# Preserving the Night Sky: Monitoring Light Pollution Affecting the Central Idaho Dark Sky Reserve

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CENTRAL IDAHO DARK SKY RESERVE

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… and all others working to preserve our night skies.

## Disclaimer

The information presented in this report is strictly the opinion of the authors and does not reflect the University of California as a whole nor the Central Idaho Dark Sky Reserve as a whole.

## About the Authors

As part of the Environmental Science major senior practicum project, all authors are Environmental Science majors working toward their Bachelor of Science from UCLA. Maria Carias is a fourth-year student with a concentration in Conservation Biology and a minor in Geographic Information Systems & Technologies who wants to attend graduate school to study the ecological effects of anthropogenic changes and would love to continue working on light pollution-related issues and research. Shawn Fujioka is a fourth-year student with a concentration in Geography/Environmental Studies and a minor in Geographic Information Systems & Technologies who plans to work in the field prior to continuing her studies in graduate school. Jacob Phaneuf is a fourth-year student with a concentration in Environmental Engineering and a minor in Earth and Environmental Science who will be attending Stanford University to pursue a Master's Degree in Environmental Engineering with a concentration in Human Health and the Environment. Megan Potter is a fourth-year student with a concentration in Atmospheric and Oceanic Sciences who will be utilizing her GIS skills in the transportation industry but would love to continue to work on light pollution research in the future. Ieva Vaiciunas is a fourth-year student with a concentration in Conservation Biology who plans on pursuing a career and/or higher education in wildlife conservation. Lynn Wilder is a third-year student with a concentration in Environmental Engineering and intends to pursue a career in renewable energy. Cassidy Wood is a fourth-year student with a concentration in Conservation Biology with a passion for wildlife conservation. Jacqueline Yu is a fourth-year student with a concentration in Atmospheric and Oceanic Sciences who plans on pursuing a career in environmental consulting. Dr. Travis Longcore served as the project's advisor. He is an expert in light pollution research and is an Associate Adjunct Professor at the UCLA Institute of the Environment and Sustainability.

## For More Information

For more information about light pollution and the Central Idaho Dark Sky Reserve, please visit www.idahodarksky.org/.

To view our story map which includes additional maps, figures, and access to the data, please visit bit.ly/darker-skies.

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# Executive Summary

Light pollution has become a major issue for astronomical observation, wildlife conservation, cultural heritage preservation, and human circadian health as a result of an increase in urbanization and development of other areas with high concentrations of artificial light. The Central Idaho Dark Sky Reserve (CIDSR), an area with minimal levels of light pollution, has employed dark sky ordinances to reduce excess light at night. However, outside light sources still have the potential to compromise the reserve's dark skies. It is critical that the CIDSR develops and implements a monitoring plan to ensure dark sky ordinances are effectively reducing light pollution to protect the night skies of the reserve. More specifically, a monitoring plan will help the CIDSR maintain its reserve status, as it must continue to meet standards set by the International Dark-Sky Association (IDA). Our project's objectives were to (1) track light pollution over time in and around the reserve and predict levels of light pollution into the future; (2) analyze the effectiveness of existing light pollution ordinances; (3) research the response to light pollution of economically and culturally significant species in Idaho; (4) explore opportunities for tourism and the promotion of dark skies; and (5) establish a replicable approach to monitor light pollution. We achieved this by analyzing Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) data and ground-based observations collected using a Sky Quality Camera (SQC), comparing ordinances at county and city levels, conducting an ecological assessment, creating a suitability model to assess tourism potential within the reserve, and properly documenting our steps to allow for future replicability.

We found that although VIIRS satellite data is a useful method for tracking light pollution threats to the reserve, there are some critical challenges when it comes to accurately interpreting trends from the data. The main challenges result from the VIIRS satellite's failure to measure the blue light emitted by newer white LED lights and a relatively small – although increasing – dataset. The VIIRS satellite only began recording nighttime upward radiance in late 2011 and data prior to April 2012 is not available for download. Despite these difficulties, we found that the nearby Thompson Creek Mine is a significant source of luminance and an increasing threat to the reserve. Additionally, an SQC is able to measure the blue light that is unfortunately unaccounted for in VIIRS data. However, unlike VIIRS data – which can be accessed remotely – an SQC requires being on-site. This highlights the importance of utilizing both methods, rather than just one, to track light pollution. Our policy evaluation, which studied all Dark Sky Ordinances in and around the reserve, revealed that although current policies are variable in both strength and implementation, lighting ordinances are effective and could be even more so after key improvements. Additionally, our research highlights the impacts light pollution can have on the incredible wildlife that all call Idaho home. Fish species in particular could play a key role in raising awareness of such wildlife impacts. Our thorough analysis of the reserve's astrotourism potential uncovers endless opportunities for the CIDSR and surrounding area – economic, recreational, and educational. We hope the astrotourism analysis will inspire new and creative perspectives on the future of the CIDSR and other dark sky places current and to come. Ultimately, the purpose of this report is to not only develop a method of tracking light pollution, but also raise awareness about the importance of continued efforts to protect and improve the reserve as well as draw attention to its sheer beauty and value.

# Project Introduction

CHAPTER 1

## Background

A clear view of the night sky can offer cultural, spiritual, and even biological benefits to people. However, this view is often masked by light pollution. Light pollution occurs when artificial lights brighten the night sky, altering nighttime conditions. Currently, over a third of the world's population can no longer see the Milky Way Galaxy due to light-polluted skies. Across the U.S., more than 80% of the population lives in areas where light pollution hinders the view of the stars (IDA). As light pollution increases, it not only limits our ability to see the night sky but also affects natural cycles in plants, animals, and humans (Longcore & Rich, 2016). Lighting, if poorly designed, can be dangerous for human health and ecological conservation. While some artificial nightlight is needed, a balance between necessary lighting and extraneous light pollution needs to be found. Fortunately, light pollution can be reduced by turning off unnecessary lights or by adjusting the sources of light, such as the types of light bulbs or lamp fixtures used. On a larger scale, lighting standards, such as Dark Sky Ordinances, can help regulate light pollution from public spaces and commercial and industrial buildings. Additionally, Dark Sky Reserves are a relatively new phenomenon meant to preserve the quality of the night sky. Dark Sky Reserves are large areas of land certified by the International Dark-Sky Association (IDA) for the scientific, natural, educational, cultural, and/or public enjoyment of pristine nighttime environments (IDA, 2018). For an area to be recognized as a Dark Sky Reserve, it must meet several criteria. For instance, the Milky Way must be readily visible with the naked eye, there must be both a core area and a peripheral zone that completely encloses the core. Core areas must be free of excess artificial light as a result of lighting regulations and commitments to the long-term planning of light pollution reduction within the peripheral zone (IDA, 2018). There are currently just 18 Dark Sky Reserves in the world and of these 18, only one is in the U.S.

## The Central Idaho Dark Reserve

Our project focused on the Central Idaho Dark Sky Reserve (CIDSR), a region of remote land within the Sawtooth National Recreation Area (SNRA) of central Idaho preserved for its exceptionally dark skies, as seen in figure 1.1. The skies within the CIDSR are considered 'Gold Tier' – the highest designation given by the IDA. A Gold Tier designation is used to denote a sky that is free from all but the most minor impacts of light pollution.

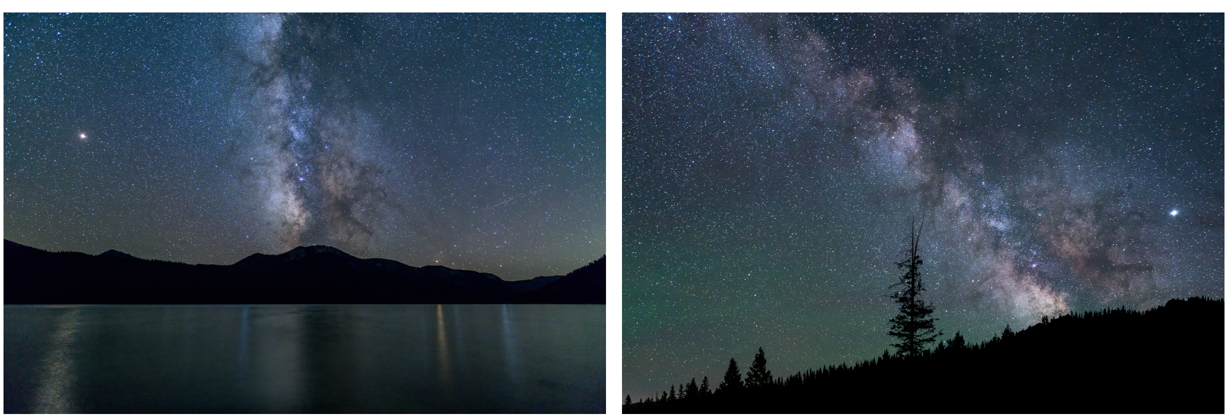


Figure 1.1. Photographs of the Milky Way taken at the CIDSR at Alturas Lake in Blaine County (left) and within the SNRA (right), by Nils Ribi.

Spanning 1,400 square miles, the CIDSR encompasses parts of Blaine, Boise, Custer, and Elmore counties; parts of three different designated wilderness areas (Sawtooth, White Cloud, and Hemingway-Boulders Wilderness); and various cities and towns – including Ketchum, Stanley, and Sun Valley. State Highway 75 runs through the center of the reserve. The reserve consists of two main core areas which must meet the minimum criteria for sky quality set by the IDA, along with a larger peripheral outer boundary designed to serve as a buffer to support dark sky preservation within the cores. These features are mapped in figure 1.2.

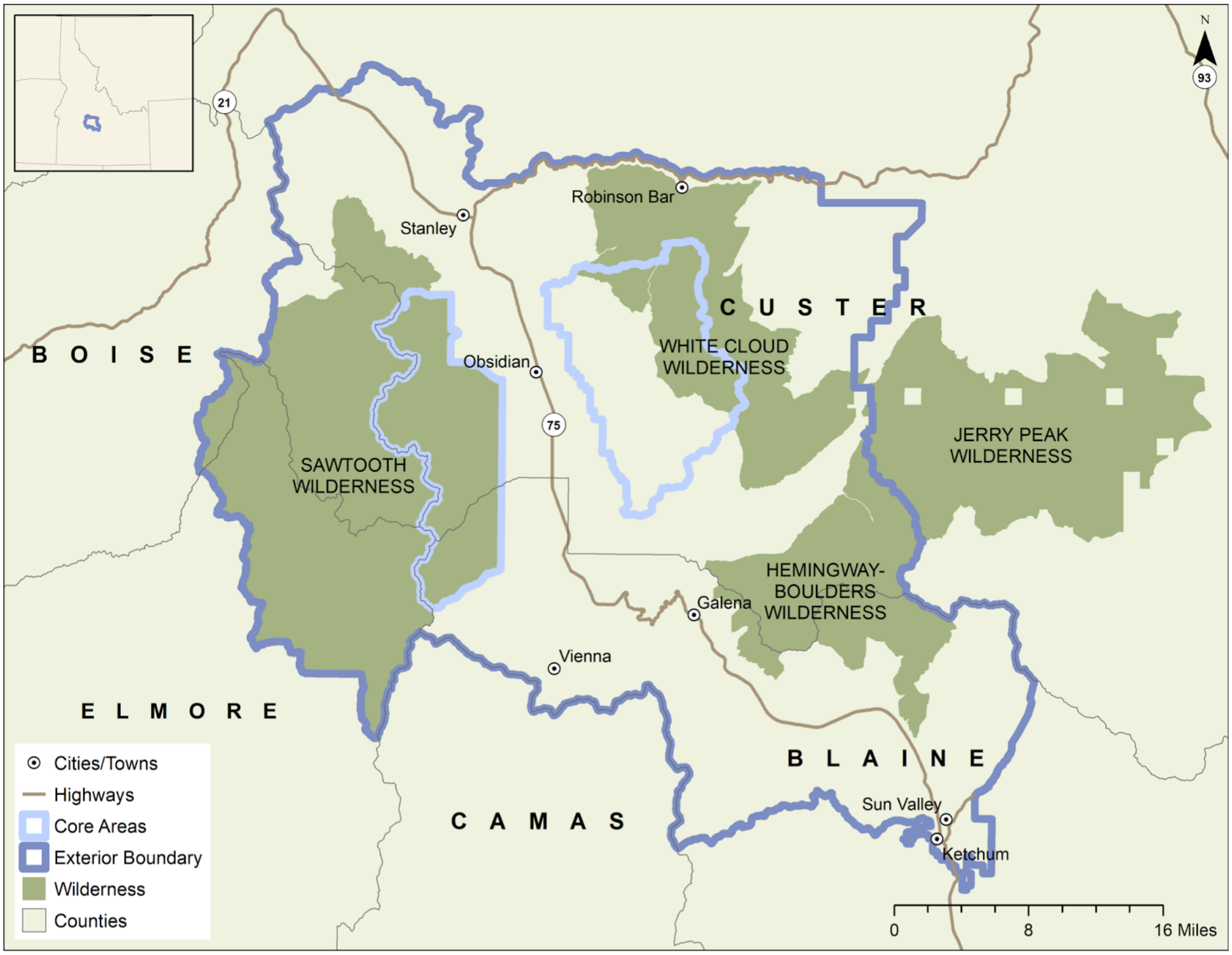



Figure 1.2. Map of the core and peripheral boundaries of the CIDSR.

While the CIDSR is tightly regulated, nearby metropolitan areas are not. Since its designation in 2017, the reserve has been facing increasing light pollution originating from nearby cities and other areas associated with development – such as the Idaho state capital of Boise. Located roughly 150 miles away from the CIDSR, Boise has been experiencing economic and population growth, meaning light pollution may be increasing in the area (Blanchard, 2019). Therefore, the ongoing monitoring of night light levels is essential for maintaining the quality of the skies within the reserve.

## Our Role

The purpose of our project was to develop a long-term strategy to track light pollution trends affecting the CIDSR that achieves the goals of Dark Sky Reserves outlined by the IDA. Such goals are to mitigate light pollution threats to astronomy and the environment and to promote the value of the reserve for cultural, educational, and eco/astrotourism purposes (IDA, 2018). By creating a comprehensive analysis of the CIDSR and by including recommendations for the future, we hope the reserve can continue to mitigate surrounding light pollution long-term and remain certified as a Dark Sky Reserve under the IDA. Giving the CIDSR the ability to monitor light pollution trends would make this reserve unique among Dark Sky Reserves and would also set a precedent for developing ways for such reserves to monitor and regulate light pollution. Furthermore, we hope our work can be transferred to other dark sky areas, promoting a larger support for preservation of our night skies.

This report is broken up into chapters, each focusing on a different aspect of our project. Together, these chapters are an extremely comprehensive analysis into the relationships and effects of light pollution and the CIDSR. Chapter 2 includes trend analyses of remotely sensed upward radiance, including the methods used for calculating radiance, significant findings, and recommendations for how to continue to track light pollution in the future. Chapter 3 details our ground-based analysis of light pollution using a Sky Quality Camera (SQC), including key images of the sky within the reserve itself, future predictions of light pollution affecting the reserve, and recommendations for continuing ground-based monitoring. Chapter 4 focuses on light pollution policies at the county and city/town levels in and around the CIDSR, including a discussion of ordinances and recommendations for where and how to mitigate light pollution through policy. Chapter 5 provides readers with an ecological assessment of species at risk due to light pollution within the reserve, concluding with recommendations for how best to support these species. Chapter 6 discusses the reserve's potential for astrotourism, including tourist and astrophotographer-specialist suitability models for photography and recommendations for supporting astrotourism within the reserve. Finally, the report wraps up with a summary of our findings followed by appendices with additional figures, data, and methods.

# Trends in Remotely Sensed Upward Radiance

CHAPTER 2

# Introduction

The Central Idaho Dark Sky Reserve (CIDSR) must adopt and commit to a reliable method for tracking changes in light pollution over time to ensure its resources are protected and the reserve remains dark-sky qualified under the requirements set forth by the International Dark-Sky Association (IDA). Annual reports detailing findings can ensure sources of light pollution threatening the reserve are able to be targeted and mitigated properly.

