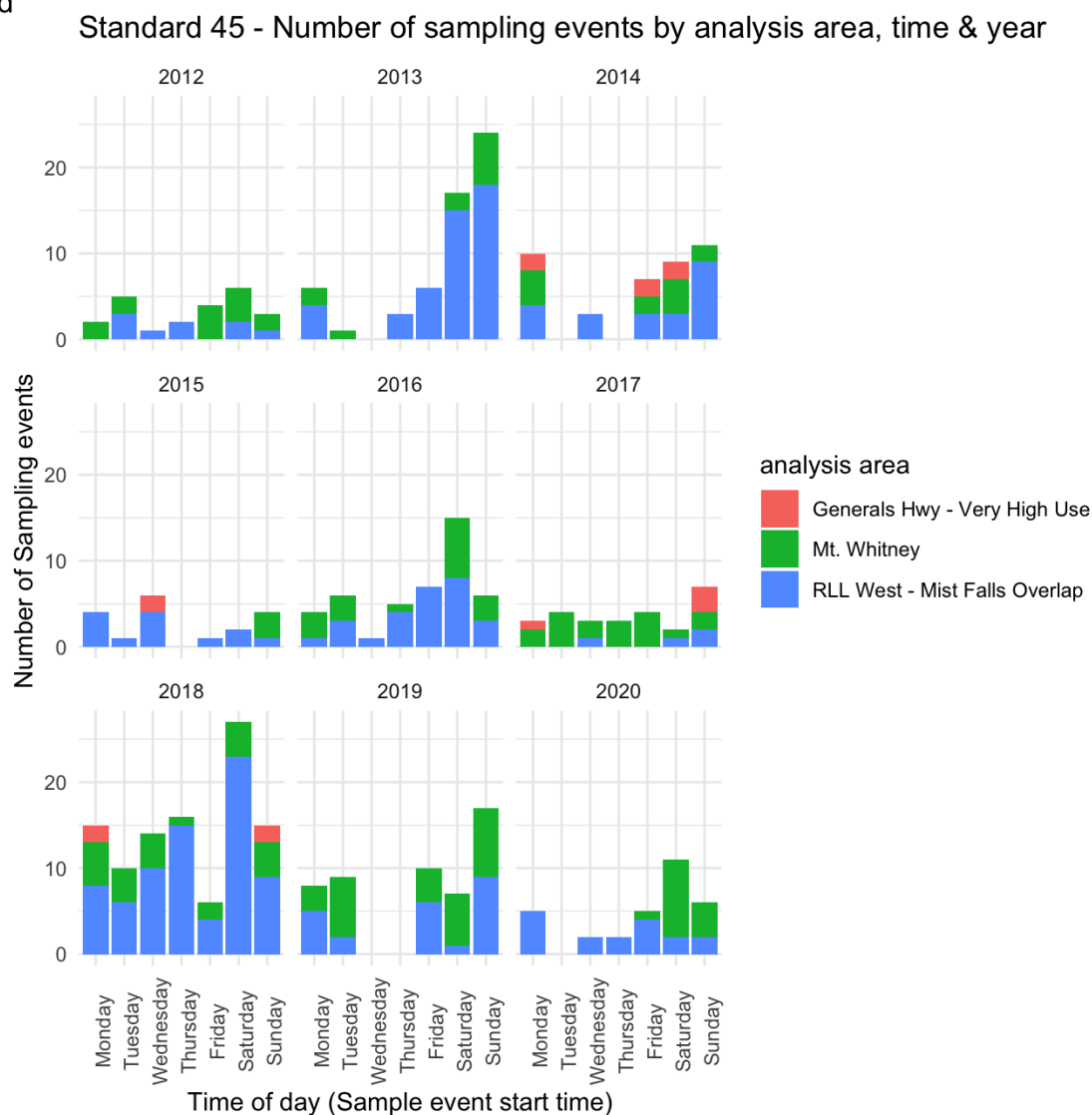


Figure 2d



Interpretation:

In general, because of the many years of convenience sampling across SEKI, we find that there has been variable but consistent sampling effort across all years, days of the week and times of days. Further, we find that while different analysis areas have received variable sampling within years, we also find that all analysis areas were consistently visited across years. These findings suggest that the survey effort is adequate to meet most sampling assumptions important for model outputs. There are areas for improvement that could help reduce possible bias in model outputs – see ‘recommendations’ for recommended sample protocol updates to reduce bias.

Summary analysis of encounter rates across time and space

The next series of figures represent people encountered within analysis areas and across temporal periods (time of day, day of week and year). Each point within the following figures is a sampling event that occurred, and the rate of people encountered during the respective sampling

event. This section is meant to help key in on factors that could have influence over encounter rates (i.e., survey time of day, day of the week and year).

Time of day: Below are 4 figures that show the time of day that sampling events occurred on the x-axis and people encounter rates (people encountered per hour) on the y-axis. Each panel is an analysis area with a color representing a trail segment ID (trailID). In general, the analysis areas classified as the highest standard see the most variation in encounter rates across time of day. Note: time of day ranges from 0500-2000 hours.

Figure 5a

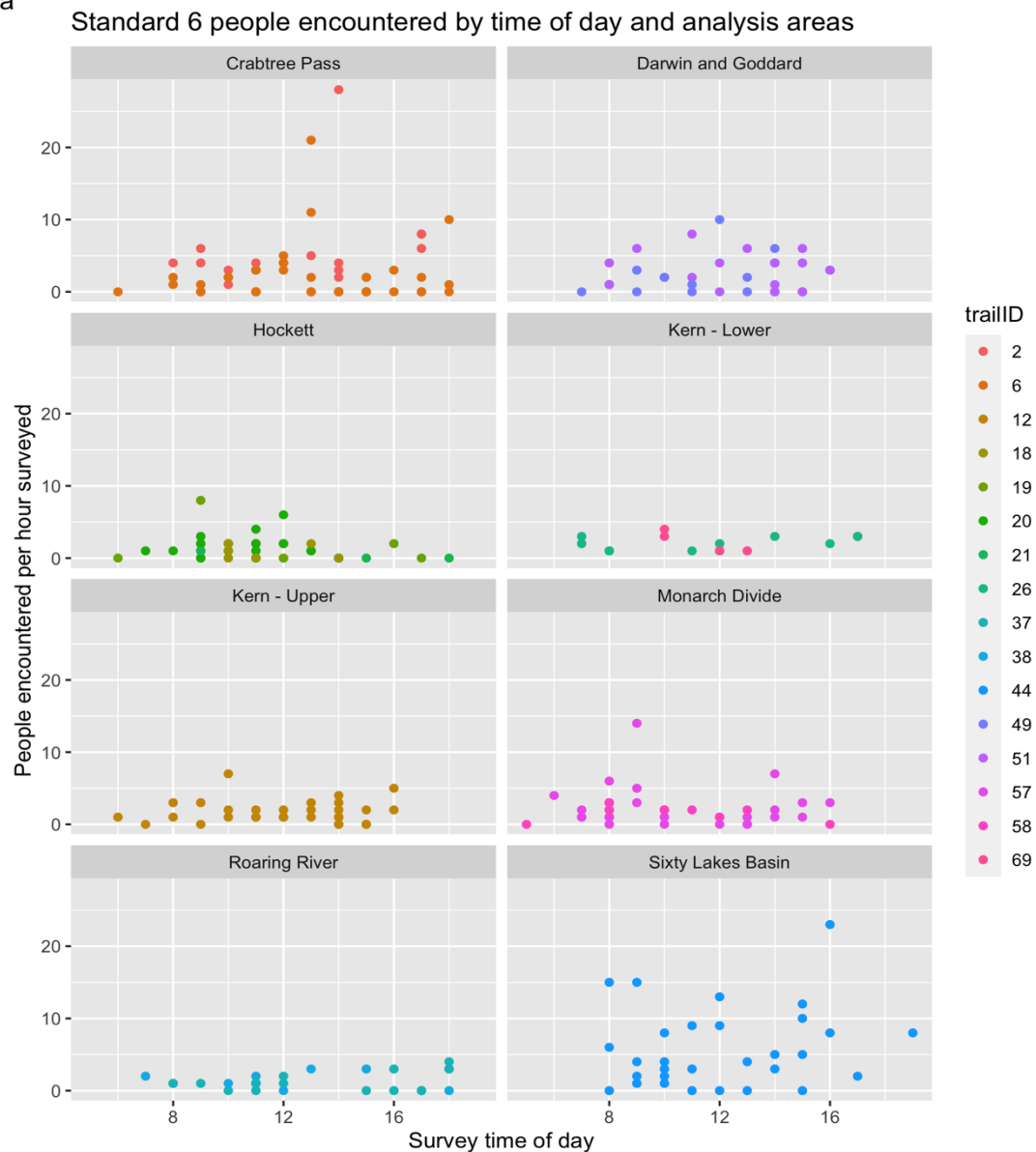


Figure 5b



Figure 5c

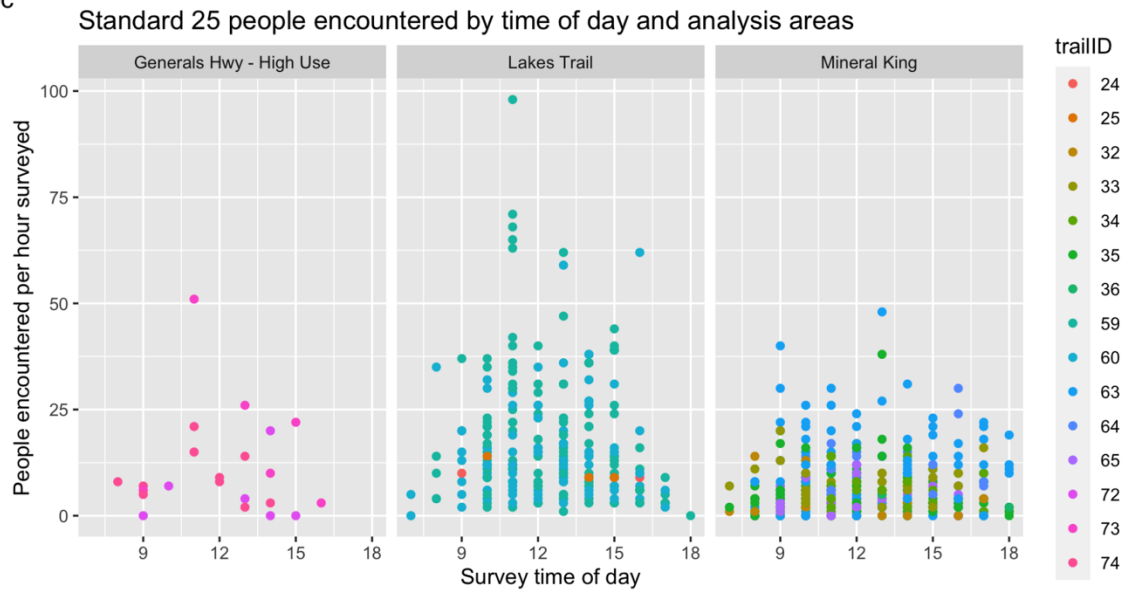
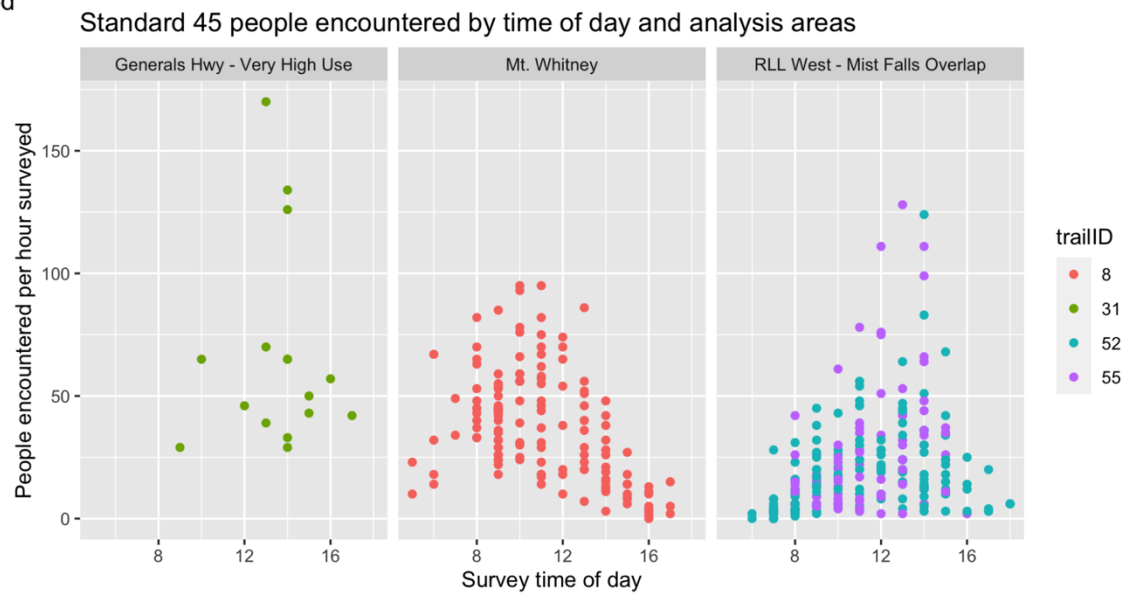


Figure 5d



Day of week: Below, the figures that show the day of week that each sampling event occurred on the x-axis and encounter rates (people encountered per hour) on the y-axis. The figures below are broken-out by standard. Each panel is an analysis area with a color representing trailID. In general, the analysis areas classified as the highest standard see the most variation in encounter rates across days of the week.

Figure 6a

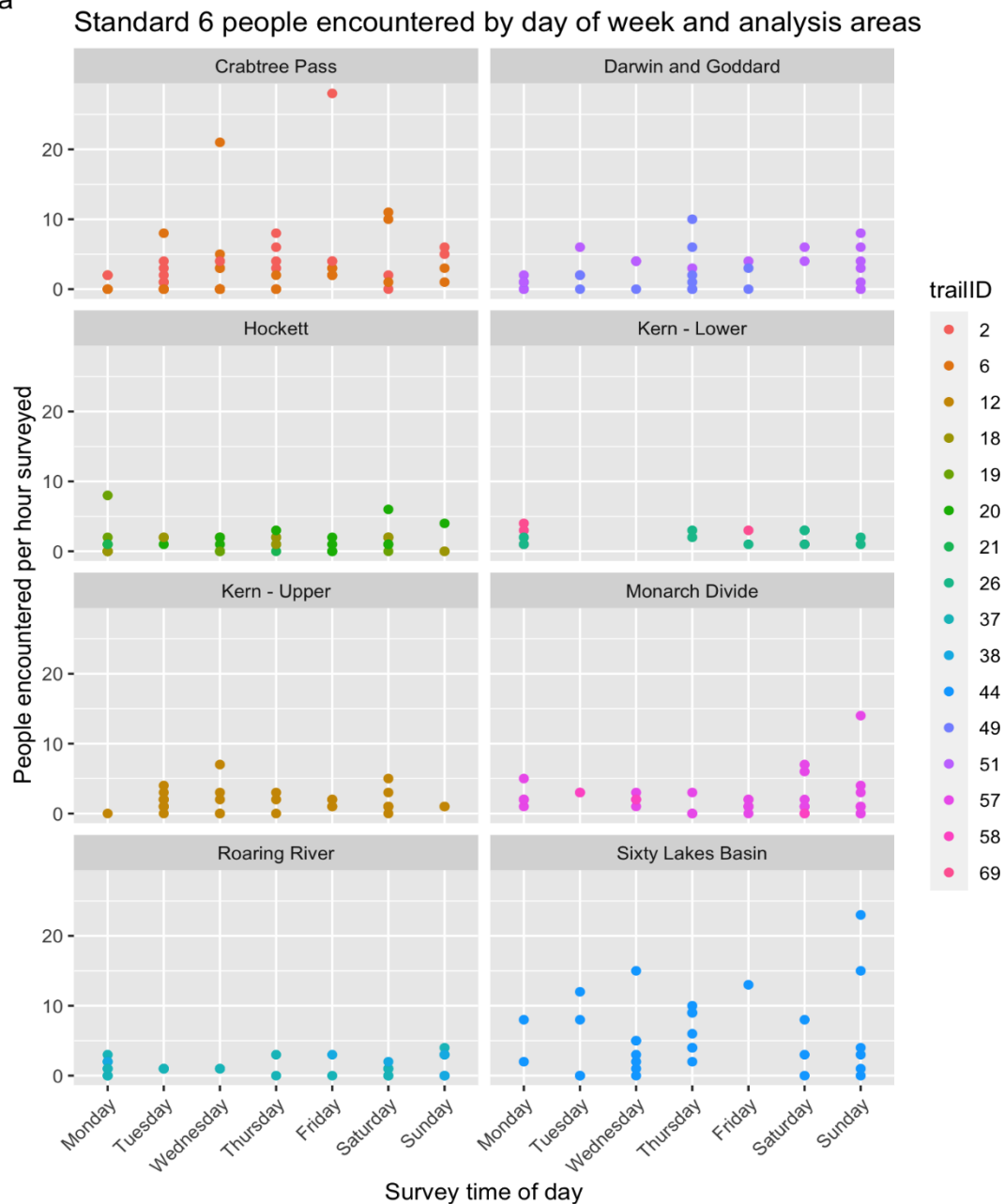


Figure 6b

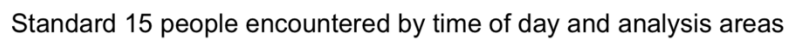


Figure 6c

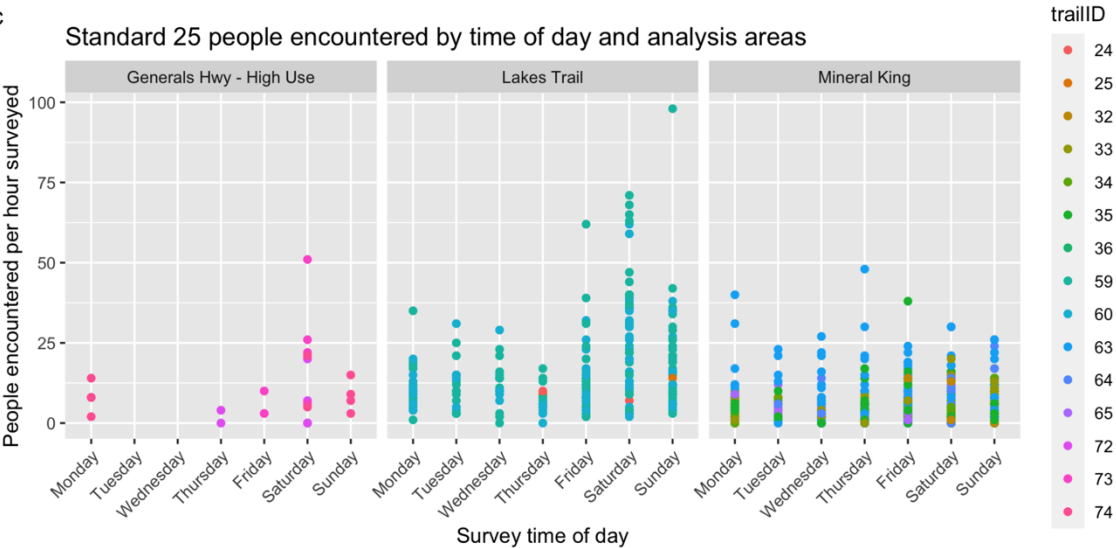
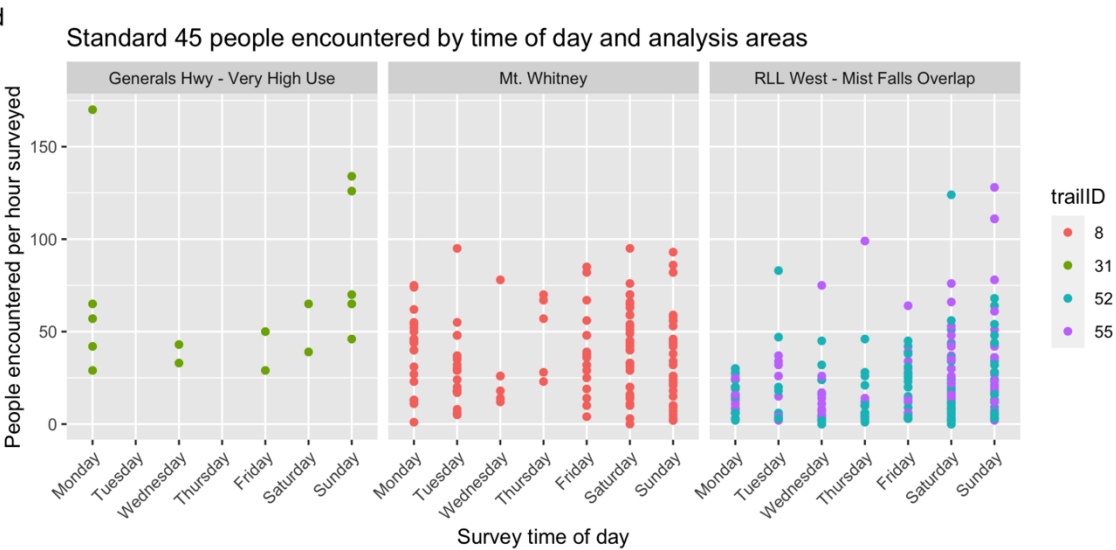


Figure 6d



APPENDIX (B)

Example analysis areas and trail segments – fine scale discussion on a few case studies.

Rae Lakes Loop- Mist Falls Overlap

This area is categorized as VH standard (45 or fewer people per hour on 90% of quota season days). Trail segments for this analysis area are Cedar Grove-1 and Cedar Grove-4. In Table 3 of the 2019 report (Frenzel, 2020, p 7), this analysis area was highlighted in yellow during the 2012-2015 monitoring period, indicating that the confidence interval for that period contains the standard of 45 people/hour on 90% of quota season days. The analysis area was highlighted in green during the 2016-2019 monitoring period, indicating that the standard of 45 people/hour on 90% of quota season days is above the confidence interval. This indicates that the Rae Lakes Loop- Mist Falls Overlap analysis area saw an improvement in relation to the standard of 45 or fewer people per hour on 90% of quota season days between the two monitoring periods.

Table 1- Start times for all samples for Rae Lakes Loop- Mist Falls Overlap, 2012-2019

Start Time	Sampling Year								Total Samples
	2012	2013	2014	2015	2016	2017	2018	2019	
6-7am	0	0	1	0	0	0	1	0	2
7-8am	1	17	1	0	1	0	9	0	29
8-9am	4	11	0	0	9	1	12	1	38
9-10am	1	3	2	3	3	0	9	6	27
10-11am	0	5	0	2	1	0	11	3	22
11-12pm	0	5	2	5	2	0	7	3	24
12-1pm	1	6	2	1	1	2	5	2	20
1-2pm	1	4	4	3	4	0	5	9	30
2-3pm	1	5	5	0	5	1	8	1	26
3-4pm	1	2	3	1	3	0	5	0	15
4-5pm	4	0	0	0	1	0	3	0	8
5-6pm	0	1	1	0	0	0	0	1	3
6-7pm	1	0	1	0	0	0	0	0	2

Table 1 shows that most samples began between 8-10am (65 samples) or between 1-3pm (56 samples).

Figure 1- Sampling Events per Year by Month for Rae Lakes Loop

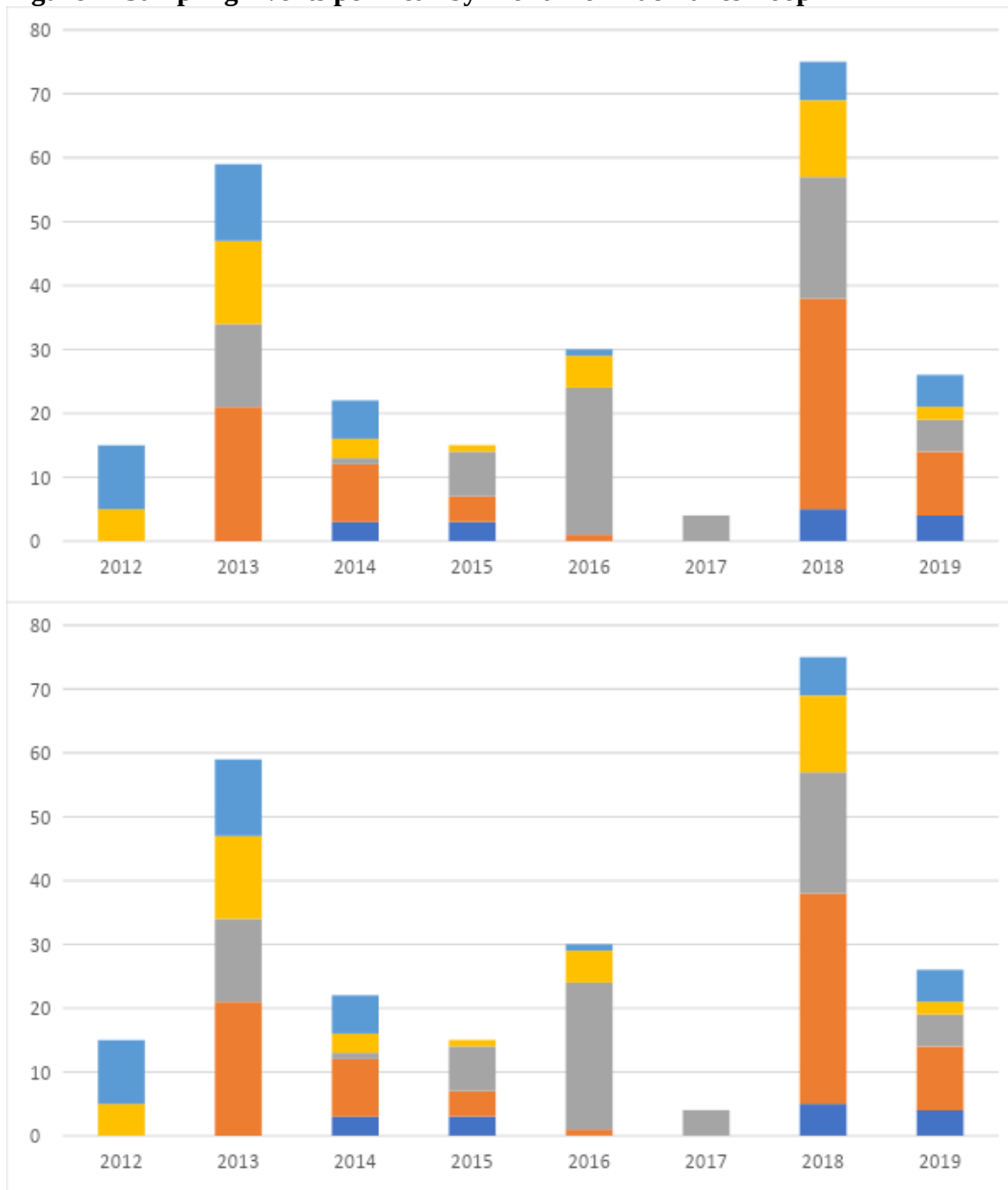


Figure 1 shows the number of sampling events across the entire analysis area each month of each year the area has been monitored. There were 111 sampling events during the 2012-2015 monitoring period and 135 during the 2016-2019 monitoring period. There are large fluctuations each year in which months receive sampling events. For example, June had 41% of sampling events in 2014, and then 27% of sampling events in 2015. In 2016, 77% of all samples occurred in July.

Figure 2- Sampling events per Year by Month for Cedar Grove-1

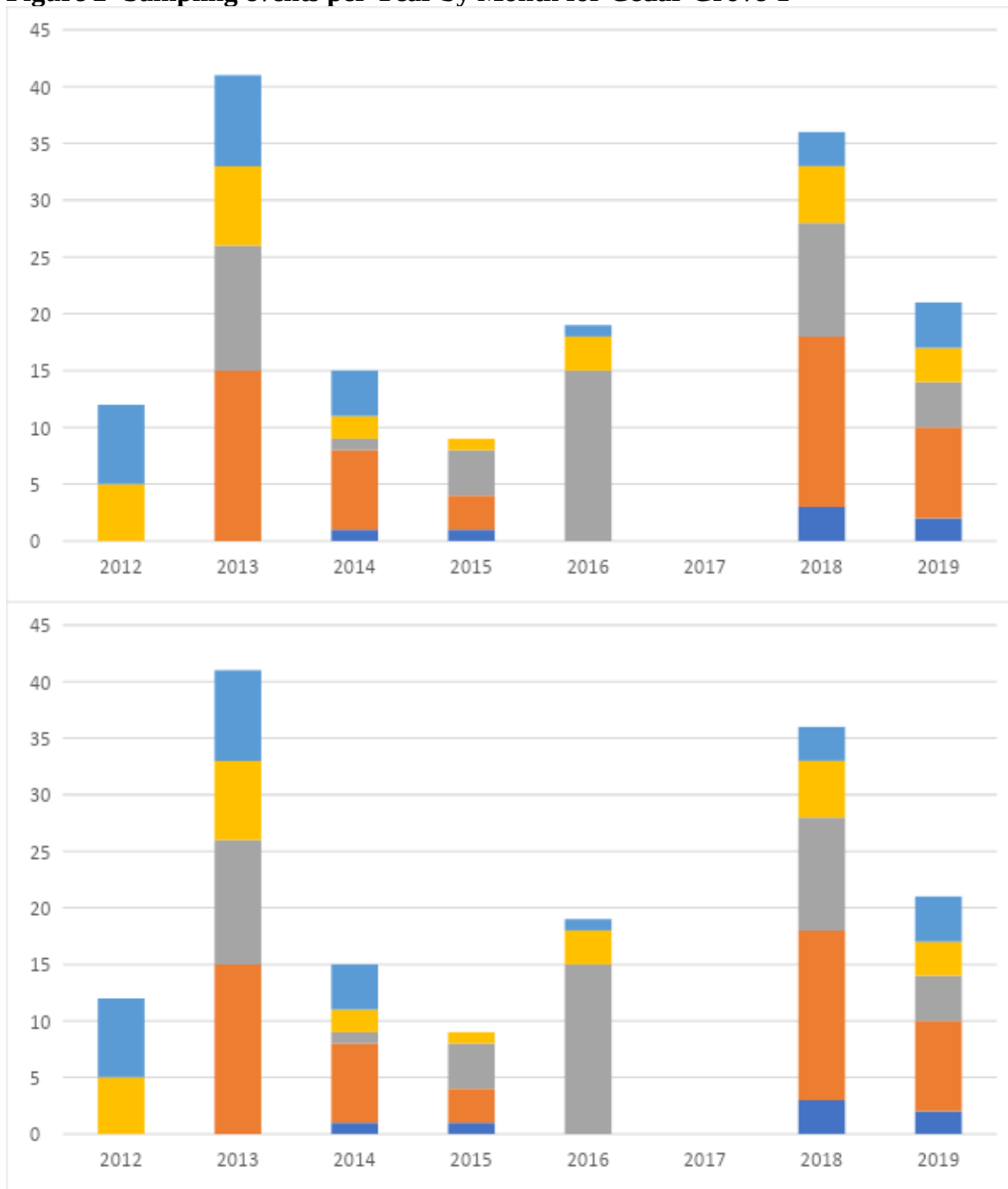


Figure 2 shows the number of sampling events on just the Cedar Grove-1 trail segment within the greater Rae Lakes Loop analysis area each month of each year the trail segment has been monitored. Except for 2013, there is an uneven distribution of sampling days per month each year.

Figure 3- Sampling Events per Year by Month for Cedar Grove-4

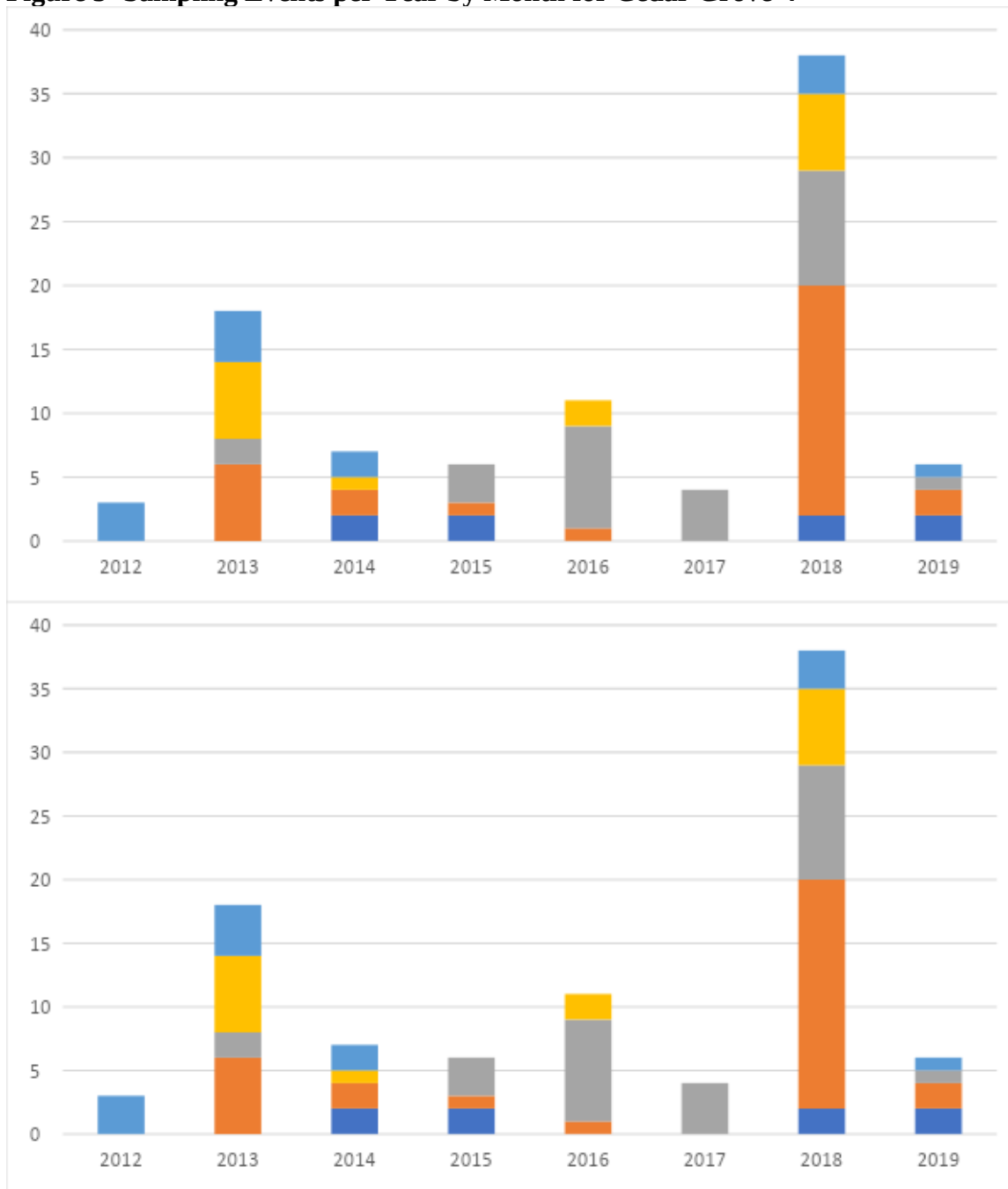


Figure 3 shows the number of sampling events on just the Cedar Grove-4 trail segment within the greater Rae Lakes Loop analysis area each month of each year the trail segment has been monitored.