There are two reliable methods for tracking light pollution. These include measuring light pollution from space using satellites as well as measuring light pollution from the ground using a Sky Quality Camera (SQC). Each of the two methods can validate the other. Measuring light pollution using satellites is advantageous for calculations across large areas and for measuring light levels consistently over time. The data also remain accessible and fairly easy to use and interpret with minimal software requirements. However, these satellites are unable to see in the blue portion of the electromagnetic spectrum and the values recorded do not perfectly correlate with sky brightness or ground level exposure. Thus, including ground-based measurements by using an SQC can confirm results found by satellite calculations. Ground measurements using an SQC can give precise measurements at specific locations of interest. However, camera and software costs can be expensive and require manual operation as opposed to the satellite that automatically takes images. Together, these methods can provide a comprehensive assessment for tracking light pollution levels.

This chapter pertains specifically to remotely sensed data collection and analysis. The best data source for this is the satellite carrying the Visible Infrared Imaging Radiometer Suite (VIIRS) Day Night Band (DNB).

The VIIRS instrument sits onboard the Suomi National Polar-Orbiting Partnership spacecraft, which launched in October 2011 (Yale University, 2021). Twice a day, the VIIRS instrument observes and captures images of Earth’s surface, scanning a swath roughly 3,000 kilometers wide at a resolution of about 750 meters (Yale University, 2021). VIIRS allows for stable measurements of light pollution variability by measuring radiance over time. VIIRS measures radiation in both the visible and infrared portion of the electromagnetic spectrum across 22 channels or ‘bands’ ranging in wavelength from 0.412 μm to 12.01 μm (Seaman, 2013). The DNB is one of the 22 channels and is sensitive to radiation in wavelengths ranging from 0.5 to 0.9 μm (Seaman, 2013). This DNB band allows the detection of low levels of lights during the night, making VIIRS DNB revolutionary in the field of light pollution research (Seaman, 2013).

Rather than using the raw data output from the VIIRS DNB instrument, researchers generally obtain partially corrected VIIRS DNB data from various sources (Kyba et al., 2014). In the past, for example, the Earth Observation Group (EOG) of the National Oceanic and Atmospheric Administration (NOAA) produced corrected VIIRS DNB data by combining multiple passes of the sensor on nights both cloud-free and moonlight-free and aggregating them into monthly averages (NOAA, 2021). Today, the EOG creates similar cloud-free composites produced through the Colorado School of Mines, which are publicly available for download on their website (Colorado School of Mines, 2021). Those cloud-free composites serve as the basis for the VIIRS analysis portion of this project, obtained from the EOG’s website.

To analyze light pollution within and around the CIDSR, light radiance measurements were extracted from the VIIRS DNB. These radiance measures serve as an indicator of light pollution levels. Once values were summed together for various geographies for consecutive months across time, we were able to track individual geographies’ contributions to light pollution and develop trends, as well as pinpoint locations contributing the least and most to light pollution. This effort will allow the reserve, further researchers, and the public to gain a better understanding about what areas may be jeopardizing the reserve's night skies the most and therefore target intervention efforts. The analysis was performed in such a way that it can be repeated over time as more data become available.

To compare and analyze trends in light pollution in and around the CIDSR, we used VIIRS DNB data averaged by month for the years 2013 to 2020[1]. As mentioned previously, VIIRS data is advantageous due to its accessibility, ease of use, and ideal time series. For the purpose of this analysis, summed radiance by area serves as a measure of each area's contribution to light pollution. Data were initially downloaded and clipped to a 300-kilometer (km) buffer around the CIDSR[2]. Download specifications for the data are listed in table 2.1. To compare the summed radiances by month over time, various levels of geographies intersecting or within the 300 km region were created. These levels incorporate state, county, city, reserve, and other bounds. Computed values were then cleaned and graphed to visualize trends. We also included calculations of summed radiance by area (km2) for all counties of interest in an effort to standardize data across the various sized counties for greater clarity in comparison. The VIIRS analysis data serves as a basis for the various other portions of our project, enabling time-scaled conclusions to be drawn about the variation in light pollution in and around the reserve. This enables us to make recommendations about ground-based monitoring for the reserve and inform policymakers on possible solutions to the light pollution.

Table 1.1. Data download specifications

| | |
|---|---|
| **Delivery File Type** | tgz (gzipped tar ball) |
| **Delivery File Content** | avg_rade9h, cf_cvg, cvg |
| **Delivery File Configuration** | vcm, vcmsl |
| **Unit** | (avg_rade9h) nW/cm$^2$/sr |
| **Image File Type** | GeoTIFF |
| **Image CRS** | EPSG:4326 (Geographic Latitude/Longitude) |
| **Image Resolution** | 15 arc second (~500m at the equator) |
| **Tiled** | Yes |
| **Coverage** | 180W, 75N, 180E, 65S<br>Note: The global coverage of monthly VNL is greatly affected by the length of day in different times of year. In summertime the northern hemisphere will have less nighttime coverage due to longer days. |

[1] Excluding May through July, see 'Methods' for reasoning

[2] See 'Methods' for reasoning

VIIRS DNB data can be used for more than just light pollution research. In the past, VIIRS has assisted researchers in a variety of projects – such as assessing damage to infrastructure after natural disasters; detecting small-scale light sources like fires, shipping vessels, light flashes, oil spills, and gas flares; and investigating nighttime cloud cover, aerosol, and particulate matter concentrations (Román et al., 2018). One study, for example, assessed the infrastructure impact of natural disasters such as the Gorkha Nepal Earthquake of 2015, the Central Italy Earthquake of 2016, and the Louisiana Flood of 2016 by comparing nighttime light emission data before and after each disaster (Zhao et al., 2018).

Within the field of light pollution, there are many applications of VIIRS DNB data. VIIRS data is useful for examining individual light sources, rates of light pollution change at various scales, and importantly, monitoring lights in protected areas (Coesfeld et al., 2018). One study specifically used VIIRS DNB data to compare nighttime light use between Germany and the U.S. The researchers found significantly larger nighttime artificial light per capita in the U.S. compared to Germany (Kyba et al., 2014). Another study conducted a similar analysis of VIIRS DNB data to find that reduced air and road traffic during the COVID-19 lockdown in Berlin, Germany resulted in decreased levels of artificial light at night (ALAN) across the city (Jechow & Hölker, 2020). In summary, this project is just one example among many of how this data can be used for research purposes, especially within the field of light pollution.

The following section details our specific methods for calculating our eventual summed radiance values, which serve as the basis of this project. Our results follow, in which we have included notable findings related to trends across different geographies over time. Lastly, we conclude this chapter with recommendations and additional discussion of continuing to track light pollution in the CIDSR.

# Methods

The following section details methods used to download, derive, calculate, and produce the summed radiance data. Detailed step-by-step methodology for the data-download and processing are listed in the Appendices.

## *Pre-Analysis Specifications*

Prior to conducting calculations or analyses, certain parameters must be established:

- **Geographic Scale**: A buffer of 300 km around the outer CIDSR boundary was created to serve as a reasonable maximum region of analysis for the extent of light polluting sources that may affect the CIDSR (Falchi et al., 2016).
- **Areas of Interest**: In order to create a comprehensive dataset of summed radiance values for various areas, eight different types of analysis areas became the focus of this study. The type and prevalence within each category is as follows:
    1. The CIDSR outer boundary (1)
    2. The CIDSR core boundaries (2)
    3. State of Idaho (1)
    4. Thompson Creek Mine (1)
    5. A 300 km buffer circle around the outer CIDSR (1)
    6. Cities within 300 km of the reserve (356)
    7. Counties within 300 of from the reserve (79)
    8. Significant National Parks/Monuments/Preserves within 300 km from the reserve (3)
- **Coordinate System**: NAD_1983 Idaho Transverse Mercator is the coordinate system applied to all rasters and layers for the purpose of this project.

### *Downloading VIIRS Rasters*

VIIRS rasters were downloaded from the EOG. Raster files from the EOG are available from as early as April 2012. However, we focused only on years with all months of data available, meaning analyses started in January 2013 through December 2020. Upon further analysis, the months of May, June, and July were excluded from the study for every year. This was due to later sunset times in these months causing the angle of the sun to hit the satellite as it passes high overhead, creating conditions that make readings impossible. Solar elevation was cross referenced with historical overflight times provided by the NOAA VIIRS SNPP Satellite Trajectories map to confirm this occurrence. An additional confirmation of this phenomena was performed by referencing a secondary radiance light trend map, which also displayed missing radiance values for these months.

From the EOG download, we analyzed the monthly cloud-free DNB composites. It is crucial to use cloud-free observations to ensure values at or near zero mean no lights were observed and not that there may have been clouds blocking readings. The *vcm* series used excludes any data impacted by stray light. The data downloaded as a raster file (.tiff) with average radiance values by pixel. Because these rasters are large (XXGB), a rectangular shapefile that conservatively covered all areas of interest was created and each raster was clipped to that shapefile. This enabled a quicker and easier processing of the files later on.

### *Summed Radiance Calculations*

After shapefiles of areas of interest were created and merged into one shapefile with overlapping polygons, we performed zonal statistics for all rasters by geographic area. This calculation sums each pixel of average radiance across a specified polygon representing a geography, giving a summed radiance by area. Our calculations resulted in a data table of all raw values, equaling over 32,000 different summed radiance calculations (445 geographies, nine months over eight years). A detailed tutorial of this process can be found in *Appendix 2A: VIIRS Methodology*.

### *Data Cleaning*

For all analyses, summed radiance values calculated for months before 2017 (January 2013 – December 2016) and after 2017 (January 2017 – December 2020) were analyzed separately. Before 2017, the ‘zero point’ for the VIIRS DNB included airglow, meaning a value of zero corresponded to no artificial light. Airglow corrections therefore could lead to values at or below zero. After 2017, the ‘zero point’ for the DNB included airglow, meaning a value of zero corresponds to zero light. This means observation values post-2017 will almost always be positive due to natural light, which could lead to post-2017 values appearing higher than they should when compared with pre-2017 summed radiance values (Coesfeld et. al., 2020). Due to the difference in how data are reported, trend analyses for this report were split up into pre- and post-2017. Resulting negative or zero values were also removed. Furthermore, values above or below two standard deviations from the mean were removed in an effort to disregard outliers. These outliers sometimes occurred due to satellite overhead times occasionally being influenced by sunlight hitting the satellite for certain areas outside of the May/June/July window. This resulted in certain areas with missing pixel values, often reported as small negative numbers. Standard deviation tests operate best on normally distributed data. For large areas, the sum of many negative pixel values creates a longer tail on the bell-curve, which means the data are distributed more normally and these pixel values are more likely to be removed by the standard deviation test. For small areas, however, data are not as normally distributed. While some outlier values are still removed by the standard deviation test, it is important to note that not all were removed. This means we must keep a mindful eye when viewing results, interpreting values within the context of the whole.

### *Statistical Tests*

In order to assess the strength of light pollution trends within areas of interest, we performed linear regression analyses on the collected summed radiance data. Due to the change in the 'zero point' of VIIRS data described above, separate linear regressions and associated statistical tests of significance were run on pre-2017 and post-2017 summed radiance data. Additionally, because summed radiance values are heavily influenced by seasonality (e.g. snow conditions), significance tests were run by month (i.e., a trendline through the same month of each year). The statistical values calculated were p-values and r-squared values, and a 95% confidence interval was used. Open-source R software was used to perform the tests. All code, including thorough comments, can be found in *Appendix 2B: Significance Testing*. In *Appendix 2C: Data Download*, the excel documents containing the data for the significance tests and their specific formatting can be viewed.

### *Summed Radiance by Area Calculations*

In an effort to visualize the data in a way that makes county radiance trends comparable, we calculated the summed radiance by area in cubic kilometers for each county. This allowed for larger counties to be viewed comparatively to smaller counties, as larger counties may falsely look like they are contributing greater to light pollution simply due to the greater land area covered by them. Total area for each county was taken from the U.S. Census Bureau, then each county's total summed radiance value for each month (post-cleaning) was divided by that area. The slope across all available months for each county from 2013 to 2020 was taken to observe the trend in either the growth or decline of light pollution per area.

## Results

### *Summed Radiance by Area: Counties*

Figure 2.1 shows all the counties within 300 km of the reserve included in our analysis. Figures 2.2 and 2.3 visualize trends found from calculating the summed radiance by area for all counties of interest. Figure 2.2 shows the average summed radiance by area across all months between 2013 to 2020. It is notable that many of the counties that intersect with the reserve boundaries are fairly dark, meaning they recorded low summed radiance values per square kilometer. However, Elmore County is shown as the lightest (brightest) of the CIDSR-surrounding counties, possibly due to extraneous light pollution coming from the two brightest counties that neighbor Elmore: Ada and Canyon County. Figure 2.3 shows the trend in summed radiance values by area over time by visualizing the average slope of pre- and post-2017 calculations. Once again, calculations before and after 2017 must be separated due to a difference in how the VIIRS data records its zero point. The slope of the summed radiance values by area were thus calculated separately for 2013-2016 and 2017-2020 and then averaged together. Interestingly, Ada County shows a large decrease in measured summed radiance by area over time, despite having a significantly high average summed radiance by area overall. Almost all the counties intersecting the reserve show an upward trend, meaning they have increased their summed radiance values per km from the 2013 to 2020 period. These graphs serve as a method for standardizing light pollution levels in order to compare counties against one another despite differences in size (land area).

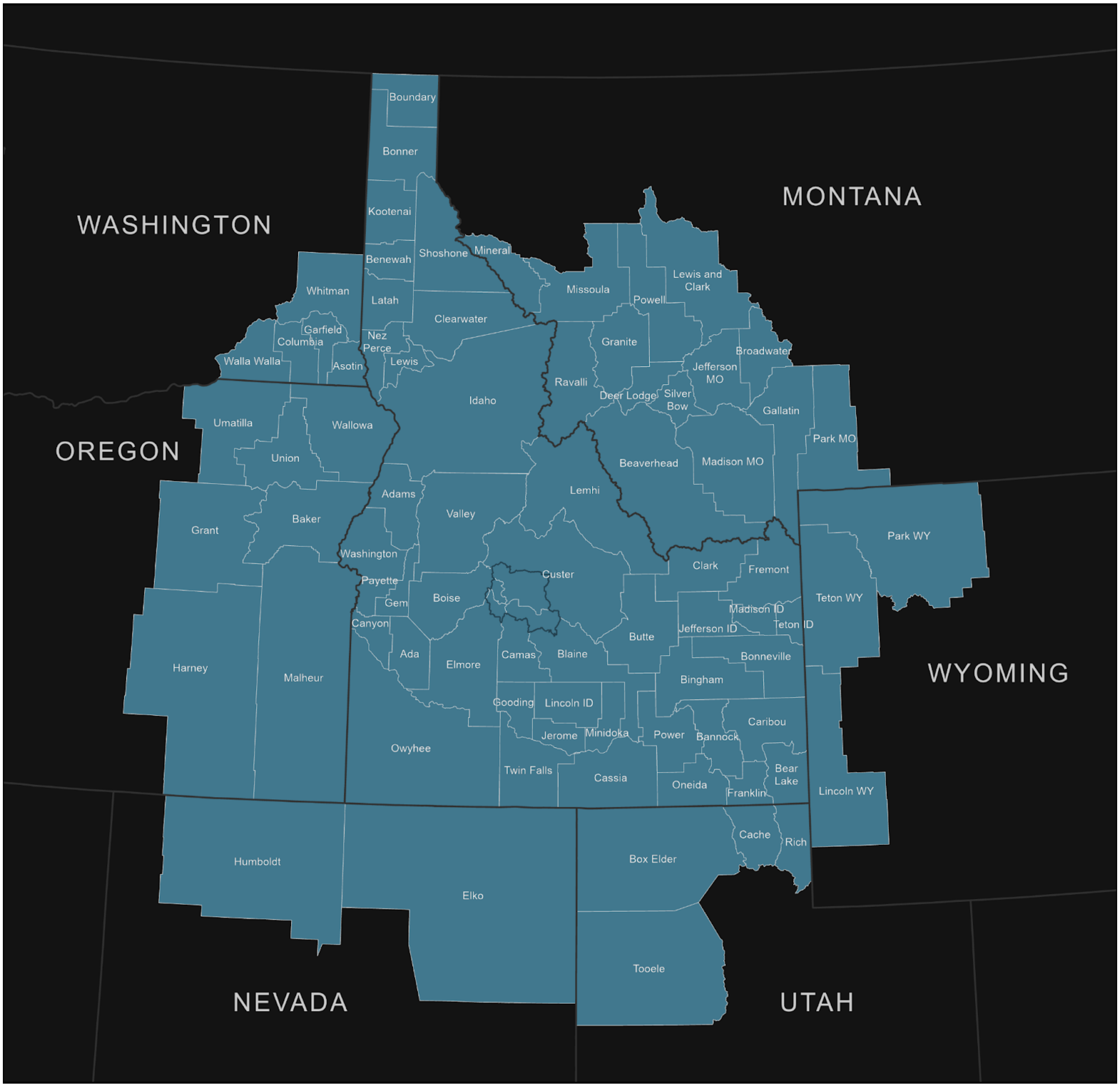


Figure 2.1. Counties of interest included in our analysis of light pollution trends.