Figure 4- Sampling Events per Year by Weekday for Rae Lakes Loop

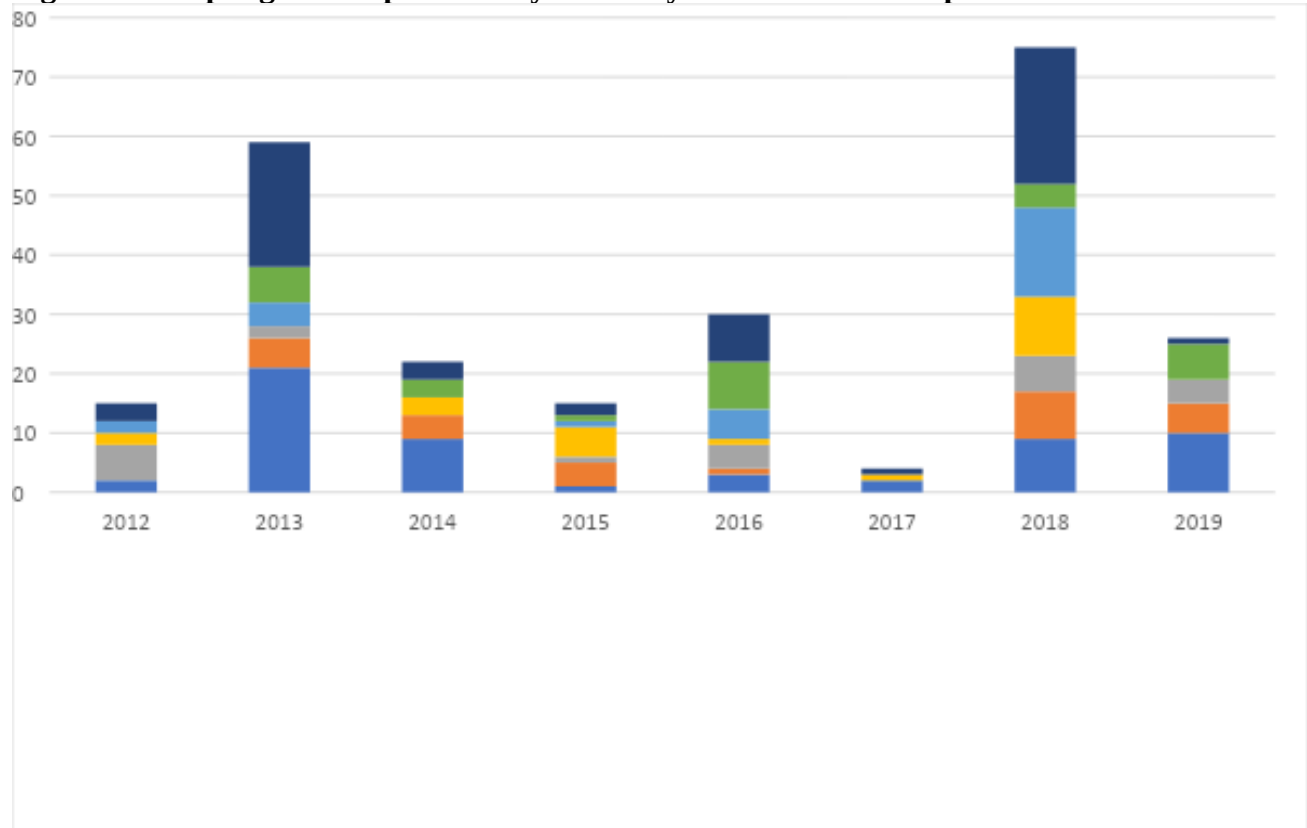


Figure 4 shows which weekdays all sampling events for the analysis area were completed for each year. Generally, weekends (Saturday-Sunday) are most commonly sampled for the Rae Lakes Loop analysis area. Midweek (Tuesday-Thursday) is least commonly sampled, despite SEKI's encounter monitoring protocols encouraging monitors to focus on sampling all weekdays during the season.

Figure 5- Number of Unique Sampling Days per Year by Month for Rae Lakes Loop

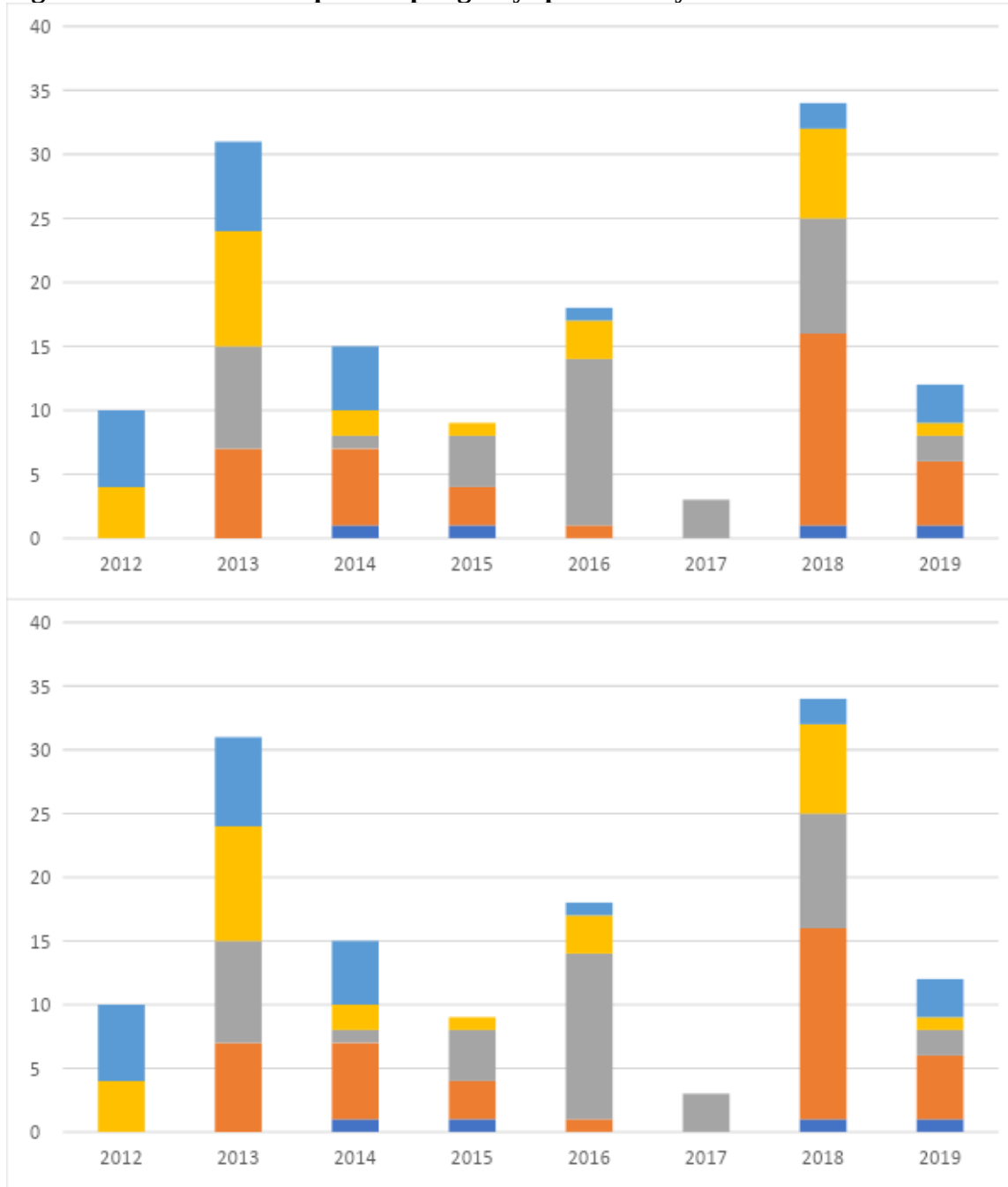


Figure 5 shows how many unique days were used to collect samples across each year in each month within the Rae Lakes Loop analysis area. There are far more sampling events than days the sampling events occurred.

Figure 6- Total People Encountered in Rae Lakes Loop Analysis Area in 2018

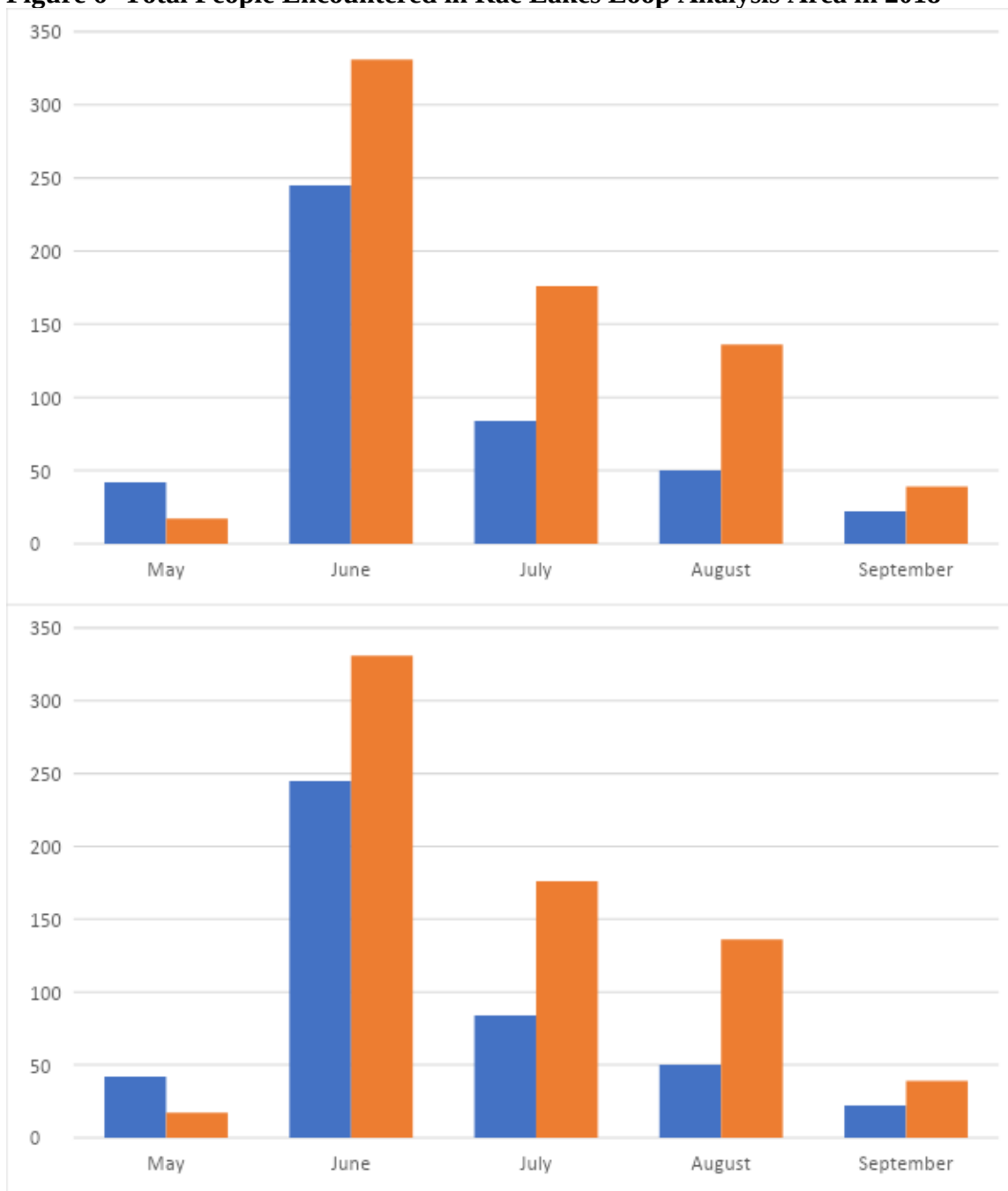


Figure 6 shows the total number of people encountered within the Rae Lakes Loop analysis area in each month of 2018. This year was chosen because it had the most sampling events within the 2016-2019 monitoring period. Total number of encountered people were also split between the two trail segments.

Rae Lakes Loop- Mist Falls Overlap Summary

There are large fluctuations each year in the total number of samples collected in this analysis area and the number of samples collected in each month (see Figure 1). Additionally, samples are more commonly collected on weekends than any other days of the week (see Figure 4).

When the two trail segments within Rae Lakes Loop are analyzed separately, Cedar Grove-1 (see Figure 2) is generally monitored more frequently than Cedar Grove-4 (Figure 3). Only 2015 and 2018 have roughly similar numbers of sampling events in each month for both trail segments. In addition to uneven distribution of sampling events across the two trail segments within the analysis area, there are large fluctuations year to year and month to month. For example, there were 30 samples total taken in 2016, of which 23 occurred in July. The following year, there were 4 samples total. Uneven collection of data, potentially caused by the reliance on convenience sampling, may impact the accuracy of estimates of number of people encountered per hour within the analysis area.

Lakes Trail

This analysis area is categorized by SEKI as a High use area (a visitor should encounter 25 or fewer people per hour on 90% of quota season days). Trail segments Pear Lake-1, Pear Lake-2, Pear Lake-3, and Pear Lake-4 are aggregated into this analysis area. Lakes Trail was highlighted in green during the 2012-2015 monitoring period and yellow during the 2016-2019 monitoring period, indicating degradation in relation to standard.

Table 2- Start times for all samples for Lakes Trail, 2012-2019

Start Time	Sampling Year								Total Samples
	2012	2013	2014	2015	2016	2017	2018	2019	
6-7am	0	0	0	1	2	0	0	0	3
7-8am	0	0	0	2	1	2	1	1	7
8-9am	0	0	0	1	0	0	3	1	5
9-10am	1	1	1	0	4	5	1	2	15
10-11am	1	10	4	7	10	6	5	6	49
11-12pm	1	11	5	3	6	11	5	3	45
12-1pm	1	4	6	4	10	5	4	0	34
1-2pm	0	9	11	6	7	12	2	1	48
2-3pm	0	10	4	6	13	5	3	1	42
3-4pm	1	4	1	6	2	8	1	1	24
4-5pm	1	3	1	3	9	0	3	1	21
5-6pm	0	1	0	2	2	0	3	0	8
6-7pm	0	0	0	2	0	0	1	0	3
7-8pm	0	0	0	0	1	0	0	0	1
9-10pm	0	1	0	0	0	0	0	0	1

Table 2 shows that most samples began between 10am-12pm (94 samples) or between 1-3pm (90 samples). Generally, there is an even distribution in start times between 10am-4pm.

Figure 7- Sampling Events per Year by Month for Lakes Trail Analysis Area

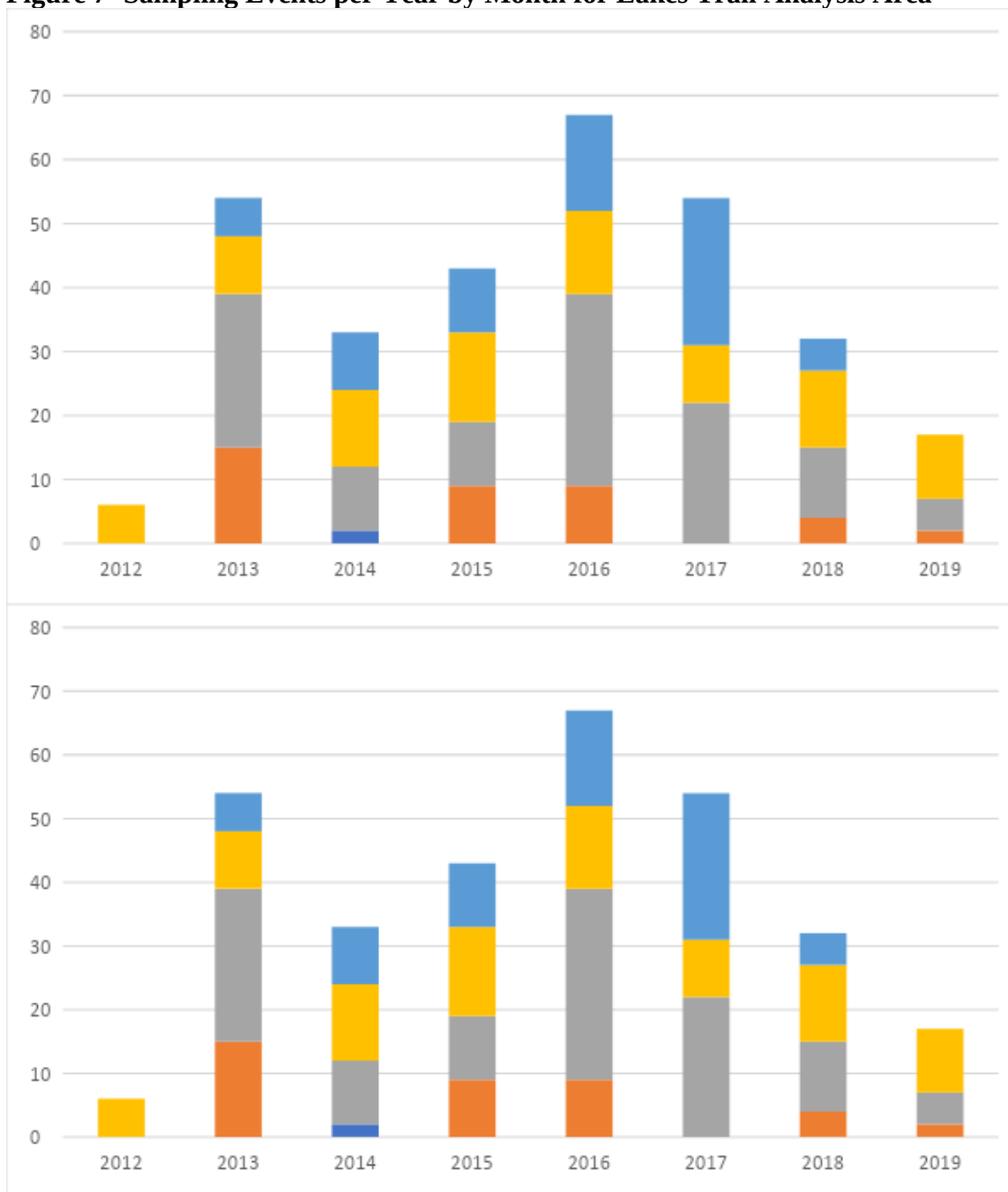


Figure 7 shows a breakdown of the number sampling events taken within the analysis area each month of each year. 2012 was the least sampled year while 2016 had the most samples.

Figure 8- Sampling Events Per Year by Month for Pear Lake-1

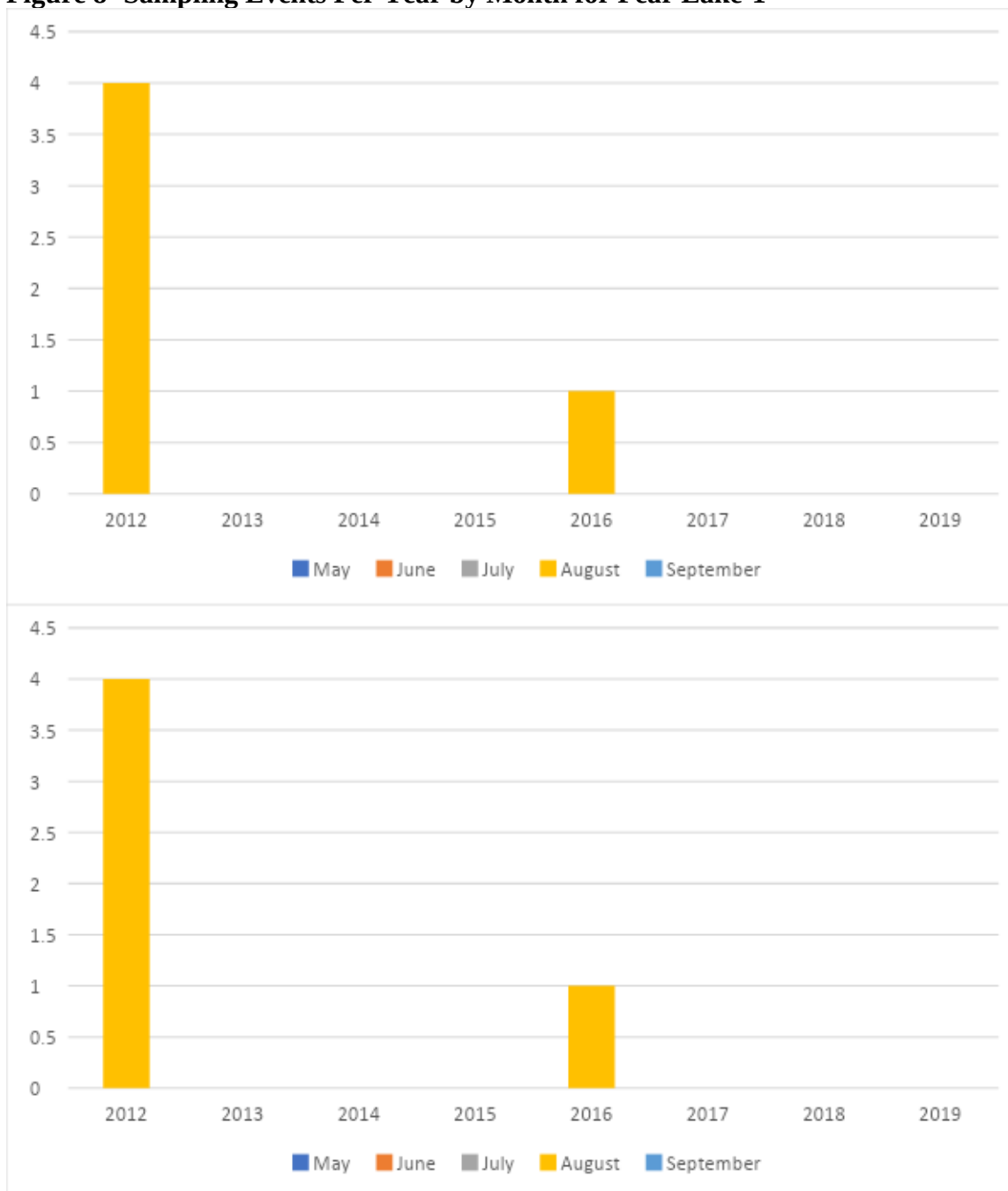


Figure 8 shows that Pear Lake-1 has only been sampled 5 times between 2012-2019. The most recent sample was one taken in August 2016.

Figure 9- Sampling Events Per Year by Month for Pear Lake-2

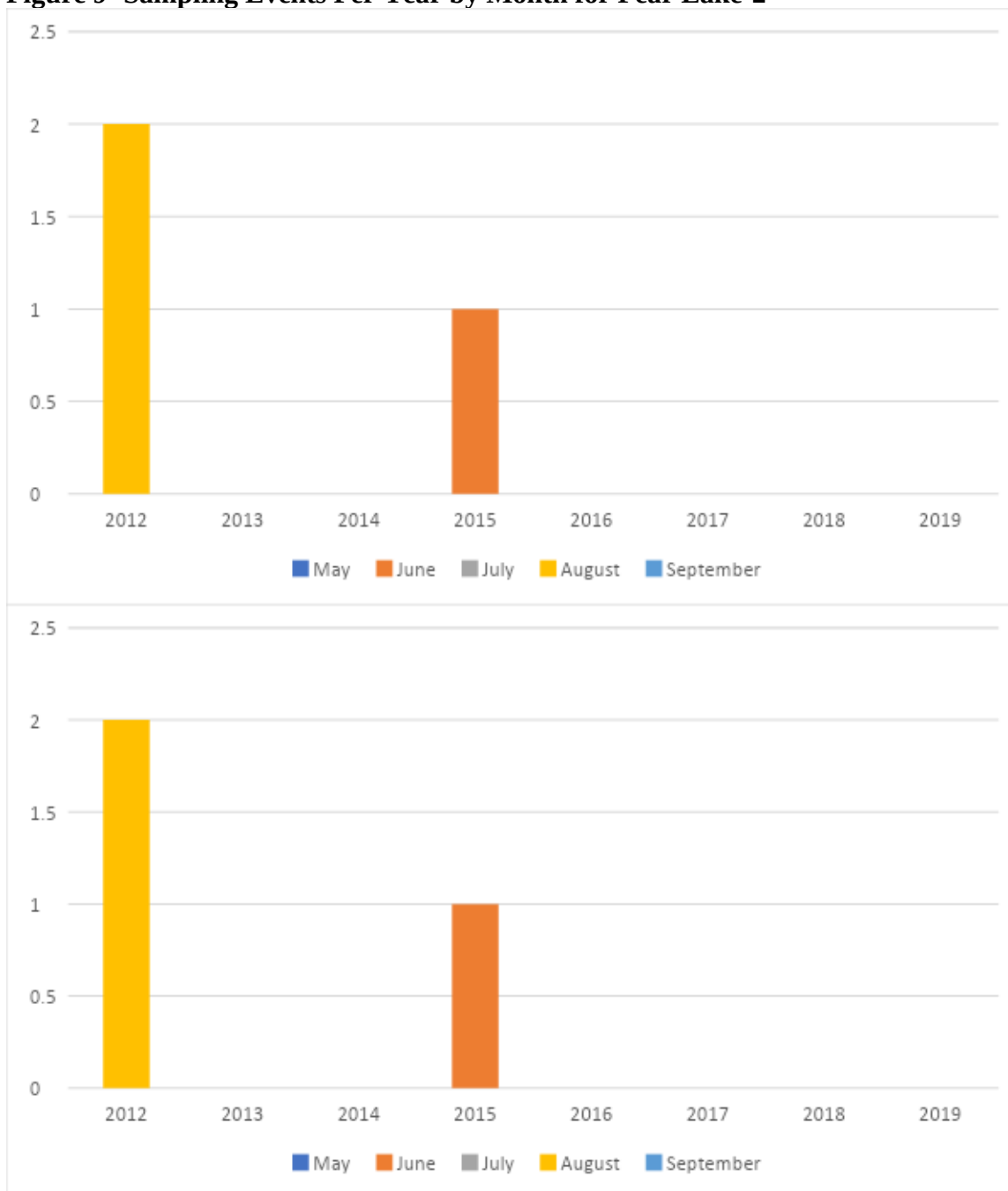


Figure 9 shows that Pear Lake-2 has only been sampled 3 times between 2012-2019. The most recent sample was one taken in June 2015.

Figure 10- Sampling Events Per Year by Month for Pear Lake-3

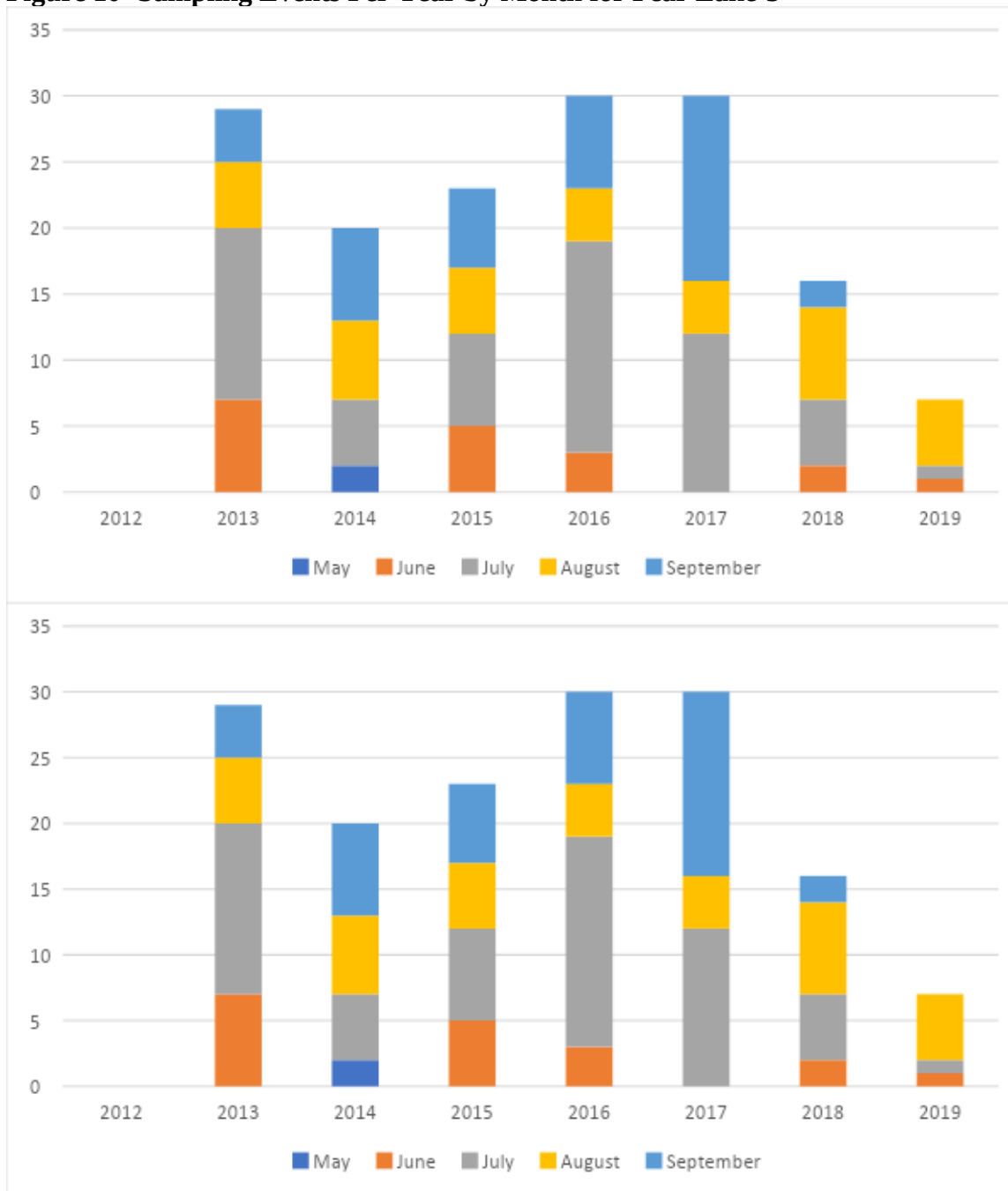


Figure 10 shows the total number of sampling events for Pear Lake-3 across all years. Aside from 2012, which had no samples, 2019 had the fewest with only 7. July is the most heavily sampled month and May the least.