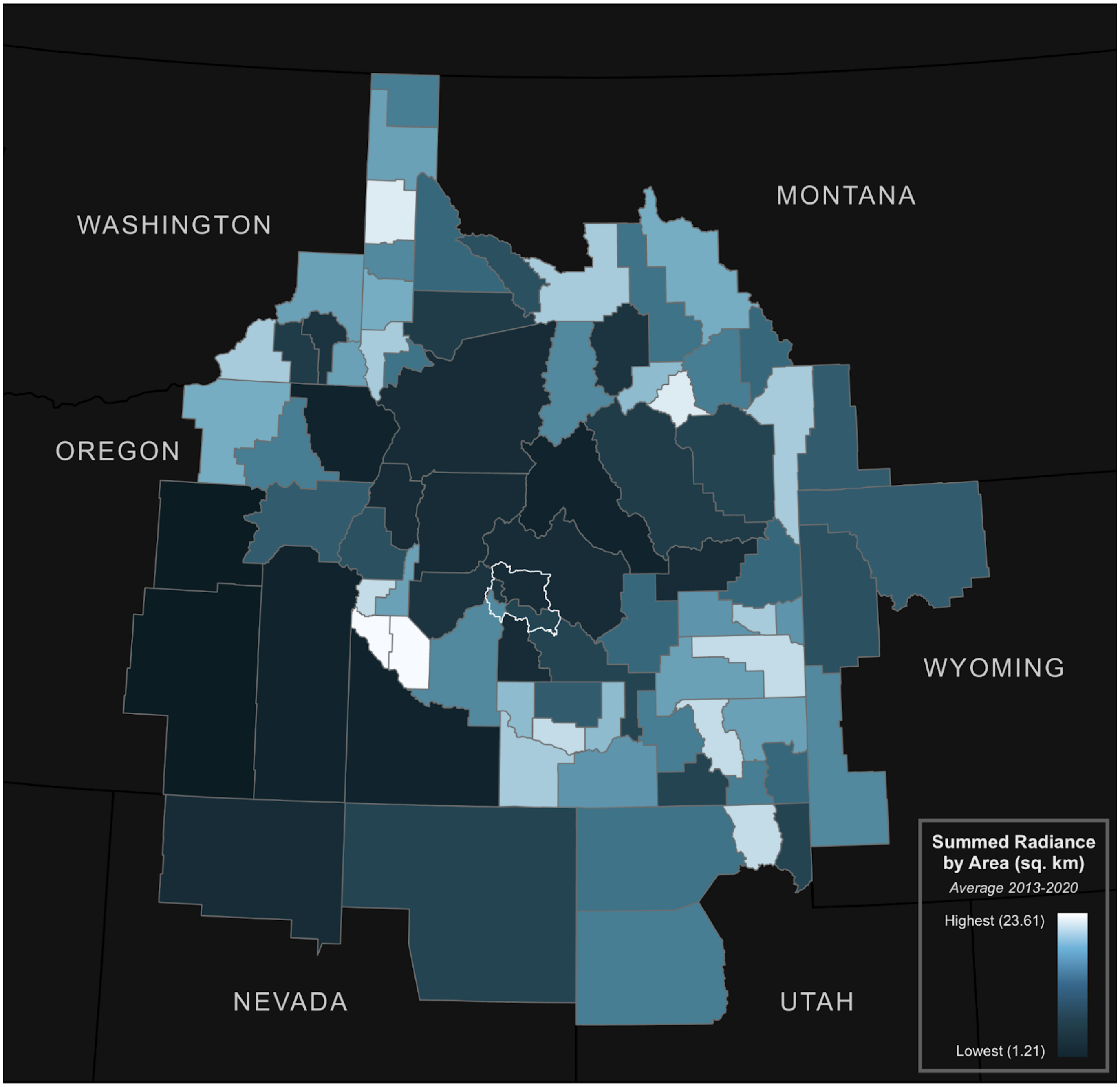



Figure 2.2. Average summed radiance by area from 2013 to 2020 ($km^2$). Darker blues represent lower light levels, while lighter blues represent higher light levels.

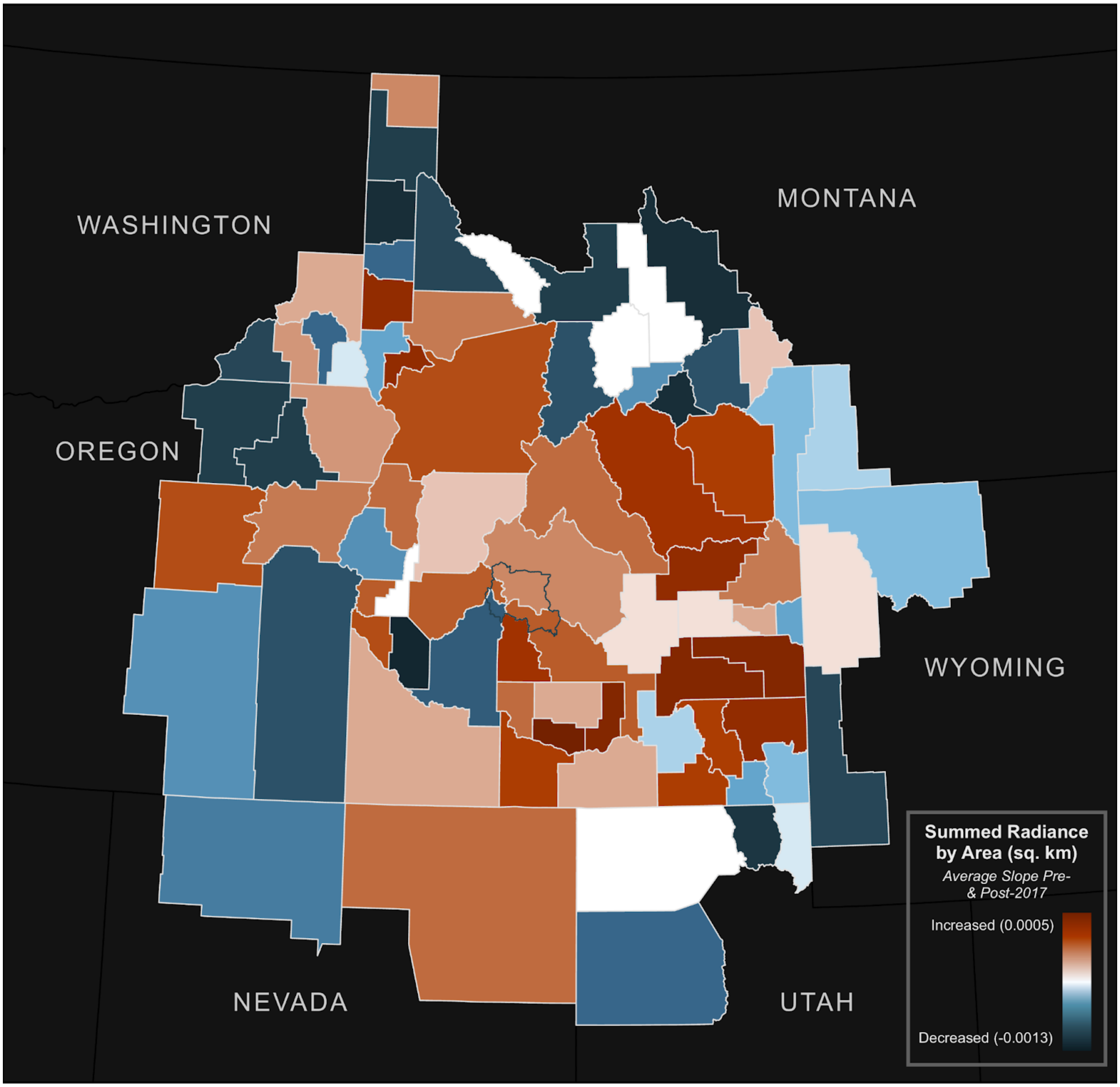



Figure 2.3. Average slope of summed radiance by area (km2), pre- and post-2017.

Figure 2.5. The Boise light dome pictured from Smiley Creek Road within the CIDSR (Nils Ribi).

## Summed Radiance Trends

As shown in the graphs, summed radiance values vary significantly with seasonality. This is especially apparent in the winter months when snow reflects both artificial light and moonlight, which results in much higher summed radiance values. The change in the ‘zero point’ of VIIRS data that occurred in 2017 is also apparent in the graphs below. Again, the zero point was no artificial light before 2017 but then became no light at all in 2017 onward. This explains the clear jump in summed radiance values that occurs in 2017.

### *Summed Radiance Trends: The CIDSR*

First, within the CIDSR, the trend in summed radiance values is slightly negative both pre-2017 and post-2017 but overall appears steady (figure 2.4). In terms of significance, for no month pre-2017 or post-2017 do light pollution trends prove to be significant – p-values range from

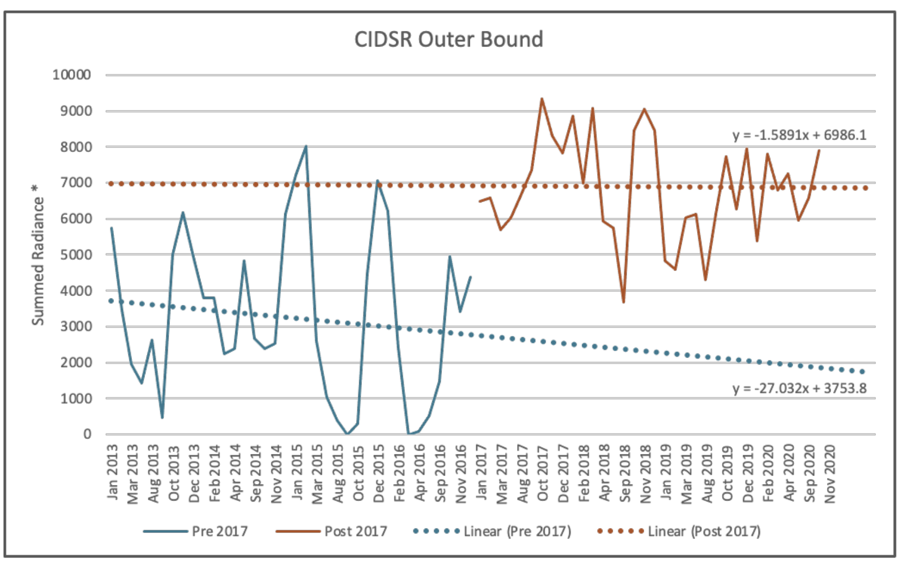



Figure 2.4. Summed radiance trends within the CIDR. Blue represents pre-2017 trends and orange represents post-2017 trends.

0.1027 to 0.98722. Despite the lack of significance, these data serve as a good indication that there has been no substantial increase in light pollution within the reserve over the past eight years.

### *Summed Radiance Trends: Boise City*

Increasing population and development and therefore increasing light pollution in Boise city is considered the greatest threat to the CIDSR by many of its advocates. The light dome created by Boise city has been observed and photographed on the horizon of the CIDSR, as seen in figure 2.5.

The VIIRS data, however, does not show an increase in light pollution in Boise city over time. In fact, light pollution has shown a negative trend over the entire time period from 2013 to 2020. The negative trend does not prove to be significant, except for the month of January pre-2017 which produced a p-value of 0.03635. Despite lack of significance, the idea that light pollution seems to be decreasing in a growing urban capital city brings up an important concern with VIIRS data: the VIIRS satellite is unable to detect the shorter wavelengths of light emitted by the newer LEDs that are replacing older styles of lights (Hung et al., 2021). Older lighting primarily emits in the yellow portion of the spectrum, which the VIIRS satellite can detect. If LEDs are replacing these older styles of lights in Boise city, the light pollution produced by the LEDs will not be detected by the satellite's sensor (Hung et al., 2021). This could result in VIIRS data suggesting decreasing light pollution trends over time when in reality light pollution is increasing (Hung et al., 2021). Therefore, it may be important to not only monitor the light pollution trends in cities like Boise through the use of VIIRS data, but also to monitor the changes in lighting types over time.

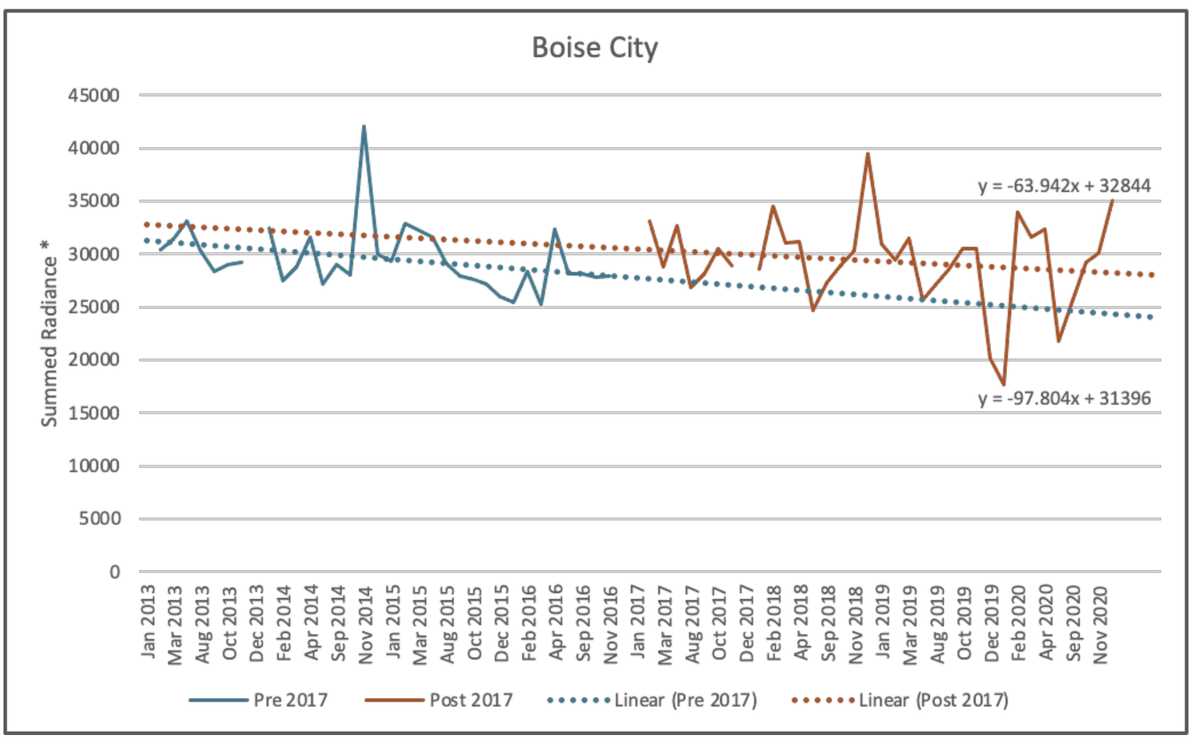



Figure 2.6. Summed radiance trends in Boise city. Blue represents pre-2017 trends and orange represents post-2017 trends.

### *Summed Radiance Trends: Thompson Creek Mine*

The Thompson Creek Mine is an interesting case study for studying light pollution trends and the impact of reducing unnecessary light pollution. The mine is located just outside of the CIDSR and the light emitted from its nighttime operations is known to impact the night sky of the reserve. Due to pressure from dark sky advocates and local groups, the mine began making a conscious effort to reduce its levels of light pollution (Salmon-Challis National Forest, 2016). The results of these efforts can be seen in the pre-2017 summed radiance data where there is a clear downward trend in light pollution. Indeed, the p-values from the significance test of this data range from 0.05671 for the month of March to 0.30099 for the month of February. Although these p-values values are not low enough to consider any of the downward trends in light pollution significant given a 95% confidence interval, they are generally much lower than for other geographies of interest such as the CIDSR Outer Bound where p-values range from 0.26996 for the month of April to 0.94258 for the month of February. Post-2017 however, a slight upward trend in light pollution is starting to appear. In fact, this upward trend is found to be significant in the month of December which has a post-2017 p-value of 0.00149.