Figure 11- Sampling Events Per Year by Month for Pear Lake-4

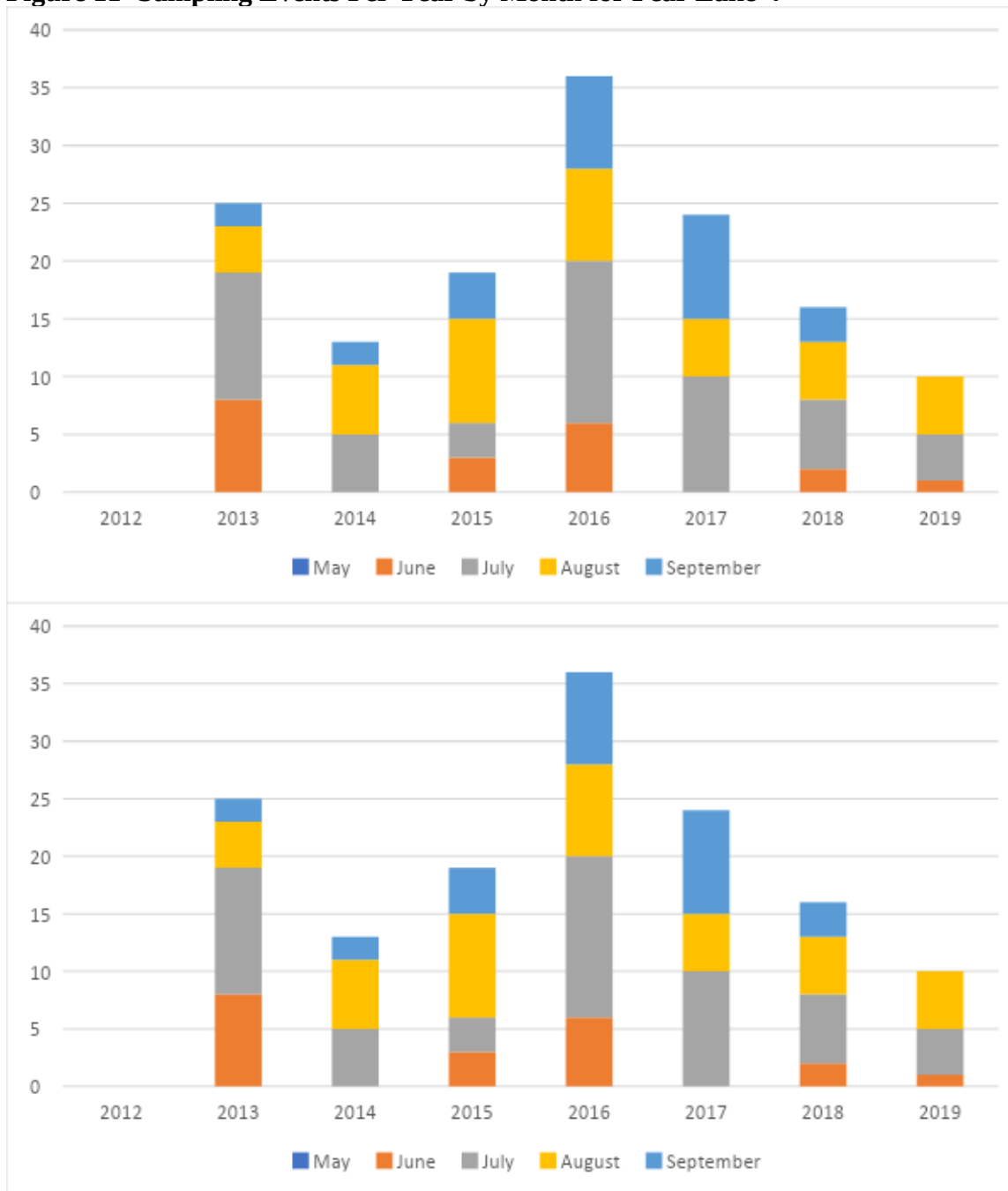


Figure 11 shows the total samples taken along Pear Lake-4 across all years. Aside from 2012, which was not sampled at all, 2019 had the fewest samples with 10 total. Generally, July is the most heavily sampled month.

Figure 12- Sampling Events per Year by Weekday for Lakes Trail

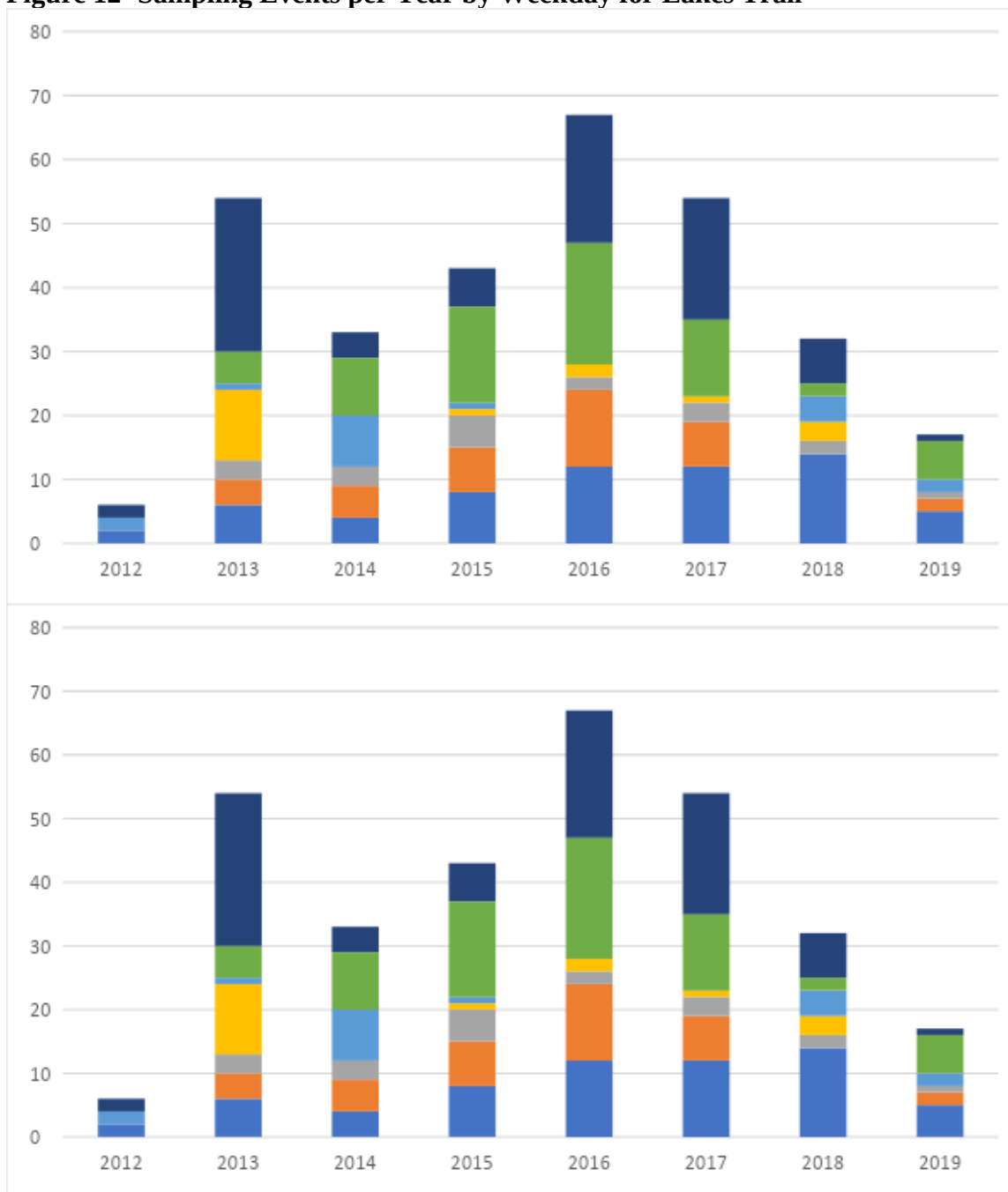


Figure 12 shows which days of the week samples were taken each year. Generally, Friday-Sunday are the most commonly sampled days.

Figure 13- Number of Unique Sampling Days per Year by Month for Lakes Trail

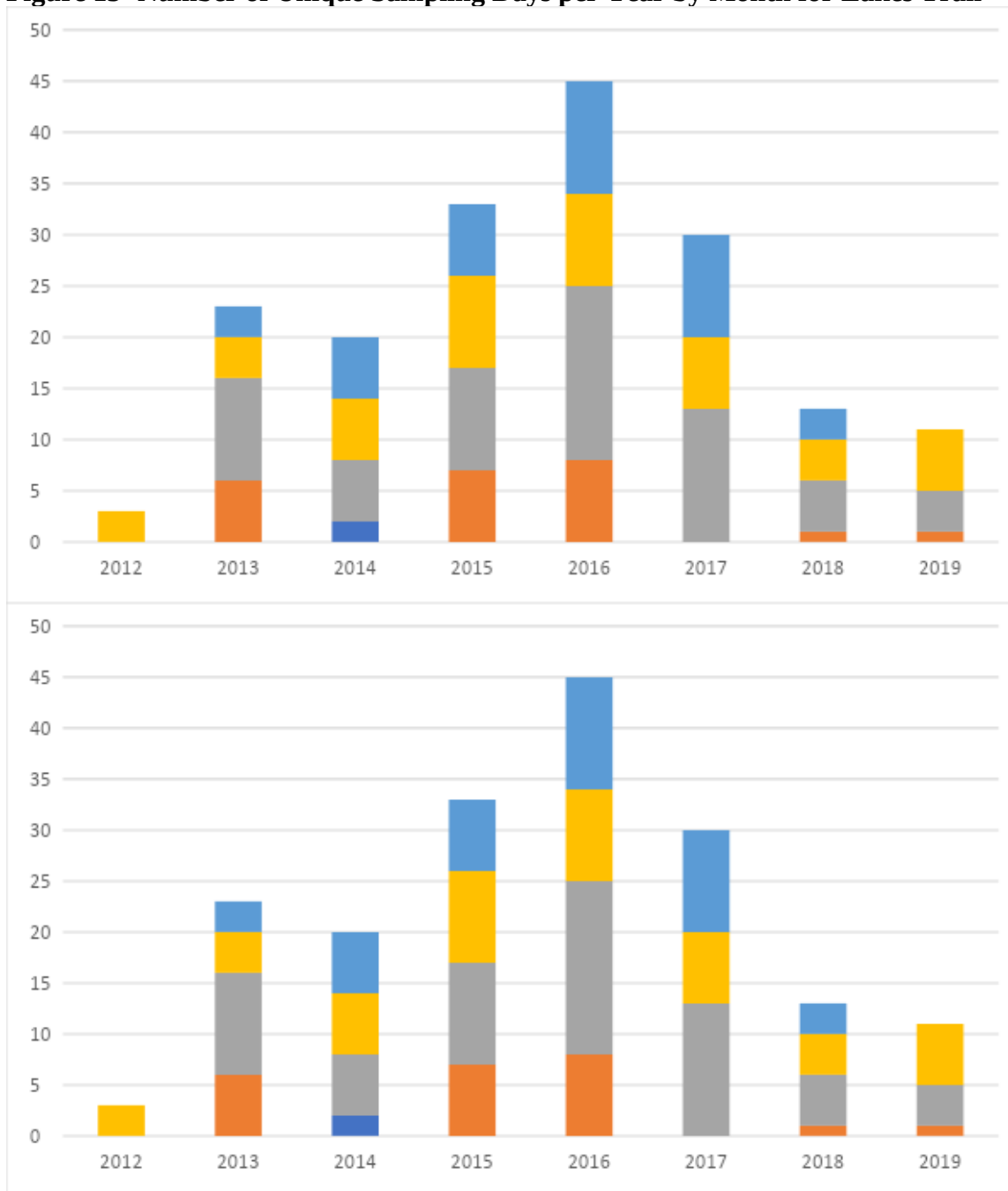


Figure 13 shows that estimates for 2016-2019 in 2019 report (Frenzel, 2020) are based on 170 samples from 99 unique days.

Figure 14- Total People Encountered in Lakes Trail Analysis Area in 2016

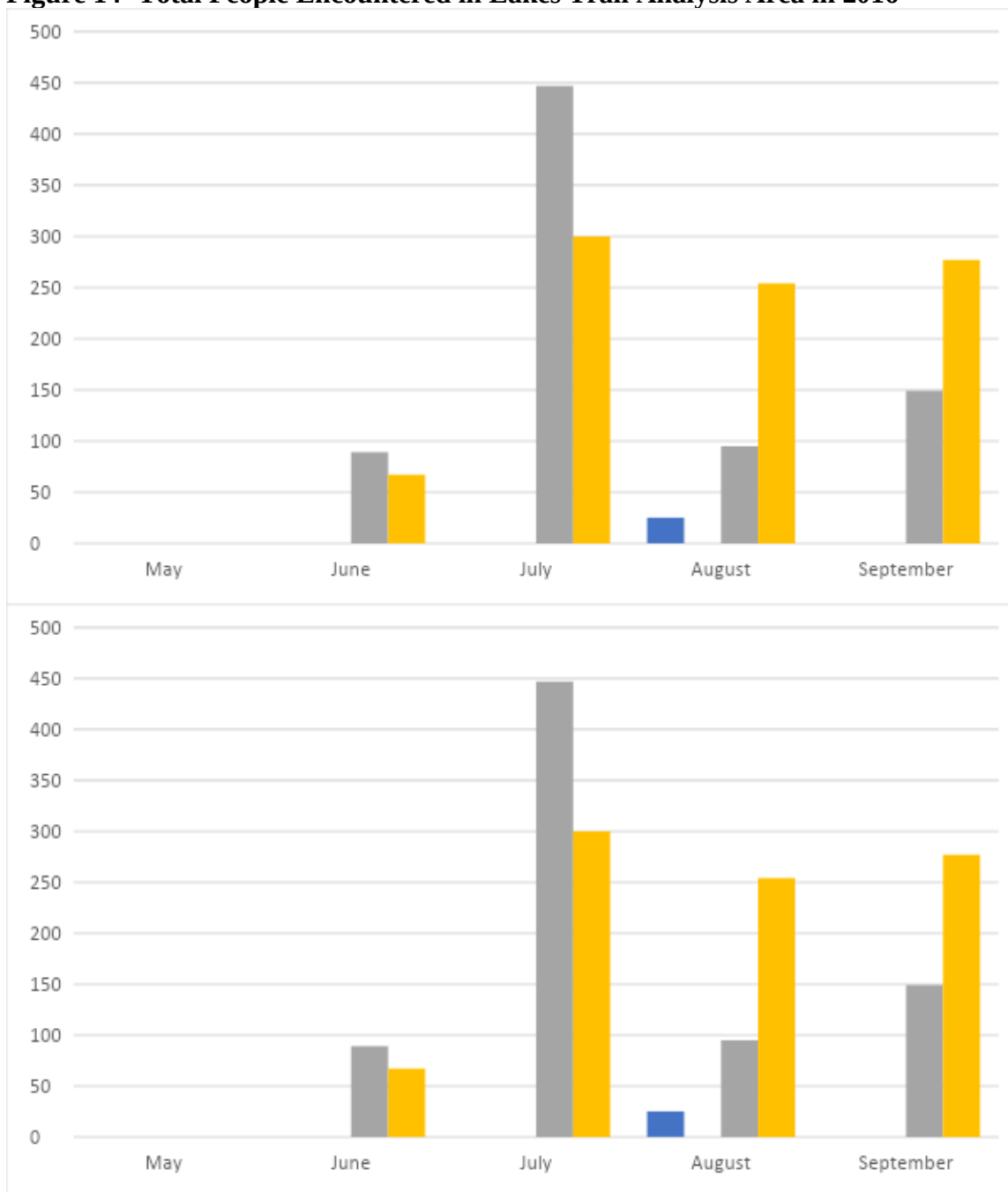


Figure 14 shows the total number of people reported in sampling events taken in 2016, which had the most samples of any year in the 2016-2019 monitoring period. The value 0 in the table indicates that there were no samples taken for the trail segment in the month. No trail segments were sampled in May 2016. Pear Lake-1 was sampled once in August. Pear Lake-2 was not sampled in 2016. Estimates for rate of encounters in the analysis area are mostly based on people encountered on only half of the trail segments within the analysis area.

Lakes Trail Analysis Area Summary

Trail segments Pear Lake-1 and Pear Lake-2 are hardly ever sampled. Combined, the two have been sampled 8 times across all years. In comparison, Pear Lake-3 and Pear Lake-4 have a combined 298 samples across all years. Since 2016, the total number of samples across the four trail segments has been decreasing, are mostly completed in July, and occur mostly on Friday-Sunday.

JMT -North Lake South Lake Loop Overlap

SEKI categorizes this analysis area as Medium use (a visitor should encounter 15 or fewer people per hour on 90% of quota season days). JMT analysis area is composed of the LeConte-4; McClure-1; McClure-3; and McClure-5 trail segments. The analysis area was highlighted in yellow for the 2012-2015 monitoring period and red for the 2016-2019 monitoring period, indicating a degradation in relation to standard.

Table 3- Start times for all samples for JMT analysis area, 2012-2019

Start Time	Sampling Year								Total Samples
	2012	2013	2014	2015	2016	2017	2018	2019	
6-7am	0	0	0	0	1	0	0	0	1
7-8am	1	0	0	2	1	0	0	0	4
8-9am	1	3	4	2	1	0	0	2	13
9-10am	7	7	4	4	2	0	3	7	34
10-11am	2	4	4	2	7	4	2	1	26
11-12pm	1	5	0	3	1	0	2	3	15
12-1pm	1	0	2	3	2	1	0	2	11
1-2pm	3	3	0	3	4	0	0	2	15
2-3pm	1	3	0	5	2	1	2	1	15
3-4pm	0	2	3	0	1	0	1	3	10
4-5pm	1	7	0	1	2	0	1	3	15
5-6pm	0	3	1	1	0	1	0	0	6
6-7pm	0	0	1	0	1	0	0	0	2
7-8pm	0	0	1	0	0	0	0	0	1

Table 3 shows that most samples began between 9-11am (60 samples). Generally, there is a mostly even distribution in start times between 9am-2pm.