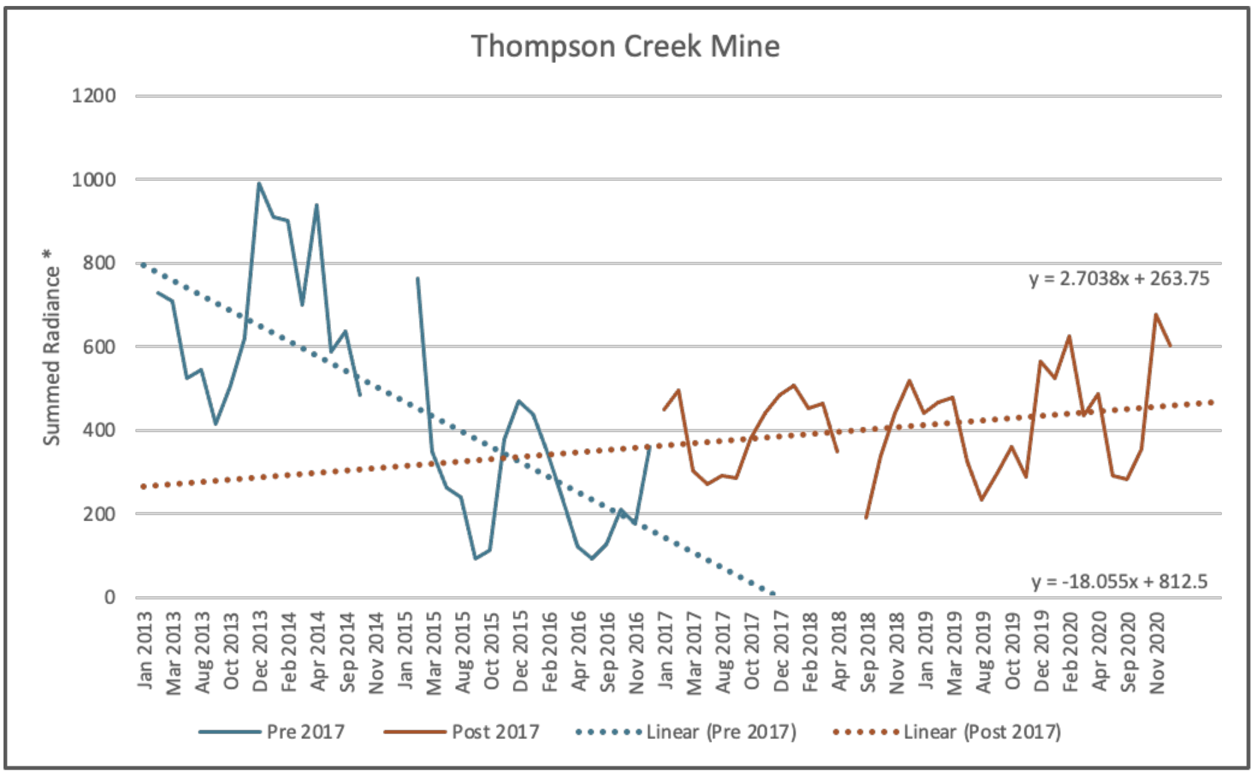



Figure 2.6. Summed radiance trends in Boise city. Blue represents pre-2017 trends and orange represents post-2017 trends.

The recent increases in light pollution from the Thompson Creek Mine are more clearly shown in Figure 2.8, which illustrates the average radiance at the mine in 2019 and 2020.

### *Summed Radiance Trends: National Parks - Grand Teton & Yellowstone*

In both National Parks that fall within the overall geographic area of interest – Grand Teton and Yellowstone – light pollution trends both pre-2017 and post-2017 are increasing. The magnitude of growth in light pollution increased from pre-2017 to post-2017 as well. When assessing the p-values associated with these trends, only the pre-2017 upward trend for the month of

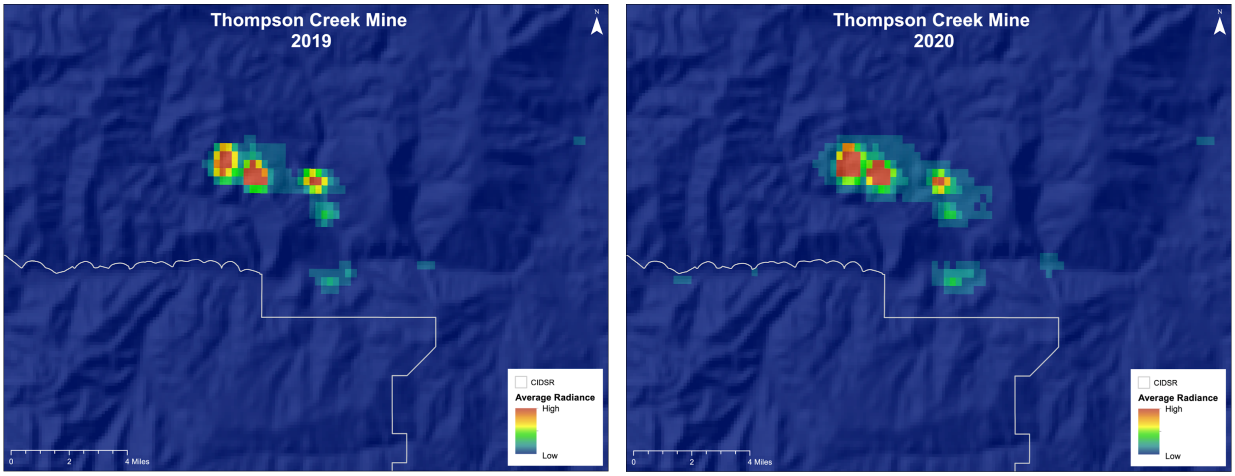



Figure 2.8. Comparison of Thompson Creek Mine average radiance between 2019 (left) and 2020 (right). Higher radiance is represented by reds and yellows while lower radiance is represented by greens and blues.

September in Yellowstone is considered significant with a p-value of 0.03264. The p-values are generally quite high, even reaching 0.99157, suggesting a much larger sample size is needed in order to accurately comment on the light pollution trends within the Grand Teton and Yellowstone National Parks.

## Recommendations & Discussion

Analysis of the summed radiance data has significant limitations. The most notable issue is the limited sample size (number of years). This problem becomes all the more limiting when the data is split into pre-2017 and post-2017 which resulted in a sample size of four years each. As noted above, there are issues with negative values for raster pixels within the VIIRS data

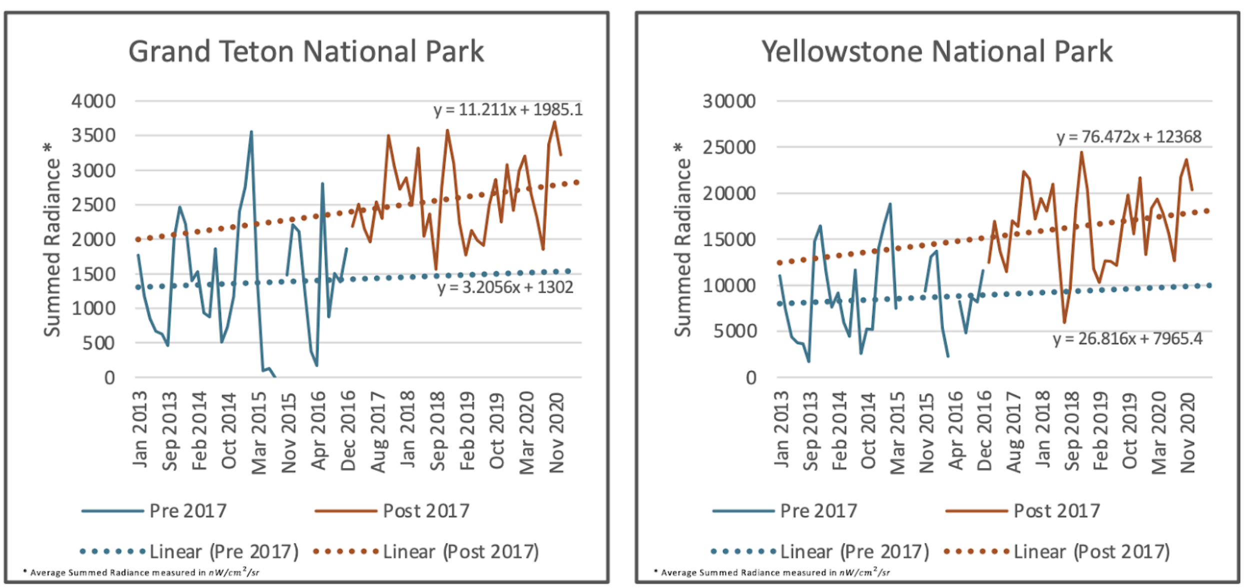



Figure 2.9. Summed radiance trends for Grand Teton (left) and Yellowstone National Park (right). Blue represents pre-2017 trends and orange represents post-2017 trends.

downloads that result from the algorithms used to process the data readings. These values indicate nonsensical radiance values that are either darker than conditions with no artificial light (pre-2017) or darker than complete darkness (post-2017). Added together across a geography, negative pixel values can result in very low or even negative summed radiance values. Additionally, at some points during the orbit of the satellite, sunlight hits the VIIRS sensor and therefore prevents summed radiance readings. Not only does this prevent data readings, but leads to broken rasters that can easily go unnoticed during data analysis. Overall, the negative pixel values and broken rasters due to a blocked sensor result in summed radiance values that must be carefully removed from the data set, resulting in a further reduction of sample size. For a given area, some months – either pre-2017 or post-2017 – only had two summed radiance values, preventing a significance test from being performed at all. Another major concern is that the VIIRS satellite is unable to detect the shorter wavelengths of light emitted by LEDs, as discussed above in reference to light pollution trends in Boise City. As the transition to LEDs continues, this could become an even bigger limitation to the use of VIIRS data to track light pollution trends.

Results indicate that while many areas are trending upward in their light pollution contribution, others are still remaining stable or declining. Of those trending upward, none are doing so at a rate too disturbing or quickly that bars any remediation from being useful. In recent years, there does seem to be an increase in light pollution from the Thompson Creek Mine. Due to the mine's close proximity to the reserve, the CIDSR may benefit from a revived effort to increase local pressure on the Thompson Creek Mine to reduce its light pollution.

We recommend the following:

- Similar summed radiance calculations to those detailed for this project should be performed and repeated as data become available, such as annually. Any new data or calculations should be amended to the existing data set to provide a greater possibility of discovering trends as the years continue.
- A reliable working group should be established in order to continue this work, keeping in mind that personnel overturn could compromise the repeatability needed for this project. To combat that, we are currently in contact with a professor from Boise State University to establish a local network. Boise State University could sponsor a research group of students who learn and apply our methodology yearly.
- If methods are updated, changes should be clarified in detail so that yearly research group additions can easily adopt the methodology.
- We suggest and request data remain publicly available and easily accessible in the interest of attracting as many individuals or groups who want to contribute.
- To anyone interested in exploring global or local light pollution, visit a light pollution map spanning the globe at lightpollutionmap.info.

# Ground-Based Light Pollution Monitoring within the CIDSR

CHAPTER 3

## Introduction

Taking ground based measurements at sufficient spectral resolution and sensitivity are vital for accurately assessing the performance of the Central Idaho Dark Sky Reserve (CIDSR). Not only do these measurements provide additional sky brightness data, but they also provide an idea of how residents on the ground view the night sky and its change over time. However, these measurements are much more difficult to obtain due to the need for expensive, specialized equipment and on-site observation; thus, they are often used to complement satellite-based measurements.

The main type of ground based measurement used in studying light pollution is taken through the capture of hemispherical photography. Researchers studying sea turtles developed the use of hemispherical digital photography (Thums et al., 2016; Pendoley et al., 2012) to extract measurements of illumination, spectrum, and directionality in the light environment. This same approach is used in astronomical measurements such as those taken by the National Park Service (NPS) Night Sky Team since the early 2000s (Duriscoe, 2016) and a growing array of international researchers (Jechow et al., 2018; Jechow et al., 2017; Pendoley et al., 2012; Luginbuhl et al., 2009). The Sky Quality Camera (SQC) allows researchers to obtain the detail and resolution of the NPS hemispherical photography in a quicker and less expensive manner.

The SQC used for this project is a digital single lens reflex (DSLR) Canon Rebel Camera equipped with a fisheye lens. This set-up is typical in recent studies regarding light pollution (Kolláth et al., 2020). The camera captures hemispherical imagery, displaying the top of the sky in the center with the horizon stretched around the border of the image in a circular display. Images are saved in .cr2 format, also known as RAW digital photography file format. These files can then be exported from the SD card in the camera to a computer with the SQC program installed. The commercial SQC software was developed by Andrej Mohar and Euromix Ltd, Slovenia (Wallner et al., 2020) and is calibrated by standard stars that help align images based on the brightest stars in the sky (Kolláth et al., 2020).

To demonstrate the use of an SQC for long-term light pollution monitoring at CIDSR, we obtained and analyzed an image within the reserve taken during winter 2021. In this chapter we describe the acquisition and analysis of light pollution data with SQC and demonstrate its use for communication about the risks of additional light pollution. We then propose a framework for long-term monitoring within CIDSR using this technology.

## Methods

Our on-the-ground analysis of the CIDSR can be broken apart into two components: (1) capture images of the night sky through the SQC; and (2) study these images in the SQC computer program and create simulations modeling future light pollution conditions. As the latter of these components was dependent on the former, the completion of this analysis was highly dependent on our team first traveling to Idaho during March 2021.

### *Capturing SQC Images*

Using the SQC in the CIDSR required detailed planning and methodical procedures in order to yield the highest quality images possible. First, prior to entering the reserve, we checked moon calendars to find the duration and time of the moon-set, and thus the ideal time to take pictures without the influence of the bright moon. We stayed in Idaho from March 22 through 25, 2021, which meant the moon set at about 4:00 AM Mountain Time (MT) the first day and then shifted about 45 minutes later each following day (Time and Date, 2021). The moon was waxing,

Table 3.1. Recorded characteristics of each of our night sky imagery locations within the CIDSR.

| | SQM READING (AVG OF 3 MEASUREMENTS) | HUMIDITY (%) | TEMPERATURE (°C) | ELEVATION (M) |
|---|---|---|---|---|
| **FOURTH OF JULY CREEK** | 21.9 (no moon) | 81 | -10 | 2073 |
| **GALENA OVERLOOK** | 17.1 (full moon) | 67 | -11 | 2573 |

starting at around half full on our first day in Idaho. In order to decide the earliest point in the evening or the latest time in the morning at which we could capture images of the sky with no daylight interference, we verified when astronomical twilight occurred in the morning and evening (the time at which the sun begins/stops lightening the sky). In our case, this started at about 6:07 AM and 9:02 PM MT on March 22 and became earlier/later with each passing day,

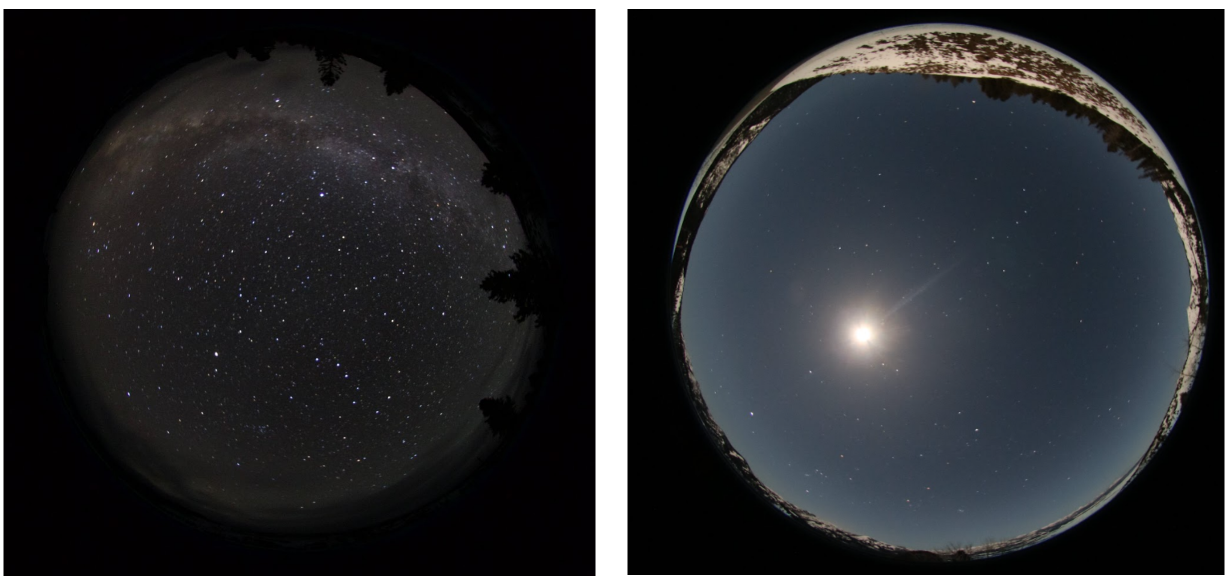


Figure 3.1. Raw SQC Images. The left image is the sixth photo taken at Fourth of July Creek with the moon below the horizon, and the right image is the sixth photo taken at Galena Overlook under a full moon.

as the daylight hours were beginning to extend with the start of spring. Thus, our ideal time for capturing images was in the early mornings of March 22 through March 24, as these were the only dates in which the moon set prior to the beginning of astronomical twilight. To minimize cloud cover in our imagery, we looked into the local weather at these times of night. Through the use of these parameters, we discovered the ideal time for taking pictures (least amount of light and cloud interference) was in the early morning hours of March 23.