Figure 15- Sampling Events per Year by Month for JMT analysis area

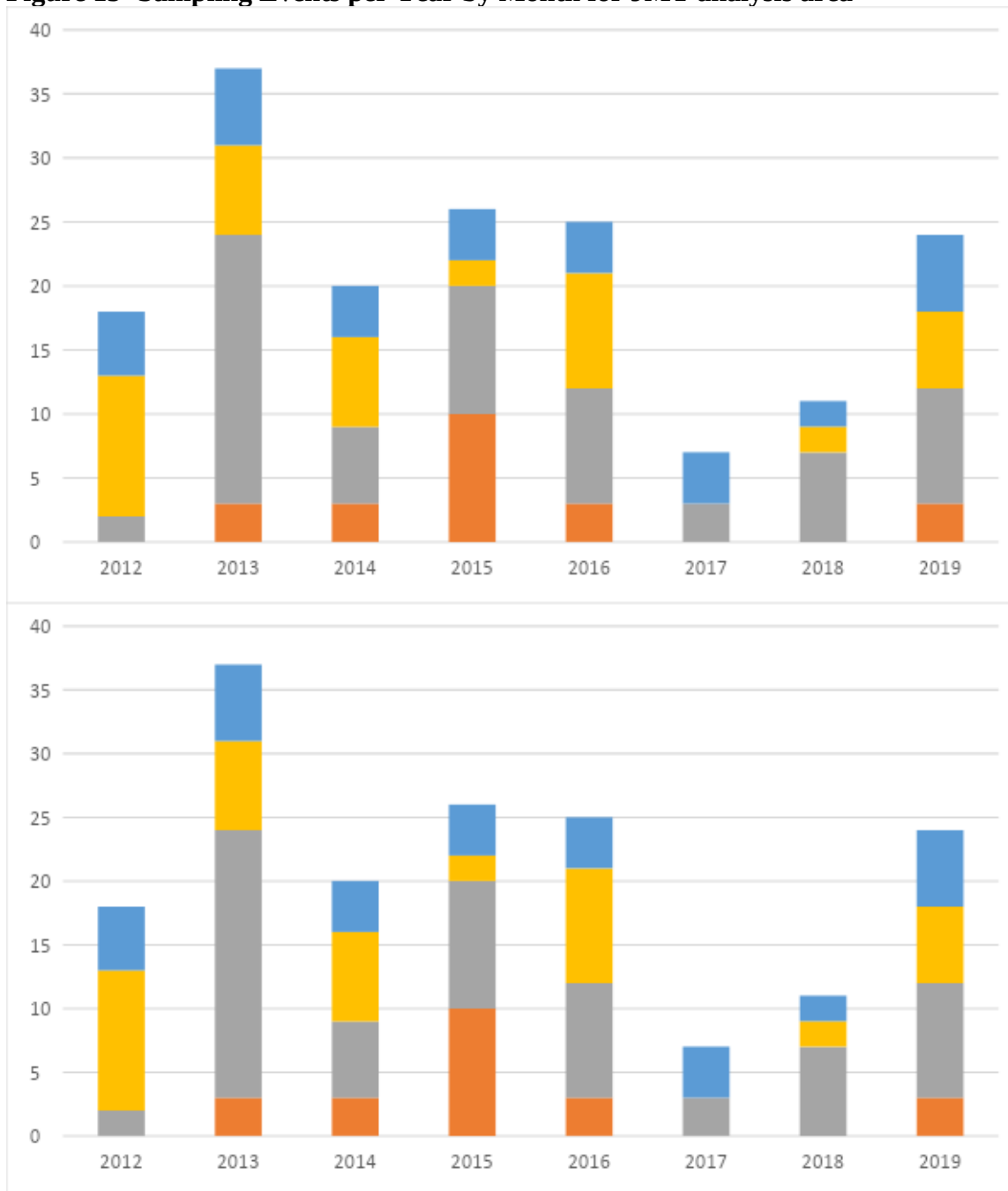


Figure 15 shows the number of sampling events completed in each month of each year for the analysis area. 2017 was the least sampled year and 2013 was the most sampled year.

Figure 16- Sampling Events per Year by Month for LeConte-4

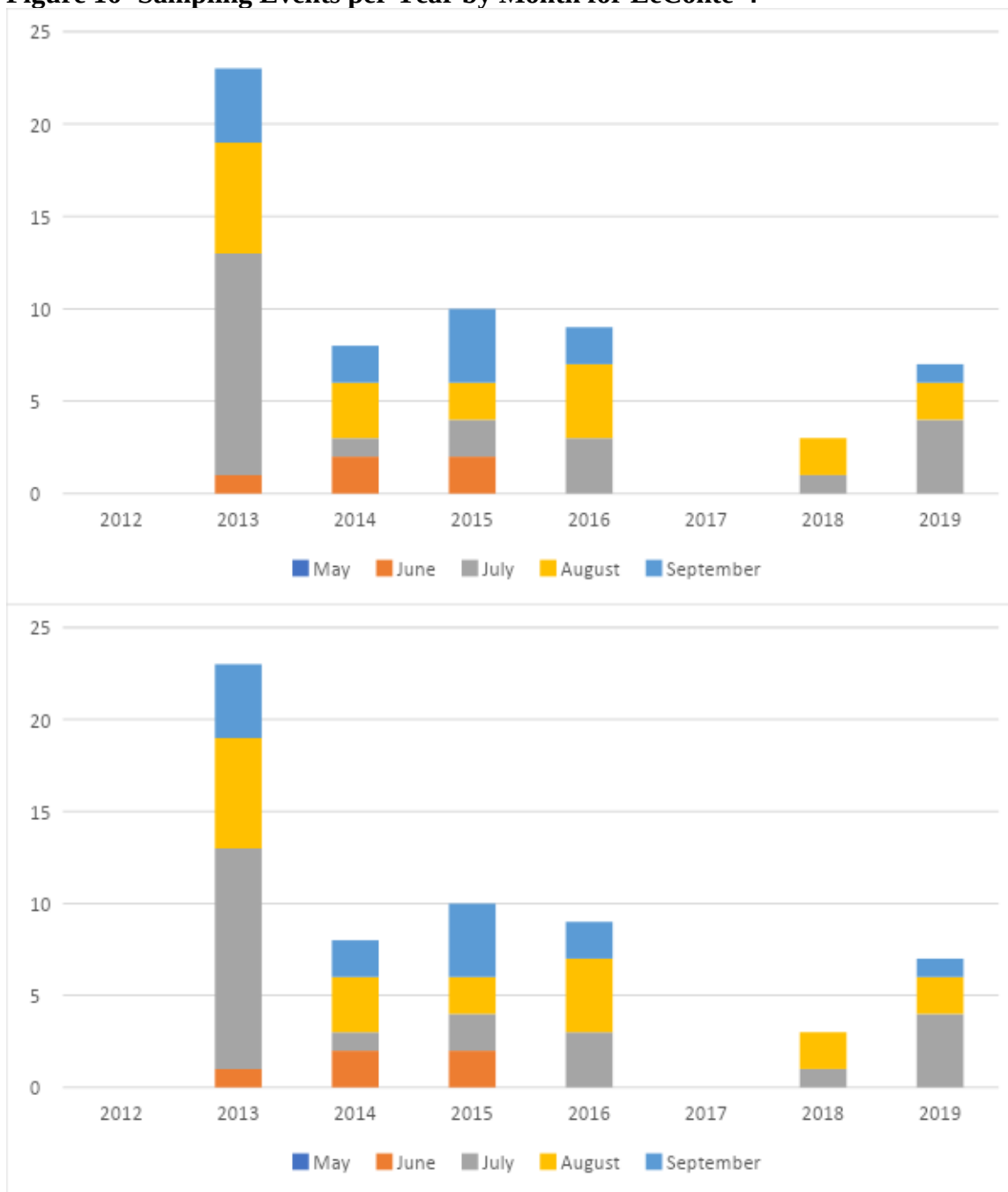


Figure 16 shows that LeConte-4 was not sampled in 2012 or 2017. Additionally, during the 2016-2019 monitoring period, it was only sampled 19 times, 4 fewer samples than were collected in 2013 alone.

Figure 17- Sampling Events per Year by Month for McClure-1

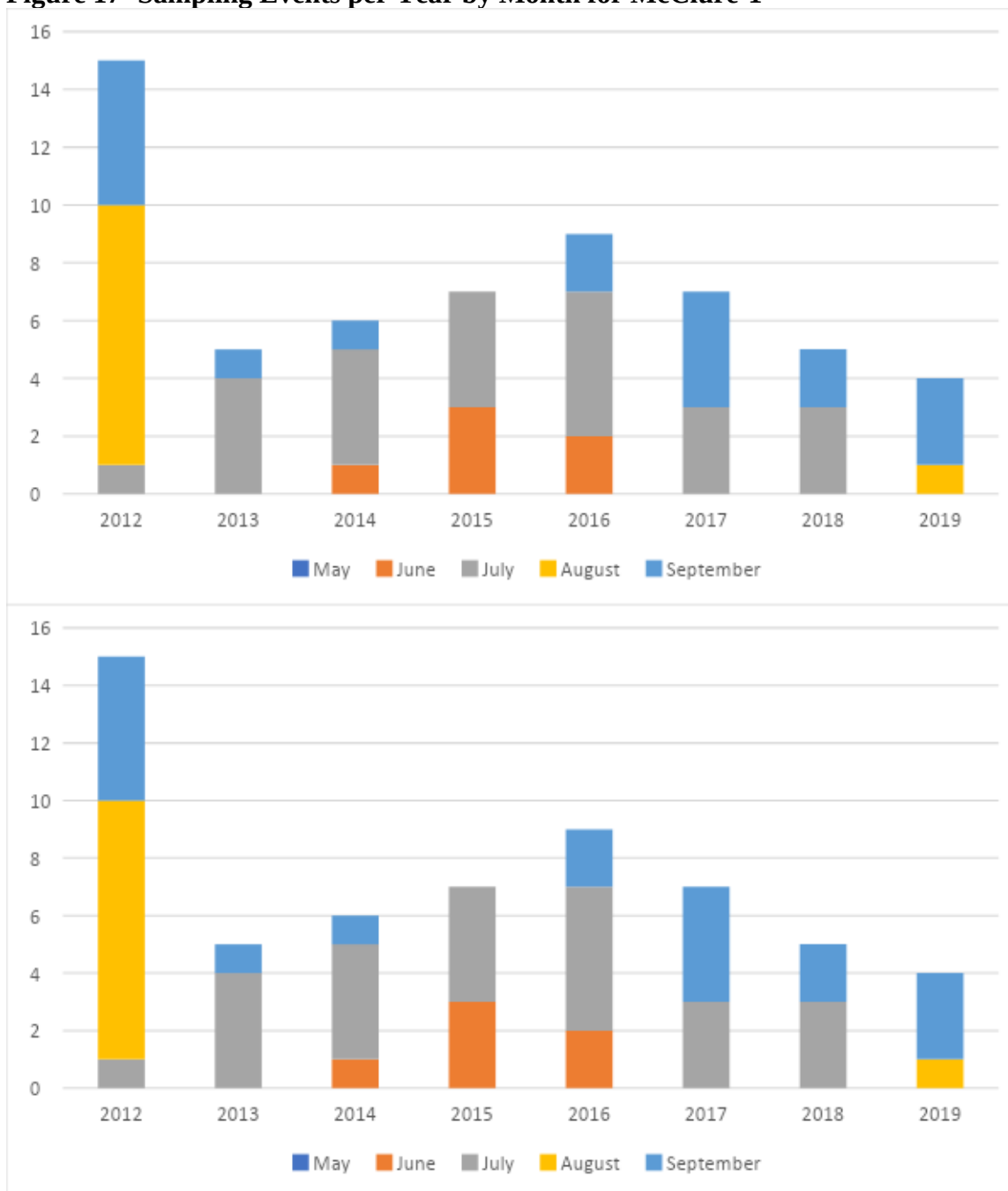


Figure 17 shows that McClure-1 is mostly sampled in July (24 of the 58 total samples, or 41%). August is rarely sampled, with 9 of the 10 total August samples occurring in 2012.

Figure 18- Sampling Events per Year by Month for McClure-3

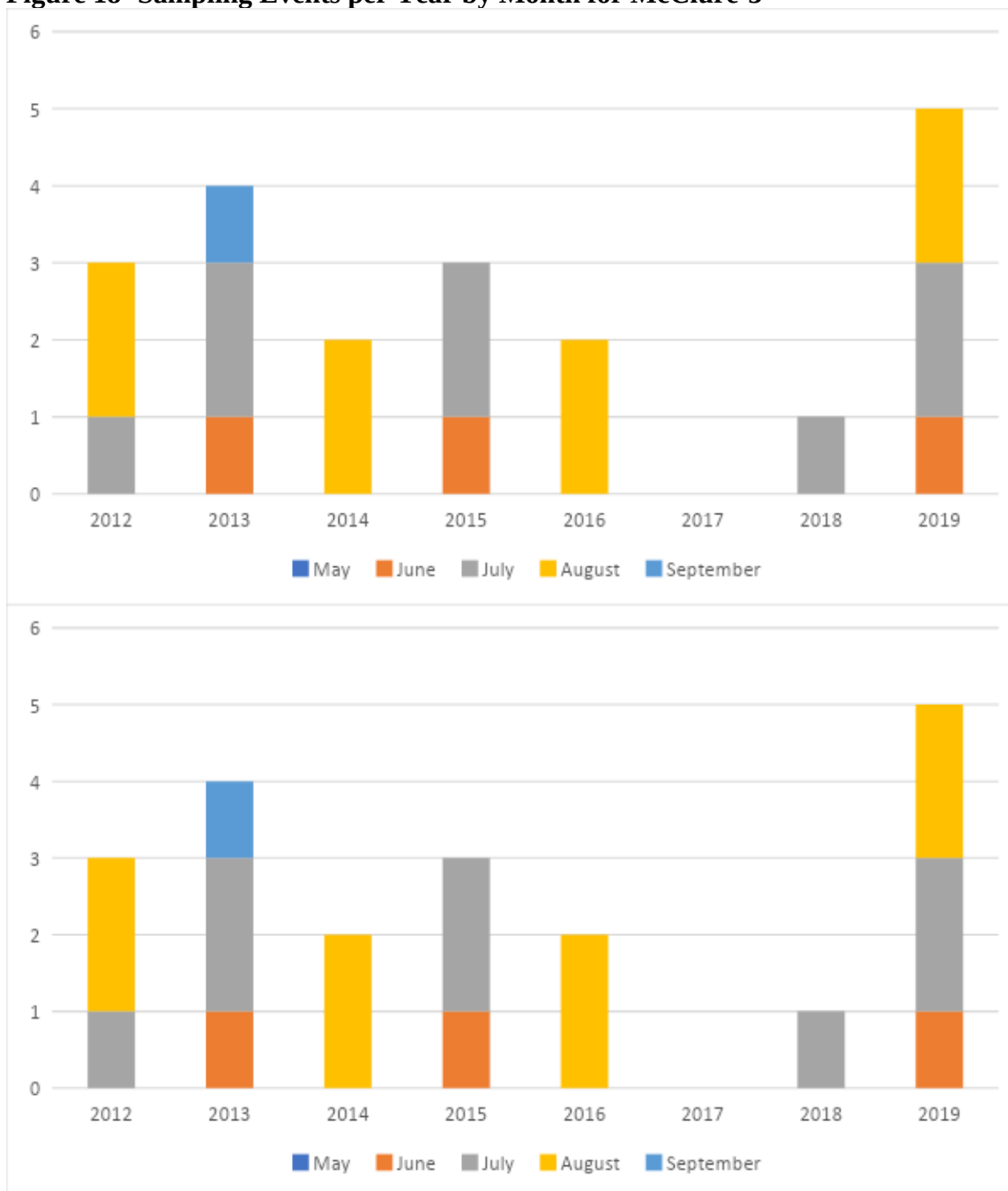


Figure 18 shows that McClure-3 is infrequently sampled, with an average of 3 samples per year.