Once our team determined when to photograph the dark sky, we traveled to the CIDSR and methodically used the SQC to capture images. We selected locations within the reserve with minimal interference from city lights. Such locations included Fourth of July Creek and Galena

Overlook. We followed detailed instructions to ensure we used the correct camera settings and we minimized any possible inference from personal light pollution sources (Appendix 3A: Instructions for Use of SQC). The process included first noting the time, latitude and longitude, humidity, temperature, and elevation. These conditions serve as reference in the SQC program (Table 3.1). In addition, we used a sky quality meter (SQM) to take three readings of each location's sky quality, meaning the darkness of the sky. SQM readings can range from 15-22, with 15 being the brightest and 22 being the darkest. We averaged these readings to approximate the sky quality of each location.

To maintain stability while taking pictures, we secured the camera onto a tripod. We then pointed the fisheye lens at the sky and oriented the camera so the top faced due north. If uncertain of the correct exposure time to use, we experimented with the camera's exposure times based on the sky quality readings (a higher SQM reading yields a greater exposure) to find the ideal balance between exposure and saturation in the image. Upon determining the exposure time, we captured six images in each location to allow for any possible abrupt shifts in setting – such as a car driving on a nearby road or shifting clouds in the sky. We also ensured that none of our personal devices were illuminated at all during the actual image capture duration.

### *Initial SQC Analysis*

To further examine the luminance and locations of nearby light pollution sources potentially impacting the CIDSR, we accessed the SQC program by remotely connecting to our advisor's desktop computer after capturing our SQC images (Figure 3.1), We followed a detailed set of instructions provided in Appendix 3B: SQC Program Instructions. First, we exported the images from the SD card to the remote desktop interface. Then, we opened each image in the program and inputted the time and location the photo was taken, as well as settings for the sky border. We set light pollution sources for each image location by examining the program's 'Light Pollution Map' and using the 'Map distance' tool to find the distance and azimuth angles. The azimuth angles describe in which directions a light pollution source starts and ends. Following this, we changed other settings in the program based on the conditions we experienced in the field, such as cloud cover and precipitation. We ran the automatic analysis to generate several images displaying specific aspects of the sky including sky brightness, luminance, correlated color temperature (CCT), and cloud cover. CCT characterizes the color appearance of a light source in Kelvin based on the proximity of the light source's chromaticity to a blackbody radiator (Valencia, Giraldo, & Bonilla, 2013). We completed this process with each of our images taken at each site; however, we found that our most useful image (with the least moonlight and cloud cover) was our sixth photo taken at Fourth of July Creek. Thus, we will be referring to this image more in depth in our results section below.

### *SQC Prediction Analysis*

One of our other objectives in completing the SQC process was to gain an idea of how future light pollution trends may impact the reserve's dark skies. To do this, we used the 'Prediction Simulation' tool in the SQC program and changed various parameters to represent different potential scenarios. These included the percentage of white LEDs and the annual change in lamp power/quality (Appendix 3C: Prediction Simulation Notes). In order to more clearly see how light pollution can create shorter and longer term impacts on the reserve, we ran simulations for 10, 20, and 30 years from the current year (target years: 2031, 2041, 2051).

When determining how to change the parameters, we chose to represent both baseline and more extreme scenarios. For the percentage of white LEDs specifically, we represented the most extreme scenario: 100% white LEDs by the target year. This illustrates the possibility of the region converting all of their exterior lighting to white LEDs, the newer lighting technology. We inspected images taken by astronauts to find the current percentage of white LEDs, which we estimated to be around 20% (Cities at Night, 2021). In terms of lamp quantity and power change per year, we chose to run simulations for both a 2% growth and a 6% growth per year. 2% represents that global light pollution is increasing at a rate of 2% annually (IDA, 2017). On the other hand, 6% represents how light pollution was found to increase 6% annually in the U.S. from 1947 to 2000 (Cinzano & Elvidge, 2003, as cited in National Park Service, 2021). From these parameters, we ran 13 different simulations: one focusing only on 100% LEDs by the target year, three focusing on 2% annual growth only, three focusing on 6% annual growth only, three focusing on 2% annual growth and 100% LEDs by the target year, and three focusing on 6% annual growth and 100% LEDs by the target year.

# Results

### *Initial SQC Analysis*

With our preliminary analysis of the SQC imagery (specifically the sixth photo from Fourth of July Creek), we came across some light pollution sources that could potentially impact the CIDSR's dark skies now and/or in the future. These included the local Thompson Creek Mine, as well as nearby cities such as Idaho Falls, Ketchum, Hailey, and Bellevue, or farther away metropolitan areas such as Salt Lake City, Utah and Boise city. These are illustrated in the northeast and southeast directions in Figure 3.2, where CCT values are shown to be lower, and thus representative of greater light pollution.

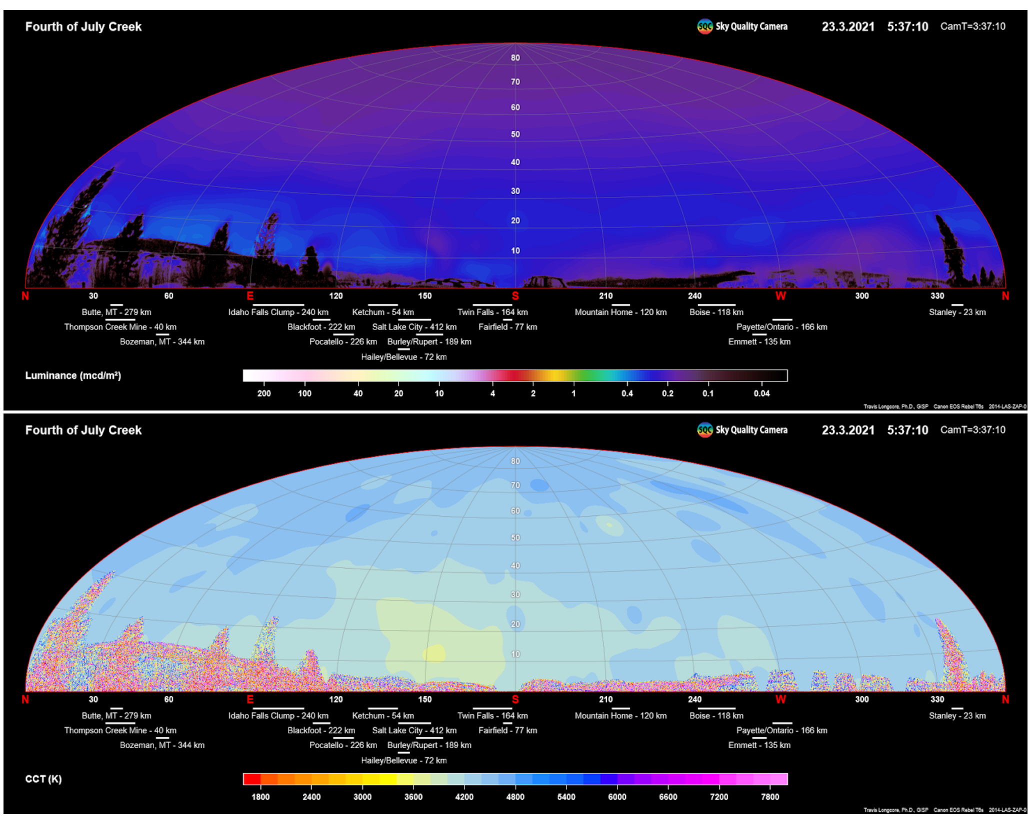



Figure 3.2. Hammer-Aitoff projection images of Fourth of July Creek taken from the SQC program, with light pollution sources indicated in their respective directions from our sampling point within the reserve. The top image focuses on luminance, displaying lower values with dark blues and purples. The lower image focuses on approximate CCT (K) in the sky, with lower temperatures representing greater artificial light pollution and higher temperatures representing less.

### *SQC Prediction Analysis*

In each of our completed simulations, we noticed that portions of the sky that were initially brighter in present-day imagery became more intensely bright (Figure 3.3). However, this change in brightness was less noticeable in simulations only focusing on one parameter (the least so with 2% annual growth only). Thus, 100% LEDs conversion plays a significant role in altering the brightness of the sky, and it is vital that the region keeps non-white lights in order to maintain minimal skyglow (Hung et al., 2021). The change in brightness was the most noticeable in the simulations focusing on 6% annual growth and 100% LEDs by the target year

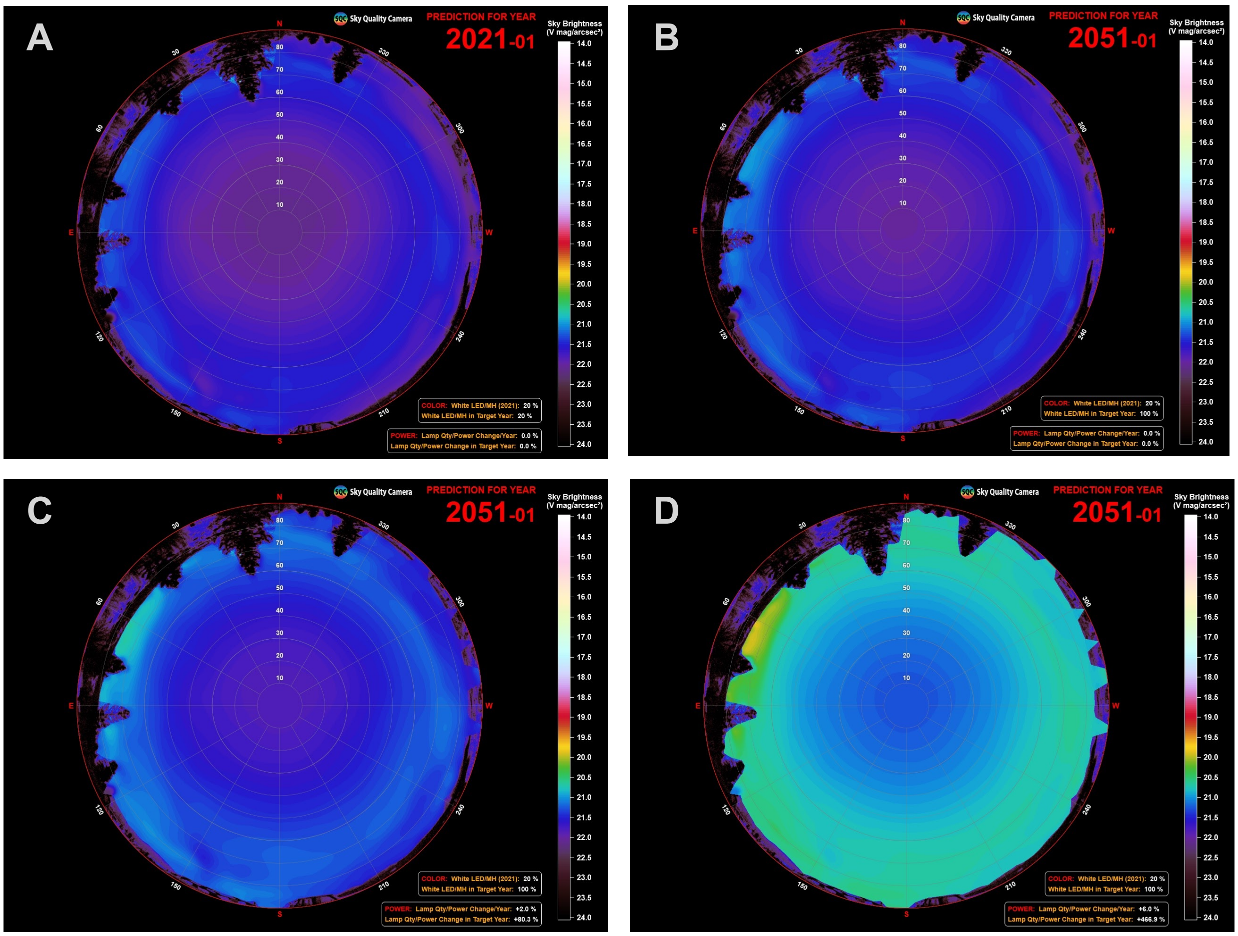



Figure 3.3. Prediction simulation output from the SQC software, including (A) current sky brightness, (B) predicted sky brightness in 2051 due to 100% conversion to white LEDs, (C) predicted sky brightness in 2051 due to 100% conversion to white LEDs and 2% annual lamp power growth, and (D) predicted sky brightness in 2051 due to 100% conversion to white LEDs and 6% annual lamp power growth.

## Discussion

### *Limitations*

Although we were able to complete analyses (both preliminary and further predictions) with the imagery from Fourth of July Creek, we unfortunately could not use our images from Galena Overlook to analyze light pollution sources. This was due to the fact that we chose to capture images at Galena Overlook while the moon was still visible in the sky. Even though the SQC program does provide a tool for cutting out major sources of light such as the moon, the entire sky was still shown in the program to be overwhelmingly bright due to the high albedo of the snow-covered landscape reflecting moonlight back into the sky. Thus, this imagery was excluded from any further analysis.

## Recommendations

After taking our own SQC photos and analyzing the potential external forces at play in disturbing the CIDSR's pristine skies, we recommend the CIDSR continues this work. Each month during the new moon, an SQC could be set up to take pictures at particular locations within the reserve to provide a baseline of keeping track of light pollution sources (Figure 3.4). We suggest at-risk areas in the reserve (i.e. points near major artificial light sources) be monitored, as well as other astrophotography points shared with us by local Idaho photographers Nils Ribi and Travis Amick. It should be noted that these sites are not necessarily compatible with colder seasons. In addition, an SQM should be placed in the reserve to take regular measurements of the sky quality and possibly send these numbers to a database for record keeping purposes. Utilizing on-the-ground measurements as well as remotely sensed Visible Infrared Imaging Radiometer Suite (VIIRS) data is vital (Chapter 2), as VIIRS data can sometimes underestimate radiance due to an inability of detecting short wavelength light (Hung et al., 2021). Shorter wavelengths of light (<500 nm) are seen in converted white LEDs, which have become more popular in recent years (Hung et al., 2021). Both of these actions would result in more effective monitoring of the reserve's skies and possible threats to it, and thus would provide leaders with more advanced notice if action needed to be taken to protect the skies.