Figure 19- Sampling Events per Year by Month for McClure-5

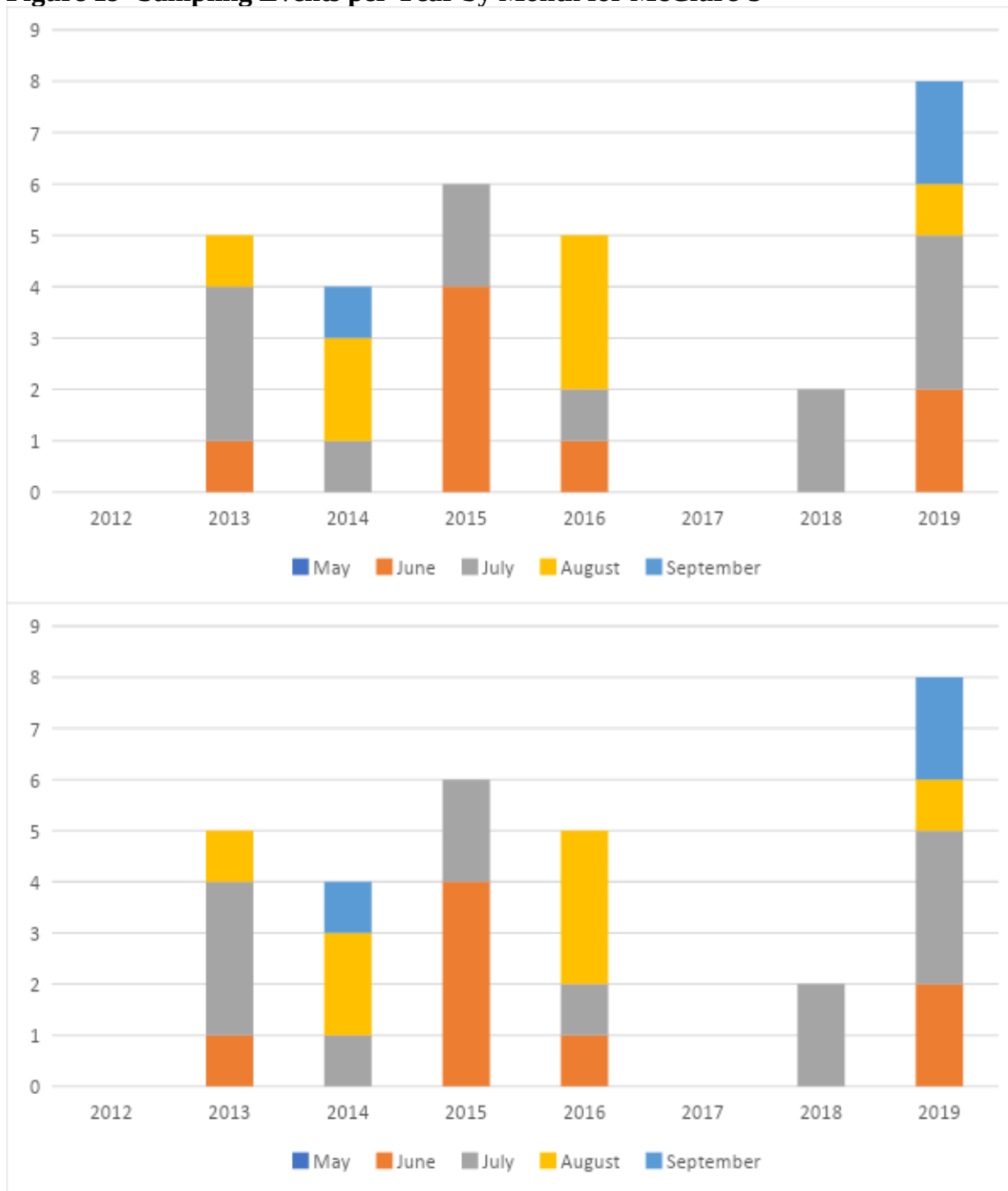


Figure 19 shows that McClure-5 is infrequently sampled, with an average of 4 samples per year (including the years 2012 and 2017 for which there were no samples).

Figure 20- Sampling Events per Year by Weekday for JMT analysis area

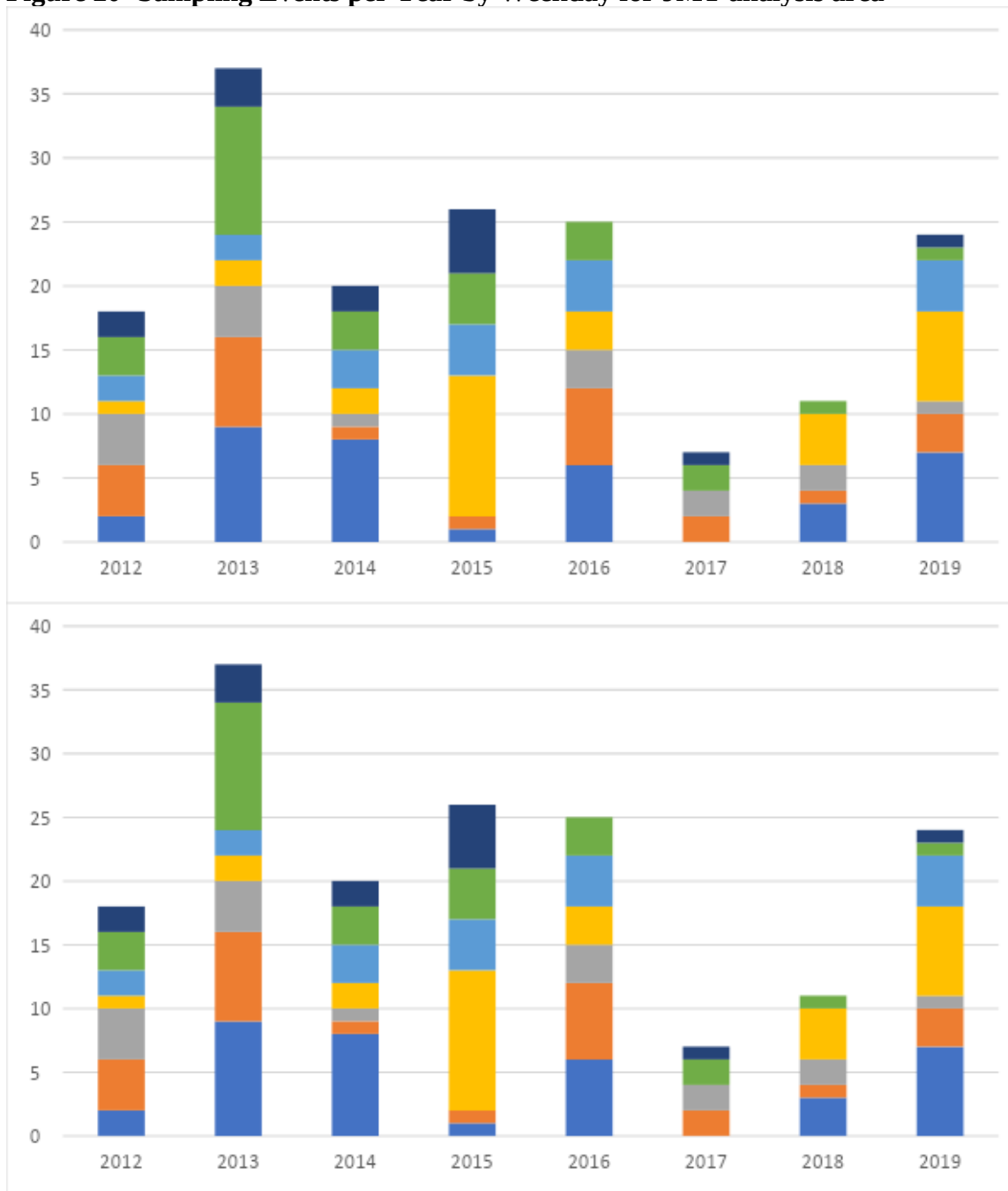


Figure 20 shows on which days sampling events were completed each year. Generally, Sundays were the most commonly sampled days in the JMT analysis area across years.

Figure 21- Number of Unique Sampling Days per Year by Month for JMT analysis area

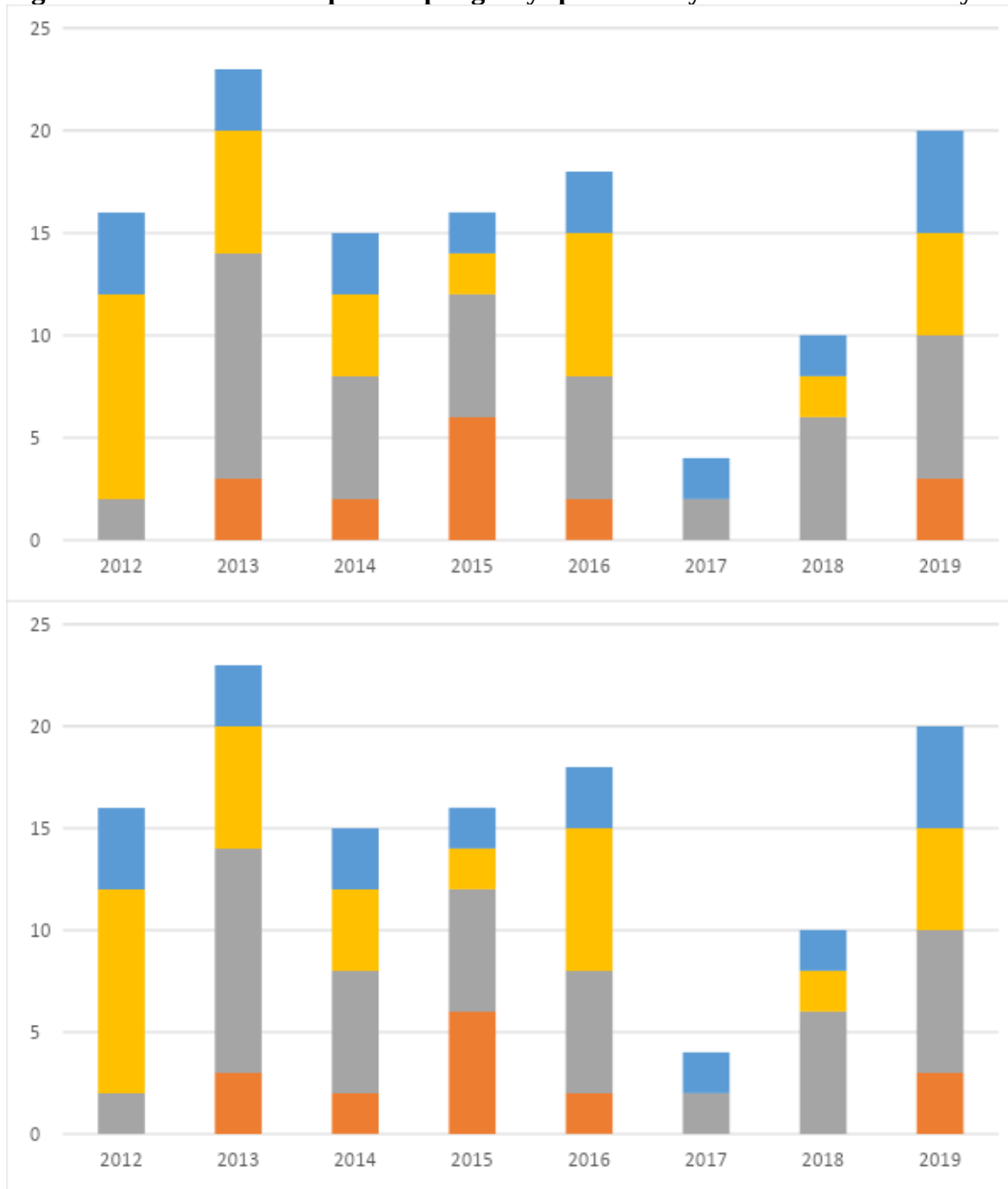


Figure 21 shows the number of unique days on which samples were taken. The 2016-2019 monitoring period had 67 total samples that were taken on 52 unique days.

Figure 22- Total People Encountered in JMT analysis area in 2016

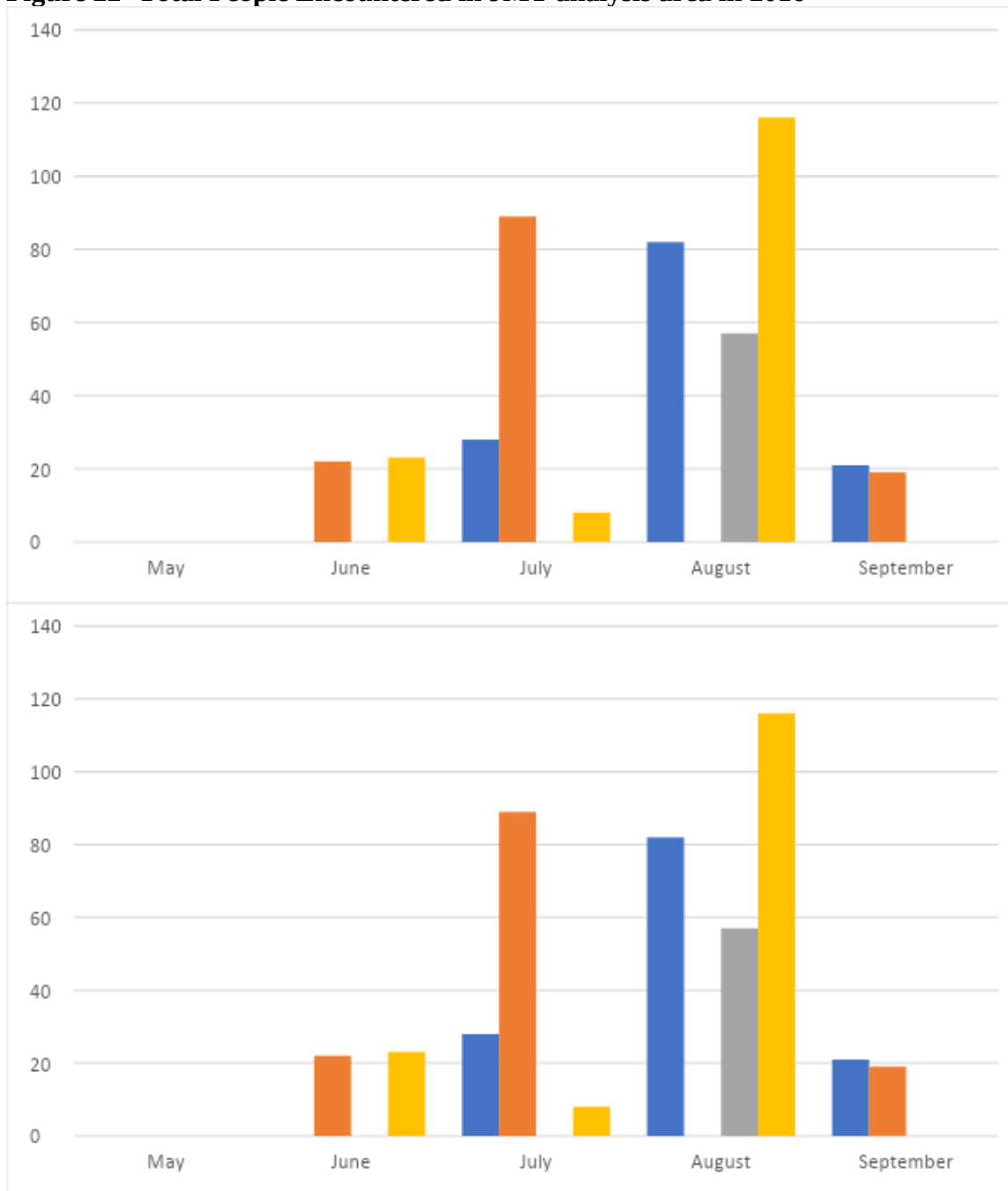


Figure 22 shows the total number of people encountered on each trail segment within the analysis area each month in 2016, which had the most samples taken during the 2016-2019 monitoring period. Values of 0 in the data table indicate that there were no sampling events for the trail segment in the month. McClure-3 was only sampled in August. None were sampled in May. McClure-1, which had the highest number of encountered people in July, was not sampled in August.

JMT- North Lake South Lake Loop Overlap Summary

There is a very uneven distribution of sampling events across trail segments in this analysis area. McClure-3 and McClure-5 combined account for 30% of all samples collected in the analysis area across all monitoring years, whereas LeConte-4 and Mc-Clure-1 each account for 36% and 35% of all samples collected, respectively. Additionally, the entire analysis area was sampled only 67 times during the 2016-2019 monitoring period (compared to 101 during the 2012-2015 monitoring period) yet still indicated that the analysis area is out of standard. Limited data collection may underrepresent how out of standard this analysis area truly is.

Kern- Upper

SEKI categorizes this area as Low use (visitors should encounter 6 or fewer people per hour on 90% of quota season days). Tyndall-3 is the only trail segment in the Kern- Upper analysis area. Kern- Upper was highlighted in yellow for the 2012-2015 monitoring period and in green for the 2016-2019 monitoring period in 2019 report, indicating an improvement in relation to the standard.

Table 4- Start times for all samples for Kern- Upper, 2012-2019

Start Time	Sampling Year								Total Samples
	2012	2013	2014	2015	2016	2017	2018	2019	
6-7am	0	0	0	0	0	2	0	1	3
7-8am	0	0	0	0	0	0	1	0	1
8-9am	1	0	0	0	0	1	0	0	2
9-10am	1	1	0	0	0	1	1	0	4
10-11am	1	0	0	0	1	4	0	0	6
11-12pm	0	0	2	1	0	0	0	0	3
12-1pm	1	0	0	0	1	1	1	0	4
1-2pm	0	0	1	0	2	0	1	0	4
2-3pm	1	1	1	1	0	0	2	1	7
3-4pm	1	0	0	0	0	0	1	1	3
4-5pm	0	0	1	1	0	0	1	0	3

Table 4 shows that most samples began at 10am (6 samples) or 2pm (7 samples).