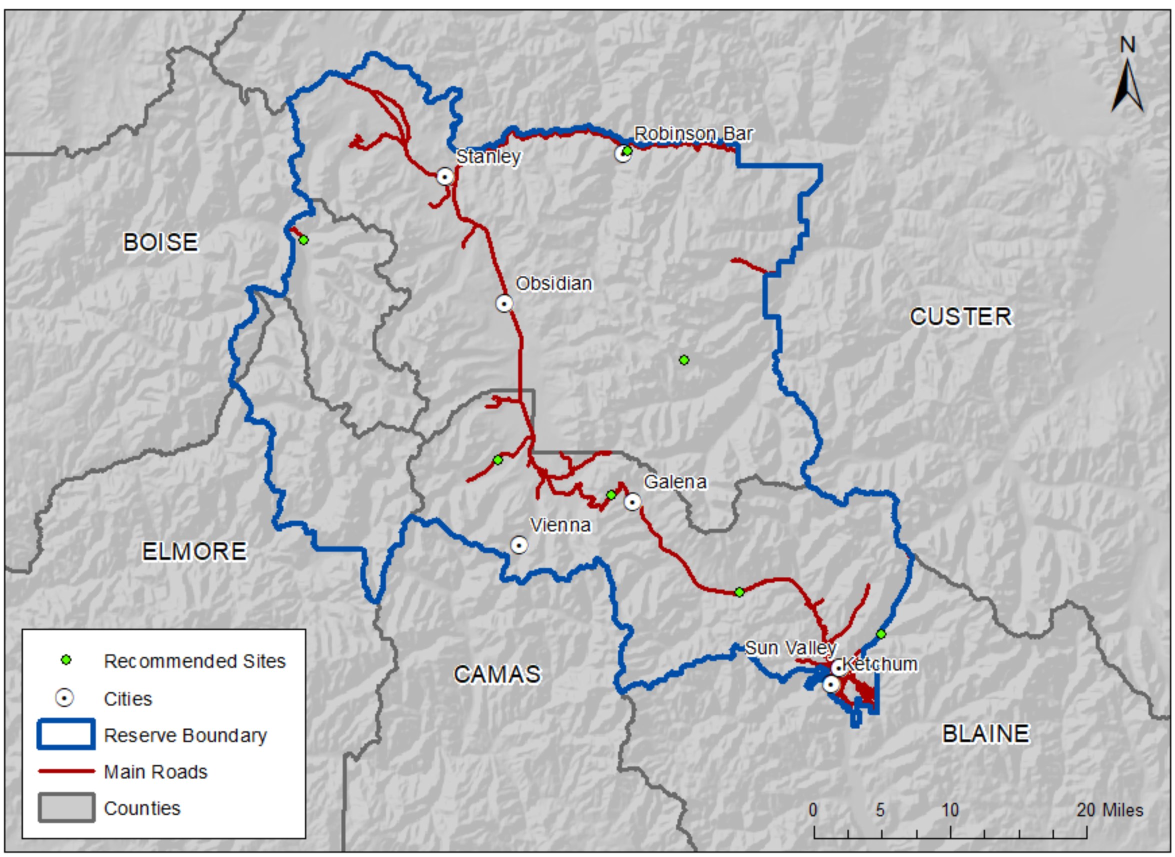
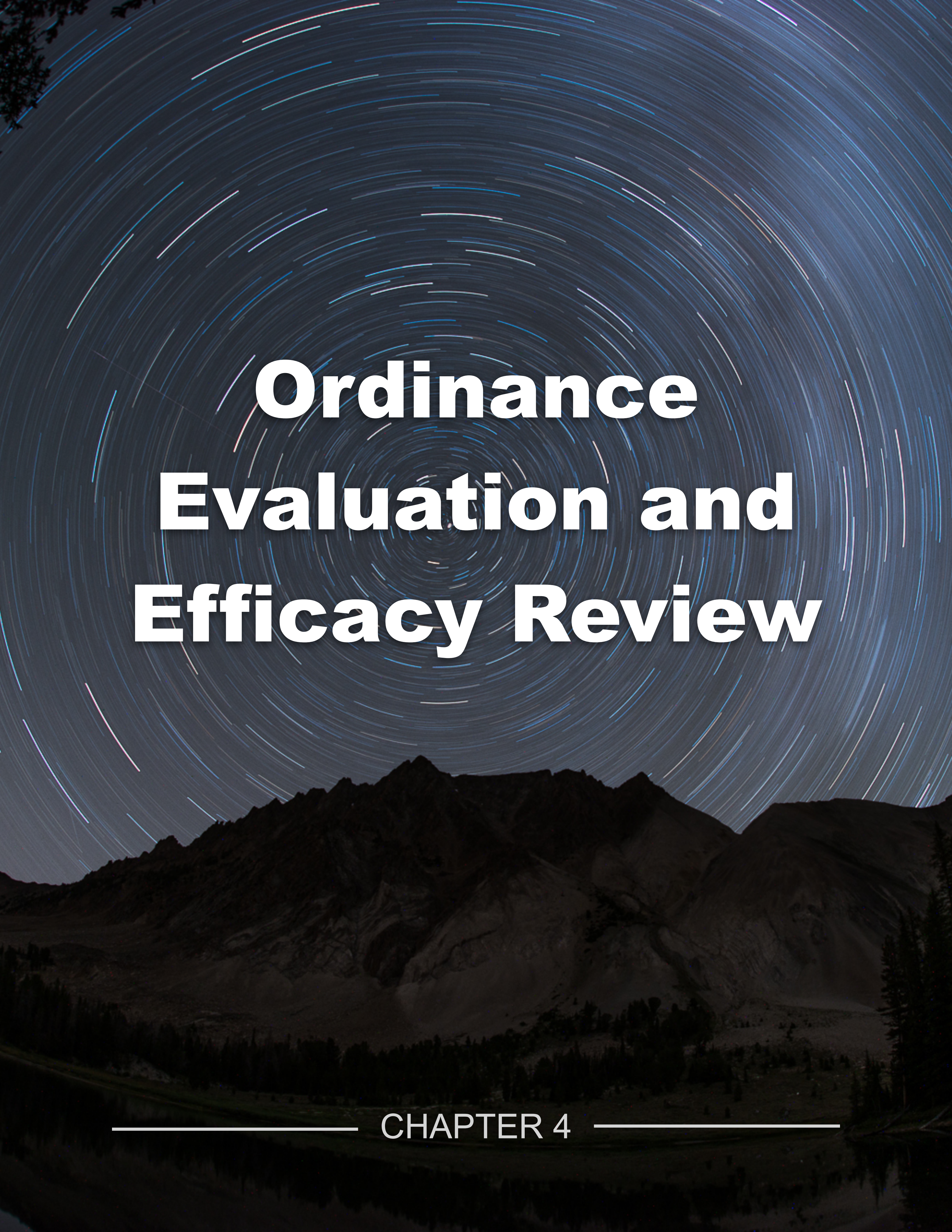



Figure 3.4. Recommended SQC monitoring sites (shown with green circles) within the CIDSR.



# Ordinance Evaluation and Efficacy Review

CHAPTER 4

## Introduction

A necessary aspect of preventing light pollution is the passing, implementation, and adherence to lighting ordinances. While the implementation of lighting ordinances in the area is more recent, the roots of political protection of the region can be traced back to the establishment of the Sawtooth National Recreation Area (SNRA) in 1972 by Congress (idahodarksky.org, 2018). Fast-forward to 1999 with the drafting and passage of the area's first modern lighting ordinance to address the issue of light pollution, Ketchum Ordinance 743. Local dark sky advocates and groups, including Dr. Stephen Pauley (also known as "Dr. Dark" by Ketchum and Sun Valley locals), were instrumental in its creation and implementation, and have continued their work over the past couple of decades to increase awareness for the need of dark skies and beneficial lighting ordinances. Since then, many other towns and cities within the reserve have passed their own Dark Sky Ordinances, while some counties in and around the reserve have included lighting regulations in their local ordinances. Lighting ordinances and specifically designated Dark Sky Ordinances are policies passed at the city or county level to decrease light trespass, skyglow, and light pollution in general. However, there still exist discrepancies between the standards and limits set forth by these ordinances, calling for a more uniform approach to dark sky policy drafting and implementation.

## Methods

During our investigation, we evaluated a total of 10 ordinances that dealt with lighting regulation in some capacity – including six cities or towns and four counties – both in and around the Central Idaho Dark Sky Reserve (CIDSR): Bellevue, Hailey, Ketchum, McCall, Stanley, Sun Valley, Ada County (Unincorporated), Blaine County, Custer County, and Valley County. We selected the most important standards and limits from those ordinances as our criteria for comparison and set the most stringent of those standards and limits as the baseline for comparison.

To help visualize light trends in areas with ordinances, we decided to plot the average summed radiance of these specific locations. The methods used to create the graphs of light pollution trends within the six cities and four counties of interest, as well as background information on relevant data, can be found within chapter 2 of the report. Unique to the policy evaluation is the addition of a date designation for policy implementation on the graphs, if applicable.

## Results

To visualize how current existing lighting ordinances compare to others in the region, we drafted the following tables (Tables 4.1 and 4.2). A green '✓' box indicates the policy fully meets the limit or standard listed, a yellow '~' box indicates the policy partially meets the limit or standard listed, and a red 'X' box indicates the policy does not include a provision addressing the limit or standard listed. We also assigned a numerical value to each notation to create a numerical efficacy rating of each ordinance, where a green '✓' box was worth 2 points, a yellow '~' box was worth 1 point, and a red 'X' box was worth 0 points (Table 4.3). These points were summed and inputted into Table 4.4.

Additionally, the average summed radiance was plotted through the study period of 2013-2020 for the areas with new or existing lighting ordinances. If an ordinance was enacted or updated during our study period, that was denoted as a red line at the time of its passage, as seen below in figure 4.1.

Table 4.1. Policy evaluation of cities and towns.

| Standards and Limits | *Ketchum* | *Sun Valley* | *McCall* | *Bellevue* | *Hailey* | *Stanley* |
|---|---|---|---|---|---|---|
| All Outdoor Lighting Must Be Fully Shielded | ✓ | ✓ | ✓ | ✓ | ✓ | ~ |
| Residential Street Lighting: 1,125 Lumens | ✓ | ~ | ~ | ~ | ~ | X |
| Nonresidential Street Lighting: 1,500 Lumens | ✓ | ~ | ~ | ~ | ~ | X |
| State Highway and Intersection Lighting: 3,000 Lumens | ✓ | ~ | ~ | ~ | ~ | X |
| Uplighting for Flags: 1,300 Lumens | ✓ | ✓ | ✓ | ✓ | ✓ | X |
| Correlated Color Temperature Limit: 2700 K | ✓ | ~ | X | X | X | X |
| Sensor-Activated Timer Limit: 5 Minutes | ✓ | ✓ | ✓ | ✓ | X | ✓ |
| Shielded Floodlights: 25° Angle Limit | ✓ | ✓ | ✓ | ~ | ✓ | ✓ |
| Full-Cutoff Area Lighting: 85° Angle Limit | ✓ | ✓ | ✓ | ✓ | ✓ | X |
| Residential Holiday Lighting: 10:30pm Cutoff | ✓ | ~ | ~ | ~ | ~ | X |

Table 4.2. Policy evaluation of counties.

| Standards and Limits | *Valley County* | *Blaine County* | *Ada County (Unincorporated)* | *Custer County* |
|---|---|---|---|---|
| All Outdoor Lighting Must Be Fully Shielded | ✓ | ✓ | ~ | X |
| Residential Street Lighting: 1,125 Lumens | X | X | X | X |
| Nonresidential Street Lighting: 1,500 Lumens | X | X | X | X |
| State Highway and Intersection Lighting: 3,000 Lumens | X | X | X | X |
| Uplighting for Flags: 1,300 Lumens | ✓ | X | X | X |
| Correlated Color Temperature Limit: 2700 K | ~ | X | X | X |
| Sensor-Activated Timer Limit: 5 Minutes | ✓ | ✓ | ✓ | X |
| Shielded Floodlights: 25° Angle Limit | X | ✓ | ~ | X |
| Full-Cutoff Area Lighting: 85° Angle Limit | X | X | X | X |
| Residential Holiday Lighting: 11pm Cutoff | X | X | X | X |

Table 4.3. Scoring key

| Compliance | Score |
|---|---|
| ✓ | 2 points |
| ~ | 1 point |
| X | 0 points |

Table 4.4. Ordinance scores

| Ordinance | Score (x/20) |
|---|---|
| Ketchum | 20 |
| Sun Valley | 15 |
| McCall | 14 |
| Bellevue | 13 |
| Hailey | 12 |
| Valley County | 7 |
| Blaine County | 6 |
| Stanley | 5 |
| Ada County (Unincorporated) | 4 |
| Custer County | 0 |

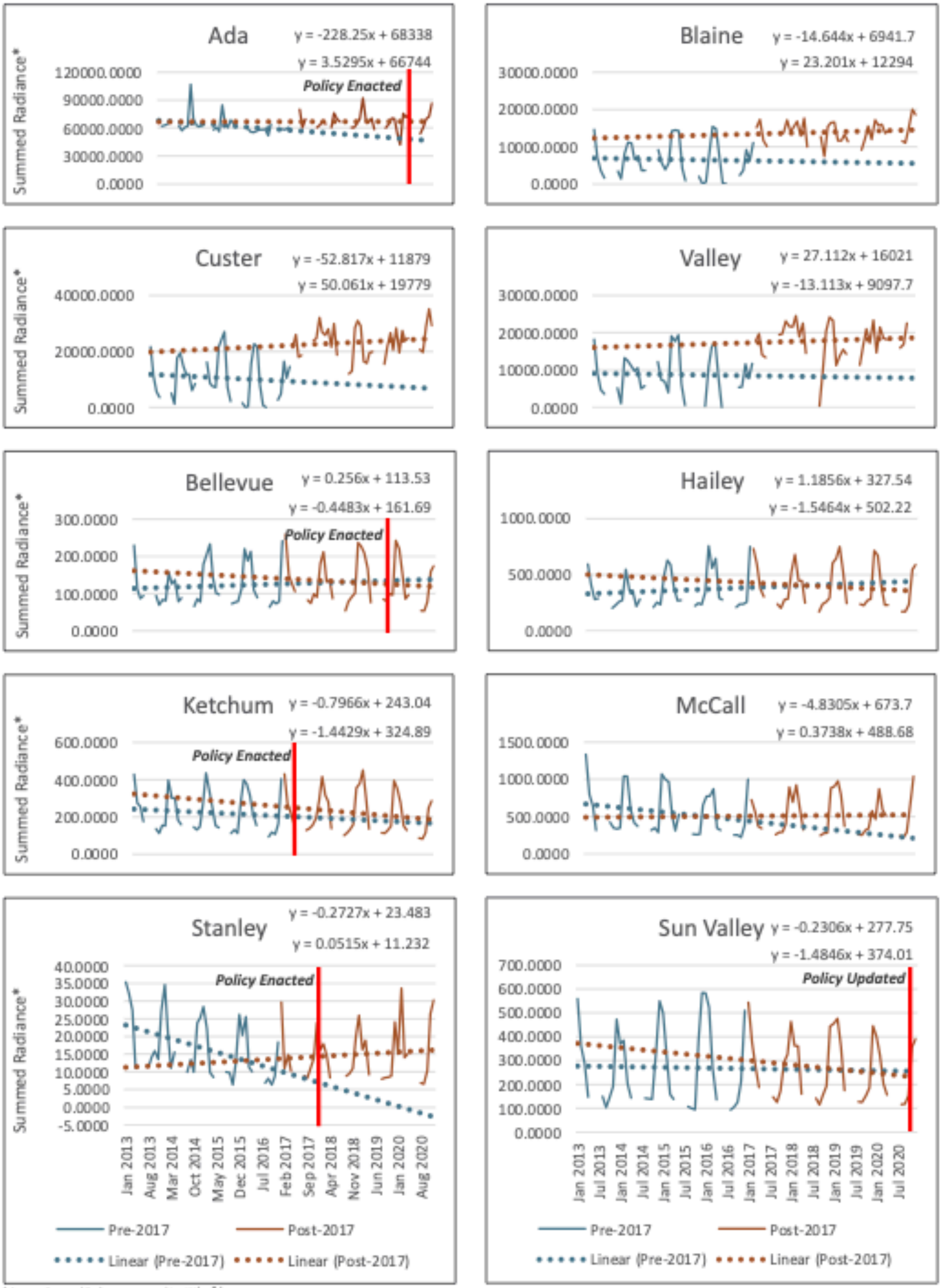
## Discussion

The Ketchum lighting ordinance had the most stringent of standards and limits, which were used to establish the baseline for which other lighting ordinances in the area were compared to – hence Ketchum received a perfect score of 20 points. In general, all cities or towns received a higher score than all of the counties, with the exception of Stanley. Additionally, Custer County received a score of 0, as they did not have any standard or limits explicitly outlined in their lighting ordinance that could be compared to the standards set forth by the Ketchum lighting ordinance. For all clarification on key terms and vocabulary associated with light pollution and dark sky ordinances, refer to Table 4.6.