Figure 23- Sampling Events per Year by Month in Kern- Upper

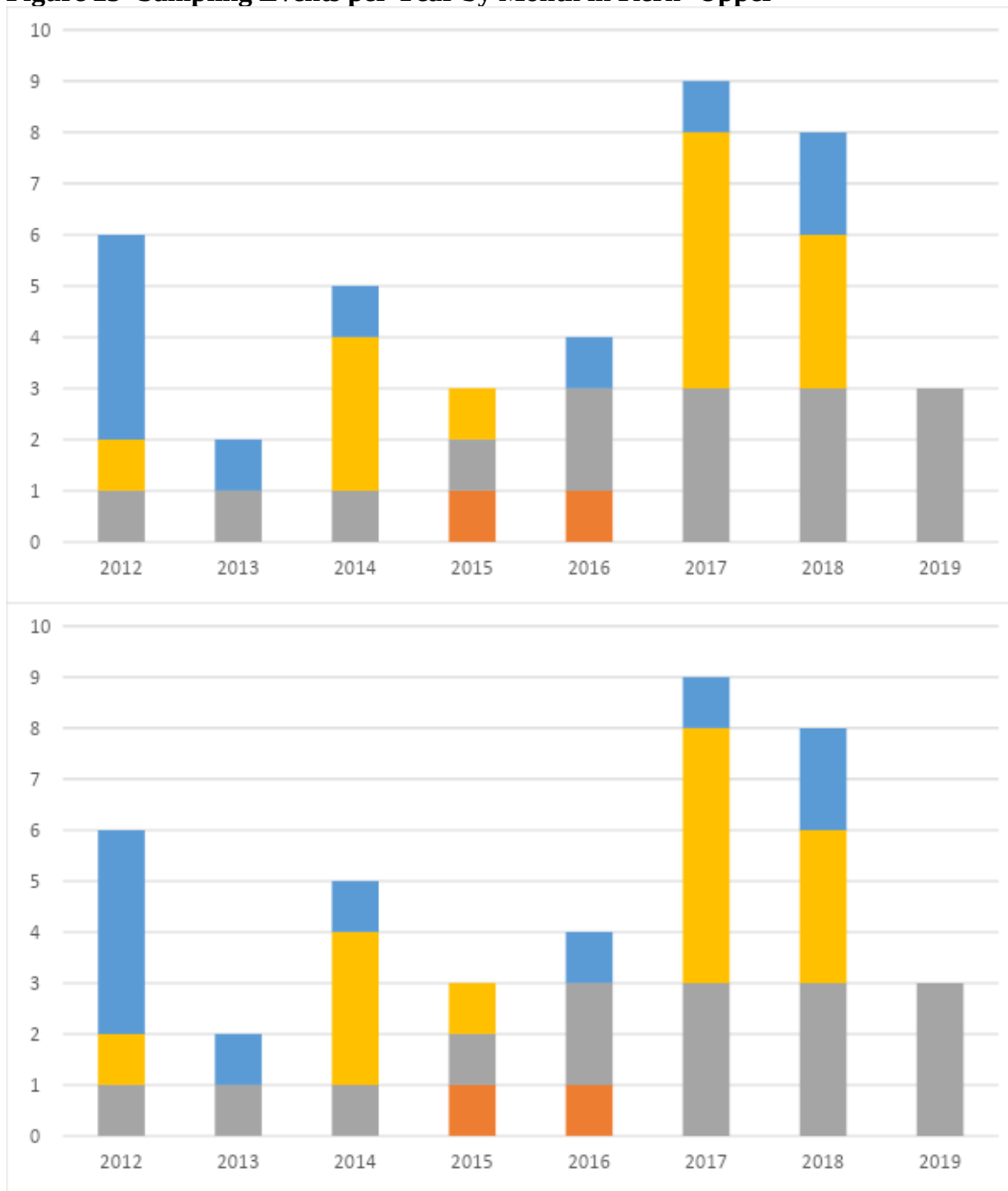


Figure 23 shows how many samples were taken in each month of each year for Kern- Upper. This analysis area has never been sampled more than 9 times in a year and averages 5 sampling events each year.

Figure 24- Sampling Events per Year by Weekday in Kern- Upper

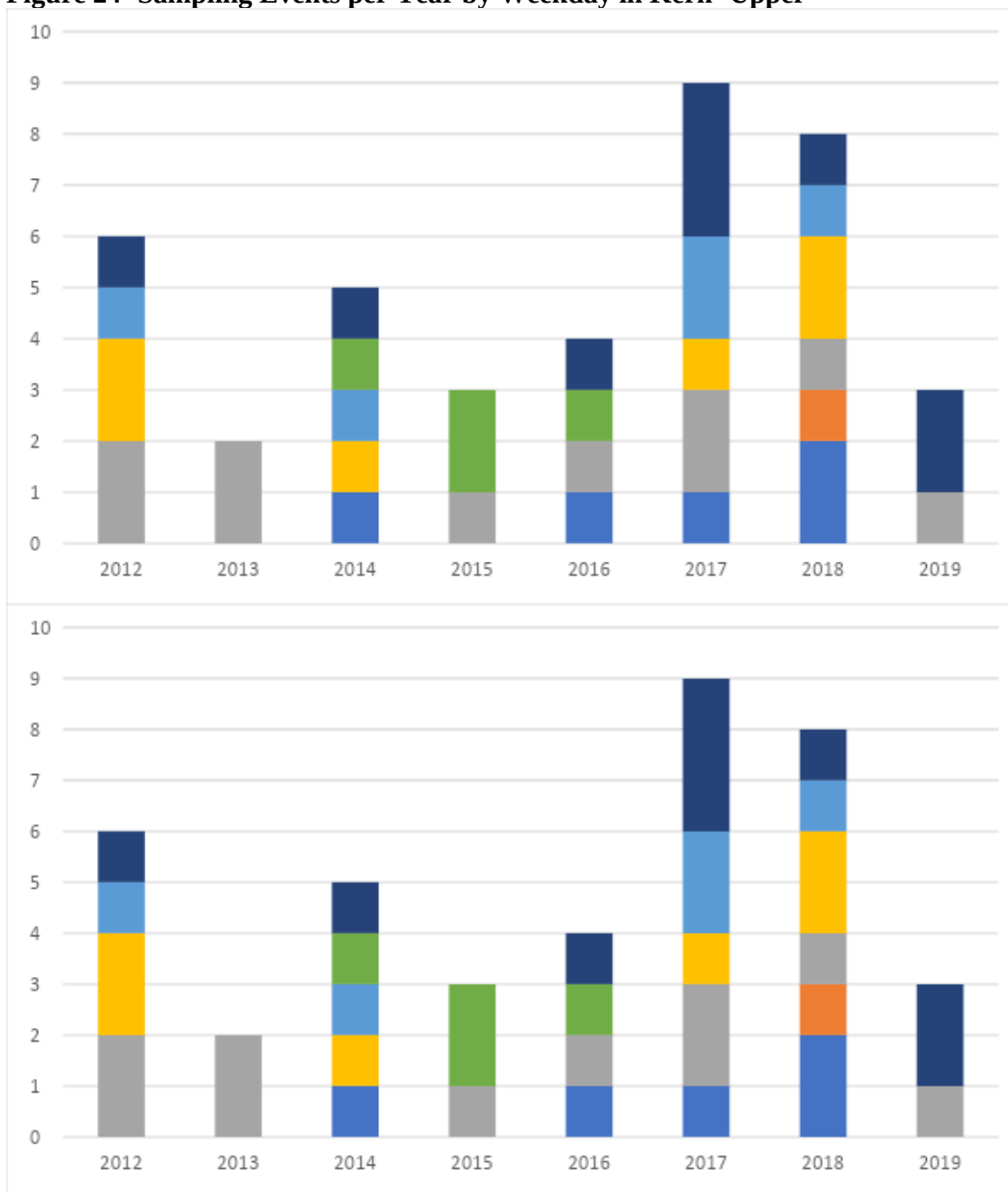


Figure 24 shows on which days sampling events were completed each year for Kern- Upper. Generally, Tuesdays and Saturdays were the most commonly sampled days.

Figure 25- Number of Unique Sampling Days per Year by Month for Kern- Upper

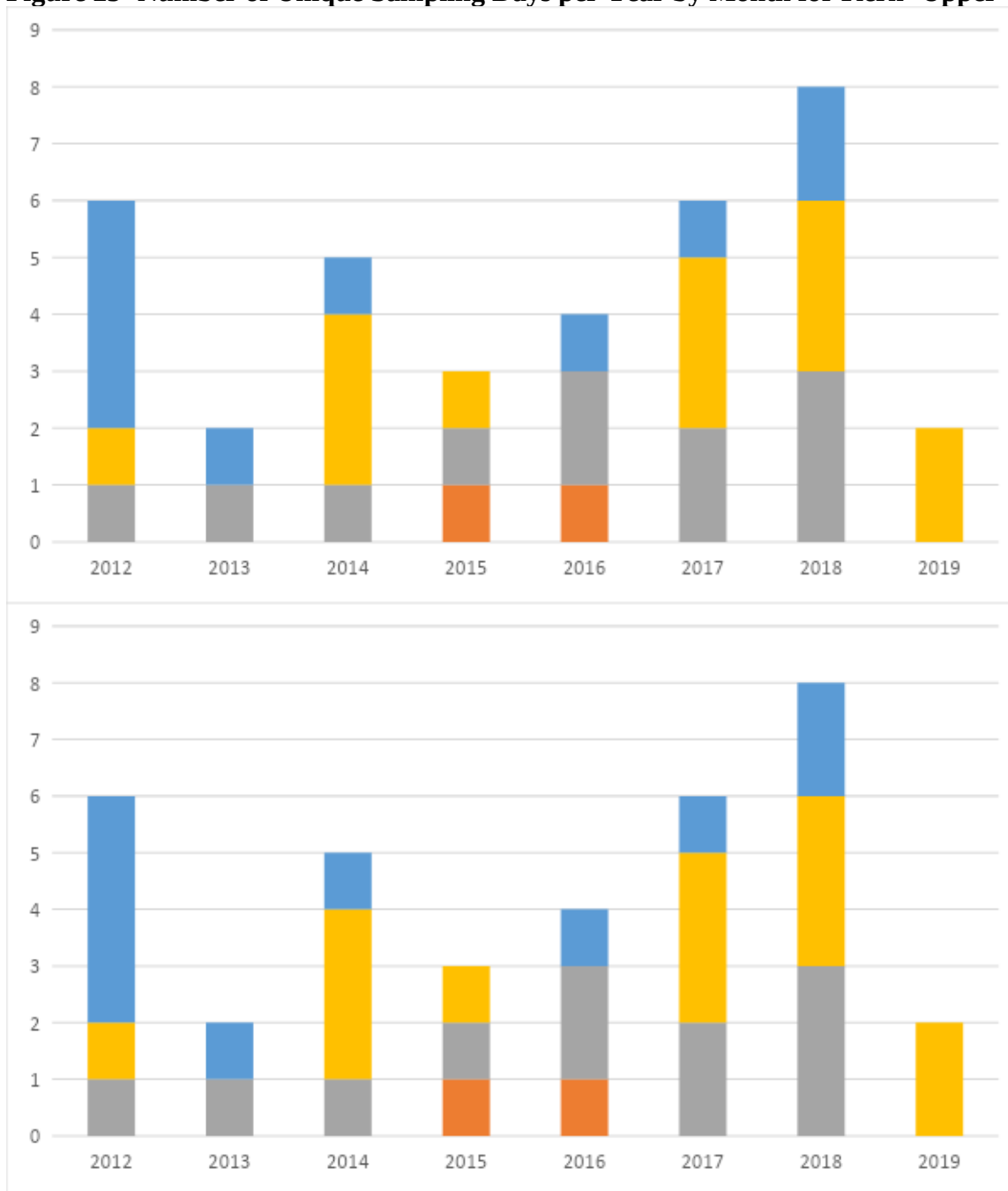


Figure 25 shows the number of unique days on which sampling events were completed for Kern-Upper each year. 2016-2019 estimate was based on 24 measurements taken on 20 unique days.

Figure 26- Total Number of People Encountered in the Kern- Upper in 2017

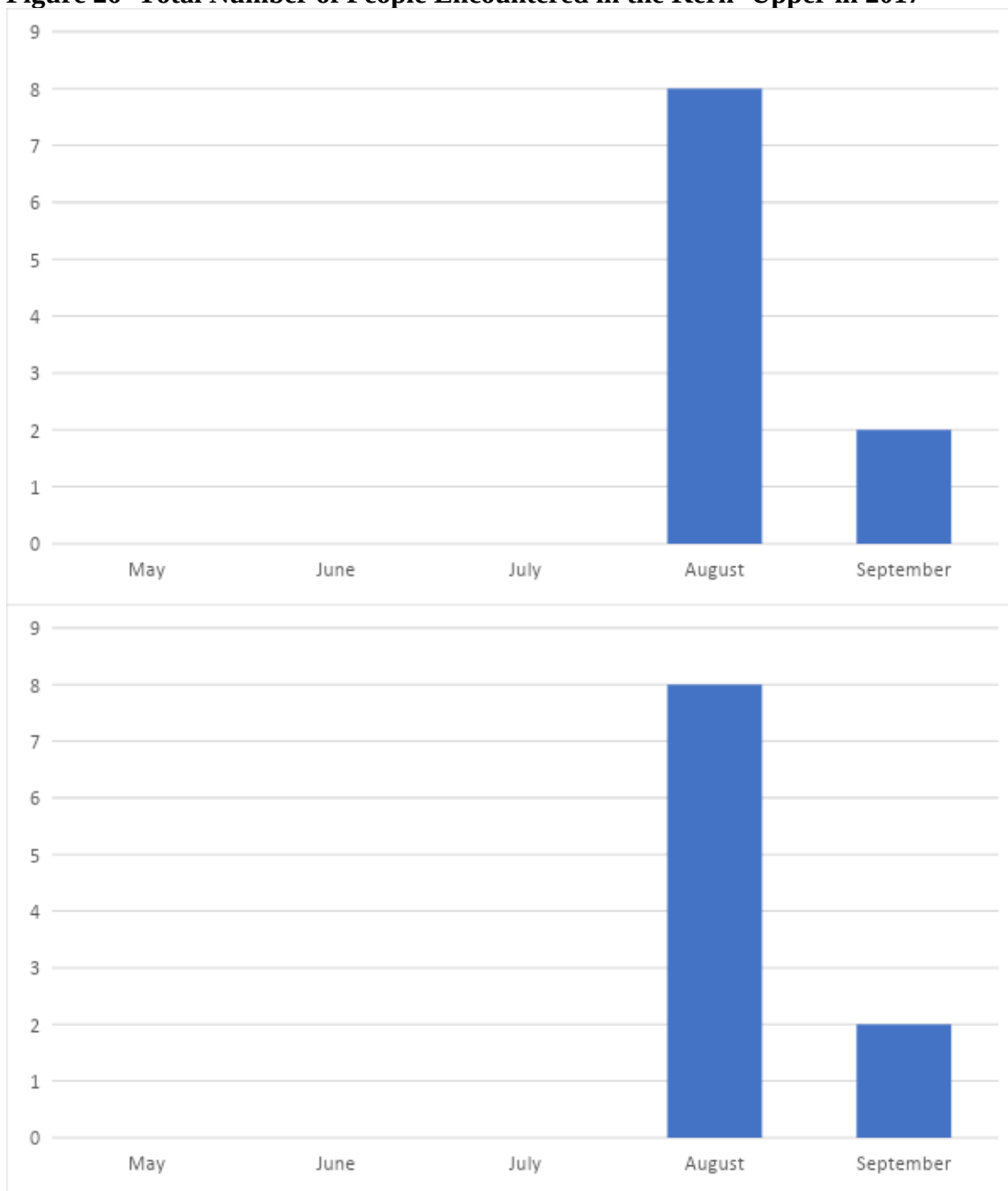


Figure 26 shows the total number of people encountered in the Kern- Upper analysis area in 2017, which was the most sampled year during the 2016-2019 monitoring period. Tyndall-3, the only trail segment within the analysis area, was not sampled until July in 2017; in July, there were three sampling events and no people encountered.

Kern- Upper Analysis Area Summary

Kern- Upper is sampled very infrequently (Figure 25, Figure 27) and is only composed of one trail segment (Tyndall-3). Because of this, there is little data to review. It may be beneficial to incorporate Tyndall-3 into another analysis area, discontinue monitoring it, or prioritize collecting more data in later seasons.