For our average summed radiance graphs, it is important to keep in mind the varying magnitudes of summed radiance for each graph and the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument's inability to detect shorter wavelengths of light that are common in white LEDs with peak emittance in the blue part of the spectrum. Data were analyzed separately pre-2017 and post-2017 to account for a change in the VIIRS 'zero point,' which is further explained in chapter 2. For the counties, while all seemed to be trending downwards in average summed radiance pre-2017, they have recently begun increasing again post-2017. For towns and cities, both Ketchum and Sun Valley have been continuously decreasing – albeit at different rates – their average summed radiance over the entire study period from 2013-2020. This may indicate effective ordinances from both areas, as they had the two highest ordinance compliance scores from the efficacy review. Both Bellevue and Hailey had upward trends of average summed radiance pre-2017 and downward trends post-2017, while McCall and Stanley had downward trends of average summed radiance pre-2017 and upward trends post-2017. As these four areas have different compliance scores that don't necessarily coordinate with their average summed radiance graphs, this may indicate the need for more uniform and effective lighting ordinances.

## Recommendations

As mentioned previously, the Ketchum lighting ordinance was used to establish a baseline for policy evaluation of other ordinances in the area, given that it contained the most stringent standards and limits. Therefore, to draft new ordinances or fortify existing ones in the region, we drafted the outline below to give a significant foundation that should be included in all new and existing lighting ordinances:




* Average Summed Radiance measured in $nW/cm^2/sr$

Figure 4.1 Average summed radiance graphs of towns, cities, and counties evaluated in the ordinance review. The top slope equation and blue line corresponds to pre-2017 trends and the bottom slope equation and orange line corresponds to post-2017.

- All exterior lighting should be fully shielded and downcast to prevent light trespass.
- Residential street lights should be limited to 1,125 lumens.
- Nonresidential street lights should be limited to 1,500 lumens.
- State highway and intersection lights should be limited to 3,000 lumens.
- Uplighting is prohibited, with the exception of uplighting for governmental flags, which should be limited to 1,300 lumens.
- All exterior lighting should not exceed a correlated color temperature limit of 2700 K.
- Sensor-activated lighting should be timed to automatically deactivate within five minutes.
- Floodlights should be shielded and allow no light escape above a 25-degree angle.
- All area lights should be 85-degree full-cutoff luminaires.
- Residential holiday lighting should be turned off by 10:30 pm.

Additionally, all new and existing lighting ordinances should include penalties for violation. For example, violators should receive formal notification of a lighting violation from the governing body of their local jurisdiction. Upon this formal notification, violators then have 30 days to abate the violation or pay a monetary fine as outlined in their local lighting ordinance.

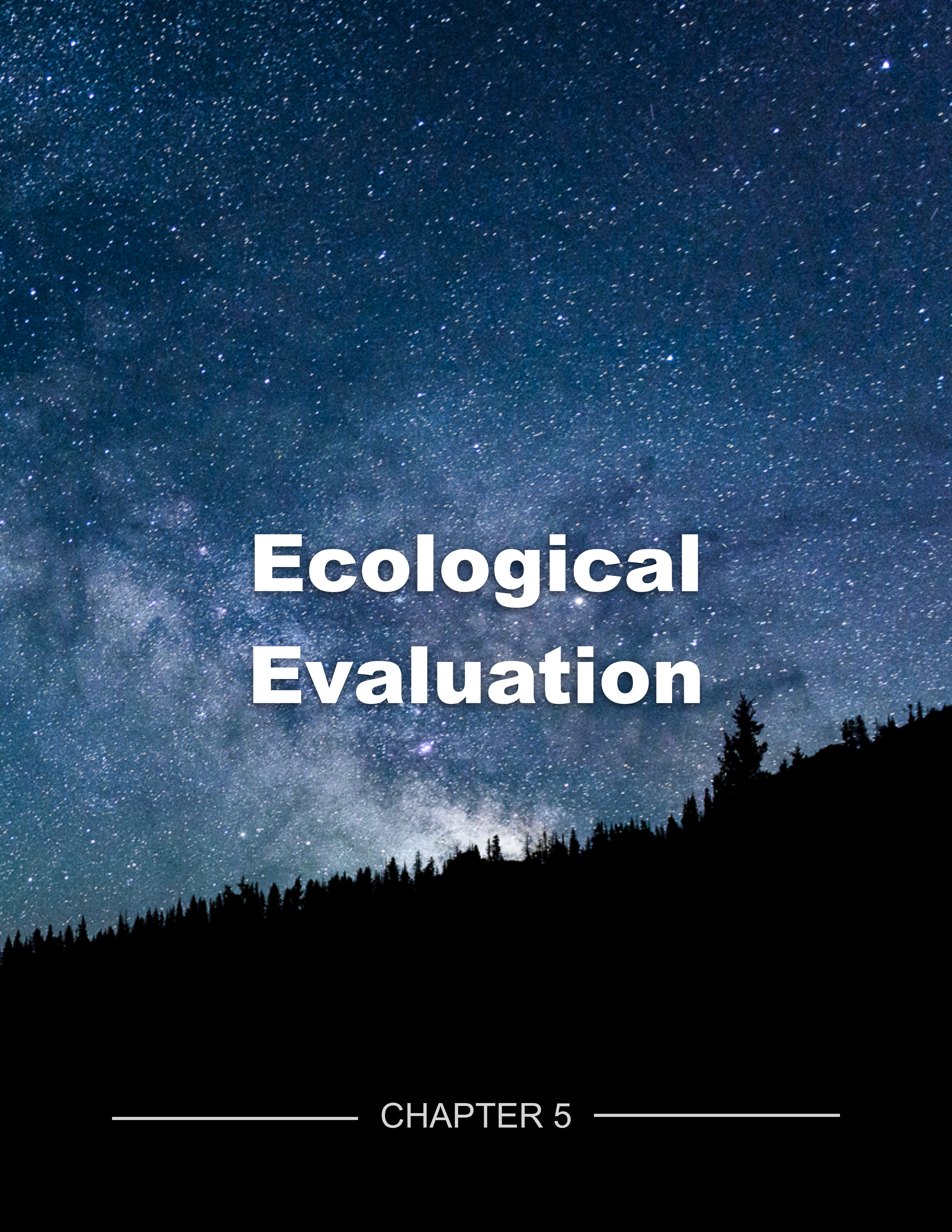
One additional recommendation for towns, cities, and counties both in and around the reserve is the inclusion of a printed copy of the local lighting ordinance upon the sale of residential property. As new residents may not be aware of their local lighting ordinance, a printed copy would provide them with the necessary background and information to educate them on local regulations and prevent possible violations.

These recommendations provide a basis for policy and ordinance improvement for the CIDSR, however, as policies change in the region, so too should this evaluation and review. This study should be updated when an ordinance is updated or newly passed, setting a baseline with the most stringent standards and limits as we previously did with the Ketchum ordinance. This may cause ordinance scores and rankings to change. Average summed radiance graphs should continue to be added to each year as new VIIRS data become available.

Table 4.5. Light pollution and Dark Sky Ordinance definitions (Sun Valley ordinance)

| TERM | DEFINITION |
|---|---|
| **AREA LIGHT:** | A luminaire equipped with a lamp that produces over one thousand eight hundred (1,800) lumens. Area lights include, but are not limited to, streetlights, parking lot lights, and yard lights. |
| **CORRELATED COLOR TEMPERATURE (CCT):** | The characterization of the color content, or spectrum (“warmness” or “coolness”), of a light source measured in Kelvin (K). Lamps with a CCT of less than 3000K are considered “warm.” Lamps with a CCT greater than 4000K are bluish-white and are considered “cool.” |
| **EXTERIOR LIGHTING:** | Temporary or permanent outdoor lighting that is installed, located, or used in such a manner to cause light rays to shine outdoors. Luminaires that are indoors that are intended to light something outside are considered exterior lighting for the purpose of this title. |
| **FLOODLIGHT:** | A light fixture that produces up to one thousand eight hundred (1,800) lumens and is designed to flood a well-defined area with light. |

| | |
|---|---|
| **HOLIDAY LIGHTING:** | Exterior lighting consisting of strings or individual lamps, where the output per lamp is not greater than fifteen (15) lumens. |
| **LIGHT:** | The form of radiant energy acting on the retina of the eye to make sight possible. |
| **LIGHT POLLUTION:** | Any adverse effect of artificial night light including by not limited to, discomfort to the eye or diminished vision due to glare, light trespass, or any man-made light that diminishes the ability to view the night sky. |
| **LIGHT TRESPASS:** | Light falling on the property of another or the public right-of-way when it is not required to do so. |
| **LIGHTING:** | Any or all parts of a luminaire that function to produce light. |
| **LUMEN:** | The unit used to quantify the amount of light energy produced by a lamp at the lamp. Lumen output of most lamps is listed on the packaging. For example, a sixty (60) watt incandescent lamp produces nine hundred fifty (950) lumens while a fifty-five (55) watt low pressure sodium lamp produces eight thousand (8,000) lumens and a fifteen (15) watt LED bulb produces ninehundred (900) lumens. LED bulbs are eighty percent (80%) more efficient than incandescent lighting. |
| **LUMINAIRE:** | A complete lighting unit, consisting of lamp or lamps together with the parts designated to distribute the light, to position and protect the lamps, and to connect the lamps to the power. When used, it includes ballasts and photocells. Commonly referred to as “fixture.” |
| **LUMINAIRE, EIGHTY-FIVE DEGREE CUTOFF TYPE:** | Luminaires that do not allow light to escape from above an eighty-five-degree angle measured from a vertical line from the center of the lamp extended to the ground. |
| **LUMINAIRES, FULL CUT OFF:** | A luminaire designed and mounted level where no light is emitted at or above a horizontal plane running through the lowest point of the luminaire. |
| **LUMINAIRES, FULLY SHIELDED:** | The luminaire incorporates a solid barrier (the shield), which permits no light to escape through the barrier on the top and sides of the fixture. |
| **LUMINAIRES, UNSHIELDED:** | The luminaire only incorporates clear glass, which permits all light to escape. |
| **UPLIGHTING:** | Fully shielded lighting that is directed in such a manner as to shine light rays above the horizontal place. |



# Ecological Evaluation

CHAPTER 5

## Introduction

The International Dark-Sky Association (IDA) reports that artificial light at night (ALAN) can have negative and deadly effects on species ranging from amphibians, birds, mammals, insects, and plants (IDA, 2021). Studies have shown ALAN can alter animal behavior, which can then lead to ecosystem changes (Bennett & Hale, 2014). The disruptions caused by ALAN and the extent organisms and ecosystems are affected depend on the characteristics of species and the characteristics of lights – such as duration, intensity, and spectral wavelength (Longcore & Rich, 2016). Disruptions mainly fall under the following categories: spatial orientation (e.g. attraction, repulsion, disorientation), circadian rhythms and other natural cycles (e.g. reproduction, migration), photosynthesis, and ecological interactions (e.g. pollination, niche partitioning, predator-prey dynamics). Freshwater fish are one type of organism that experiences deleterious effects from ALAN.

Idaho is currently facing a challenge. Multiple fish species are declining in population, and Idaho relies heavily on fish to bring in visitors that bolster the economy and also to maintain the cultures and livelihoods of the indigenous population. There are many possible reasons for this decline, including but not limited to the construction of dams, overfishing, and the pollution of rivers and lakes. In this section, we will introduce the idea that fish decline in Idaho could be in part attributed to ALAN, and explore ways that the Central Idaho Dark Sky Reserve (CIDSR) could expand its outreach and put a spotlight on wildlife conservation.

This section aims to create an understanding of the dynamics between light pollution, wildlife, and human interests. In choosing to focus on freshwater fish, we hope to appeal to a larger audience. Those who are interested in preserving wildlife and/or the night skies, as well as people who have no knowledge of either of these things could possibly find common interests in the following section. Idaho is a state that hosts a multitude of game fish that attracts anglers of all skill levels. Thus, we hope that in creating this assessment, we can engage as many people as possible with the goals and concerns of the reserve.

## Importance of Fish

While many species reside in Idaho that can be negatively affected by artificial light, perhaps the most culturally and economically significant are freshwater fish. Popular game fish in Idaho include salmon, trout, perch, and catfish. Five fish species are currently on the Idaho list of endangered and threatened species: Kootenai River white sturgeon (*Acipenser transmontanus*), bull trout (*Salvelinus confluentus*), steelhead trout (*Oncorhynchus mykiss irideus*), sockeye salmon (*Oncorhynchus nerka*), and Chinook salmon (*Oncorhynchus tshawytscha*) (fws.gov; blm.gov; “Fishing,” 2020). An increase in ALAN can be harmful to the wellbeing of freshwater fish, which could negatively impact the economy of Idaho. Across Idaho spans 26,000 miles of rivers and streams, 250,000 acres of reservoirs and ponds, and over 3,000 natural lakes populated by 42 species of game fish (“Fishing,” 2020). In 2003, Idaho’s economy gained $438 million in revenue from anglers visiting Idaho to fish. This money is spread across transportation, room and board, and equipment and tackle (“Survey…,” 2020). Fish in Idaho are not only important economically, but also hold cultural significance to local tribes. Many fish are food staples to the Kootenai tribe – including trout, salmon, and sturgeon – and were heavily utilized for cultural and subsistence purposes. To the Kootenai, these fish hold special importance to their health, culture, and economy, as this tribe uses the fish not only for food but also for trade, fuel, and animal feed. (epa.gov).

## Threat to Fish

The Snake River, a major tributary of the Columbia River, is one of the most important rivers in Idaho. The river once garnered large quantities of wild steelhead trout and salmon – at one point producing over 1.5 million Chinook salmon (National Marine Fisheries Service, 1991). However, wild fish populations in Idaho have been nearly destroyed due to issues associated with urbanization. Without proper protection and mitigation, it is projected that all runs of wild salmon and steelhead trout on the Snake River may become extinct (Mckean et al., 2011).

Artificial lighting is not the most pressing issue threatening fish in Idaho. We are focusing on light because the main goal of the CIDSR to reduce light pollution, but the threats to the fish are more nuanced and complicated. In fact, fish decline is more likely due to an amalgamation of many factors including ALAN, the building of dams, water pollution, and overfishing. In this context, we plan to solely discuss light pollution and recommend ways to combat it in the favor of fish, but this is one step in a multi-faceted solution to the conservation of freshwater fish.

Though fish are adapted to natural night lighting sources such as moonlight, starlight, and bioluminescence, artificial lighting – which can span over hundreds of miles – illuminates the night sky in a way fish are not acclimated to (Nightingale et. al., 2006). Changes in the intensity, frequency, and duration of nighttime light fish are exposed to can impact their spatial distribution, predator-prey interactions, foraging behavior, and migration and reproduction timing. In salmon specifically, light at night has been shown to slow and even halt natural migrations and alter swimming activity. Juvenile salmon tend to migrate at night. Although greater levels of illumination can potentially increase foraging opportunities for them, they can also put salmon at a much higher risk of predation from larger fish and birds (Tabor et. al., 2017). Though increased predation is a large concern for freshwater fish, the effects of ALAN expand further than that. Not only does ALAN make salmon more visible to predators, but the salmon are also attracted to light and will aggregate at these light sources rather than continue their migration (Nightingale et. al., 2006). Additionally, Brüning et. al. found that even a small amount of light from the moon can suppress melatonin levels in the perch species, which in turn suppresses necessary reproductive hormones (Brüning et al., 2018). Though reproduction in these fish is seasonal and not solely influenced by melatonin production, the study did reveal ALAN disturbed reproductive cycles. This reveals how sensitive hormonal responses in many fish species are to light. ALAN severely disturbs the seasonal natural ambient light changes necessary for fish to release the hormones and sex steriods that aid in reproduction (Brüning et al., 2018).

## Lighting Sources

Light can come from many structures, especially in urban areas. Sources include street lights, residential and commercial buildings, as well as bridges and dams (Tabor et. al., 2017). Near bodies of water, additional light can also originate from fisheries. Bridges in particular tend to have bright lights that shine directly into bodies of water during the night. The Sundial Bridge above the Sacramento River in Redding, California is an example of the dangers lighting over rivers can pose. For instance, the underside of the bridge was equipped with 240 lights. The lights were said to be constructed to point to the air to address concerns about effects on the salmon migrating underneath (Arthur, 2013). However, the Department of Fish and Wildlife (DFW) found that two-thirds of the lights were pointed into the water, and much of the light was actually reflecting off the bottom of the bridge into the water (Arthur, 2013). Light pollution was attributed to contributing to the near loss of Sacramento River Chinook salmon. Since the bridge's installation in 2004, the number of Chinook salmon returning to spawn significantly decreased from over 15,000 individuals to just over 800 in 2011 (Arthur, 2013). This light could halt the migration of Chinook salmon in the Sacramento River and increase predation risk. Where the light points may be one issue, but the level of illumination is another issue altogether. The DFW found that the illumination needed to protect the fish is somewhere between 1.5 and 3 lux (lumens per square meter), but from the edge of the water, the illumination from the bridge lights measured 25.55 lux (Arthur, 2013). This example serves as a cautionary tale about how the excess use of artificial lighting can severely impact fish abundance.

## Conclusion

It is important to note that light at night is not the most dramatic or urgent danger to fish, but it is definitely a contributing factor to their decline, as outlined above. For species already struggling to survive due to the presence of dams impeding their migration, the effects of light pollution can be even more detrimental. With this in mind, places like the CIDSR should be the optimal places for fishing. However, there have not been any comparative studies that can support this idea. But if these fish encounter dams, predators, and bright lights on their journey, they may be less likely to return the following years.

Work is already being done to combat the construction of dams in rivers such as the Snake River, which directly impedes the migration of salmon and indirectly affects their saltwater predators. With this in mind, we are aware that preserving fish in Idaho is a priority for many people. It is in the interest of anglers, hunters, and wildlife enthusiasts alike to preserve night skies, else their hobbies and ways of life might be affected. We hope to convince those that are passionate about fish that ALAN is another contributor to their decline, and action must be taken to preserve dark skies for the wellbeing of fish, the career and leisure of anglers, the passion of environmentalists, and quality of life for all living things. The dark skies should thus be a priority for many people, even those unaffiliated with Dark Sky Reserves.

## Recommendations

Given the amount of research present stating the harms of light pollution on fish coupled with the great importance of fish in Idaho, the CIDSR is presented with an opportunity to expand its outreach. We recommend that the CIDSR's educational mission include preservation of wildlife. The reserve can do this in many ways. First, by utilizing its location to attract researchers and conservationists, as well as those with a passion for fishing or wildlife. Most of the endangered fish species previously mentioned reside within the boundaries of the reserve, and are thus perfect candidates for research and education. Another direction that the reserve can take is to use fish as ambassador species. With the research clearly stating that ALAN is harmful to fish species, the reserve can advocate to protect fish and keep waterways free of light pollution, which will hopefully gain plenty of support (fish are dear to Idahoans). In doing so, the reserve will also be directly benefiting other species, as a dark night sky is beneficial to all living things.

# Astrotourism Potential

CHAPTER 6

## Introduction

As global human-derived environmental change continues to alter the world's landscape, ecotourism – the act of visiting threatened natural environments to connect with wildlife and support conservation efforts – is gaining popularity. Ecotourism is becoming increasingly prominent because it emphasizes the importance of balancing economic, sociocultural, and environmental sustainability (Kanianska et al., 2020). Astrotourism is a form of ecotourism focused on the observation of celestial phenomena in the night sky. An advantage of astrotourism is that its major attraction, the night sky, does not require maintenance or equipment since it exists naturally. However, the quality of the night sky makes a large difference in the astrotourism experience because it greatly affects the visibility of celestial phenomena (Kanianska et al., 2020). Unfortunately, night skies are extremely sensitive to a variety of anthropogenic influences. Ecotourism often occurs in rural or remote areas where there are more open, natural areas that are not as populated. The COVID-19 pandemic has caused an increased interest in rural tourism, and this interest is expected to increase in the future (Kanianska et al., 2020).

Current astrotourism opportunities in the Central Idaho Dark Sky Reserve (CIDSR) are communicated with the public mainly through the reserve website, which contains numerous resources that help connect visitors to the reserve and dark sky events. The 'Programs and Events' section details that the CIDSR cooperates with local organizations to host star-gazing events and astronomy programs. These local organizations include the Sawtooth Association, Hailey Public Library, and Sawtooth Botanical Garden. All of their individual websites are linked to the CIDSR website so visitors can find their upcoming presentations. The CIDSR website also lists all the celestial events that will occur during the current year – such as the dates for new moons, meteor showers, and lunar eclipses. Instructions on how to drive to the reserve, as well as possible flights to Sun Valley are listed. The CIDSR Annual Report, which compiles the print, radio, and online articles that have featured the reserve, is available for the years 2018-2020. Lastly the CIDSR brochure and map of the reserve are both linked to the website.

The reserve spans over a very large region and overlaps with multiple areas of national forest, so planning a visit to the reserve can be overwhelming for first-time visitors who have never been stargazing. Existing resources do not inform visitors who are unfamiliar with the region of where exactly on the reserve they should go in order to maximize their night sky viewing experience.

Visitorship and its economic benefits could be improved by synthesizing and sharing astrotourism resources. We assessed the astrotourism potential at the CIDSR by creating maps for different types of users, compiling favorite locations from local experts for astrophotographers, and reaching out to businesses to inventory existing promotions for astrotourism in the hospitality industry. Finally, we will make recommendations about increasing and tracking eco/astrotourism going forward.

## Methods: Astrotourism Suitability Model

A suitability model is a visualization used to identify the best locations to station something or the most suitable regions to conserve. To establish the ideal location for any activity, various features that affect the location and activity must be taken into account. These features are used as the criteria for assessing suitability. A suitability map ultimately describes the relative preference of each area based on the features at that location (Esri n.d.). Drawing on this concept, our objective was to develop a spatial model to evaluate astrotourism suitability at the

CIDSR based on criteria originally developed by Kanianska et al. in 2020 to evaluate astrotourism suitability in Europe. The factors included in the study by Kanianska et al. were night sky brightness, elevation, number of clear days, possibility of a professional guide, vehicle accessibility, proximity to food and accommodation facilities, and proximity to other tourism units. Using this approach, we developed two maps for astrotourism suitability, one for casual tourists and one for specialists in astrophotography and nightscape photography.

We created two suitability models to assess the potential for astrotourism within the CIDSR. Similar parameters and methods of preparation were used for both models. The parameters included in the tourist model were restrooms/campsites, restaurants/hotels, main roads, and night sky brightness. The parameters included in the specialist model were restrooms/campsites, restaurants/hotels, main roads, small paths, and night sky brightness. The data and preparation for the model follow.

### *Data Sources and Preparation*

The data layers used to create the suitability model include restrooms/campsites, restaurants/hotels, main roads, small paths, and night sky brightness. Data sources and preparation specifications for each layer are detailed in table 6.1.

In order to perform the analysis only over the extent of the reserve, each data layer was first clipped to the shape of the CIDSR. In addition, to standardize the units for each layer, they were reprojected from their original coordinate system to WGS 1984 World Mercator, which has a

Table 6.1. Suitability model data layers, their sources, and preparation method.

| DATA LAYER | SOURCE | PREPARATION |
|---|---|---|
| **Restrooms/ campsites** | Sawtooth National Forest | Area within 640,000 m2 area around point reclassified as 1. Other areas reclassified as 0. |
| **Restaurants /hotels** | Created Google Maps coordinates | Reclassified closer distances with higher scores. |
| **Main roads** | State of Idaho GIS Hub | Tourist: reclassified closer distances with higher scores.<br>Specialist:reclassified farther distances with higher scores. |
| **Small paths** | USGS | Tourist: N/A<br>Specialist: reclassified closer distances with higher scores. |
| **Night sky brightness** | New World Atlas of Artificial Night Sky Brightness (Falchi et al., 2016) | Reclassified darker areas with higher scores. |
| **DATA LAYER** | SOURCE | PREPARATION |
| **Restrooms/ campsites** | Sawtooth National Forest | Area within 640,000 m2 area around point reclassified as 1. Other areas reclassified as 0. |
| **Restaurants /hotels** | Created Google Maps coordinates | Reclassified closer distances with higher scores. |

linear unit of meters. Lastly, when using the “Euclidean distance” tool, which will be further detailed later, the processing extent on ArcMap was changed to the extent of the CIDSR under Geoprocessing → Environments → Processing Extent → Extent is the CIDSR Boundary on ArcMap.

### *Campsites/Restrooms*

To prepare the campsites/restrooms layer for analysis, the data for recreational sites in the Sawtooth National Forest was first obtained from the GIS analyst of Sawtooth National Forest. In order to select the campsites, the ‘MarkerActi’ field was queried for ‘Campground Camping’ and this layer with only campsites was exported. Based on observations from Google Maps, we estimated that, on average, the campsites had a square shape and measured about 800 meters across. A circular buffer with a diameter of 800 meters was first made around each campsite using the ‘Buffer’ tool, then these circular buffers were made into square buffers using the ‘Feature envelope to polygon’ tool. To eliminate unnecessary data, the overlapping buffers were all dissolved into one polygon with the ‘Dissolve’ tool. Finally, to reclassify the buffered areas as suitable with a value of 1 and anywhere else on the reserve as not suitable with a value of 0, the ‘Feature to raster’ tool was used and the expression ‘Con(IsNull("buffer_raster"),0,"buffer_raster")’ was entered.

### *Restaurants/Hotels*

To prepare the restaurants/hotels layer for analysis, the ‘Euclidean distance’ tool was used to calculate the Euclidean distance of each cell to the closest restaurant/hotels. The ‘Reclassify’ tool was then used to classify the various ranges of distances by natural breaks (Jenks) into suitability scores, with the closer ranges receiving a higher score. Natural breaks was chosen as the classification method in order to encompass the greatest range of variation, as classes are created to group similar values together and maximize differences between classes (Esri n.d.).

### *Main Roads*

To prepare the main roads layer, the ‘Euclidean distance’ tool was used to calculate the euclidean distance of each cell to the closest main road. The ‘Reclassify’ tool was then used to classify various ranges of distances into suitability scores by natural breaks.

### *Night Sky Brightness*

The night sky brightness layer was reclassified using the ‘Reclassify’ tool to classify various ranges of brightness into suitability scores by natural breaks.

### *Dirt Paths*

To prepare the small dirt paths layer, the ‘Euclidean distance’ tool was used to calculate the euclidean distance of each cell to the closest dirt path. The ‘Reclassify’ tool was then used to classify various ranges of distances into suitability scores by natural breaks.

## Tourist vs. Specialist Model Specification

The restrooms/campsites, restaurants/hotels, and night sky brightness layers were processed the same way for both models. The scores for the main roads layer were flipped for the tourists and the specialists – with shorter distances receiving higher scores for the tourist model and

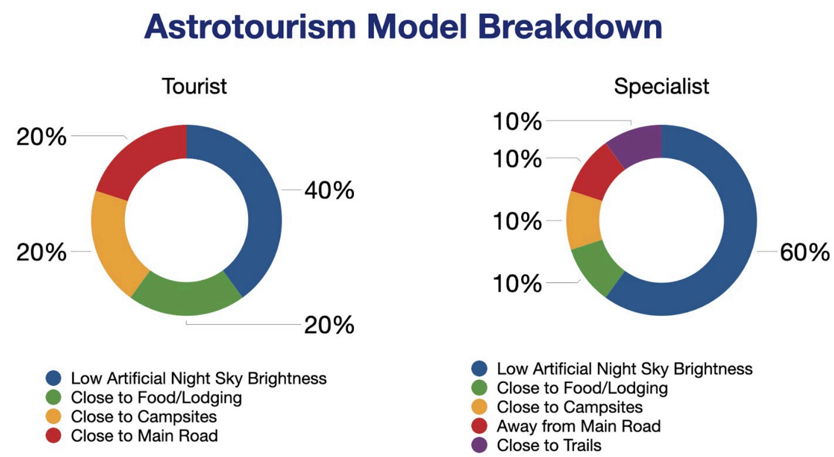



Figure 6.1. Tourist and Specialist Model Breakdown for Astrotourism Potential. The specialist model places a greater emphasis on the quality of the night sky, while the astrotourism model places a greater emphasis on proximity to accommodations and road accessibility.

greater distances receiving higher scores for the specialist model. This distinction was made because specialists should stay farther away from the main roads to avoid excess lighting, whereas tourists may need more access to main roads. The last point of difference between the processing of the layers was that the specialist model included the dirt paths layer, while the tourist model did not. Being able to traverse dirt paths could allow photographers to get to more remote areas and take better photos, but would make no difference to tourists because they are unlikely to use these paths.

### *Tourist Model*

The tourist model includes three anthropogenic factors (proximity to campsites/restrooms, proximity to restaurants/hotels, and proximity to main roads) and one natural factor (night sky brightness). For this model, the anthropogenic factors were weighted 60% and the natural factor was weighted 40% because casual tourists such as families would need to rely more heavily on the comfort of anthropogenic accommodations in such a remote area. The tourist model breakdown was calculated as follows:

60% Accommodations
- Proximity to campsites/restrooms (20%)
- Proximity to restaurants/hotels (20%)
- Proximity to main roads (20%)

40% Natural
- Night sky brightness (40%)

### *Specialist Model*

The specialist model includes four anthropogenic factors (proximity to campsites/restrooms, proximity to restaurants/hotels, distance from main roads, and proximity to small dirt paths) and one natural factor (night sky brightness). For this model, anthropogenic factors were weighed 40% and the natural factor was weighed 60% because photography specialists would place more value on darker skies to capture better photographs. The tourist model breakdown was calculated as follows:

40% Accommodations

- Proximity to campsites/restrooms (10%)
- Proximity to restaurants/hotels (10%)
- Distance from main roads (10%)
- Proximity to small dirt paths (10%)

60% Natural

- Night sky brightness (60%)

## Results: Astrotourism Suitability

By looking at the suitability maps (figures 6.2 and 6.3), we can clearly see what type of factors received more weight. The more suitable areas on the tourist map run down the middle of the reserve along the main road because many of the establishments that provide accommodations like hotels and restaurants are close to the main road. Having these accommodations within an accessible distance would make traveling in an unfamiliar place much easier for tourists. The most significant factor in the specialist model was night sky brightness, which is clearly reflected in the map. The more suitable areas on the specialist map are distributed fairly evenly aside from the cities that give off more light, such as Ketchum and Sun Valley. A notable similarity between the two maps is the positive effect of campsites/restrooms on suitability. The small green boxes are the buffer zones around the campsites/bathrooms, which have high suitability values on both maps.

## Photography Locations

Astrophotography is a type of photography that focuses on astronomical objects such as stars, the moon, and the Milky Way. Astrophotography can be done recreationally or professionally. Astrophotographers often strive to find a location that is not obstructed by hills, buildings, or light pollution. For this reason, the CIDSR is a very popular astrophotography site. A gallery of photos that were taken on the Reserve can be found on the reserve's website. As access to cameras is now more widespread, and public interest in outdoor activities has increased dramatically during the COVID-19 pandemic, spreading awareness of astrophotography may help it to gain popularity. This would benefit Dark Sky Reserves by both increasing patronage and bringing to light the issue of light pollution.

To obtain the best locations for nightscape photography and astrophotography, we contacted local photographers Travis Amick and Nils Ribi. The photography coordinates they shared were organized by the optimal season to take pictures at each location. There were four different categories of seasons: Spring - Fall, Summer, Summer - Fall, and Year-round. The coordinates for each season were inputted into separate Excel files and converted to a comma-separated values (CSV) files. To import the coordinates into ArcMap, we went to File → Add Data → Add XY Data, and selected a CSV file containing the coordinates. The geographic coordinate system was changed to WGS 1984 to match the rest of the data. This process was done four times to import the CSV files for all four categories into ArcMap.

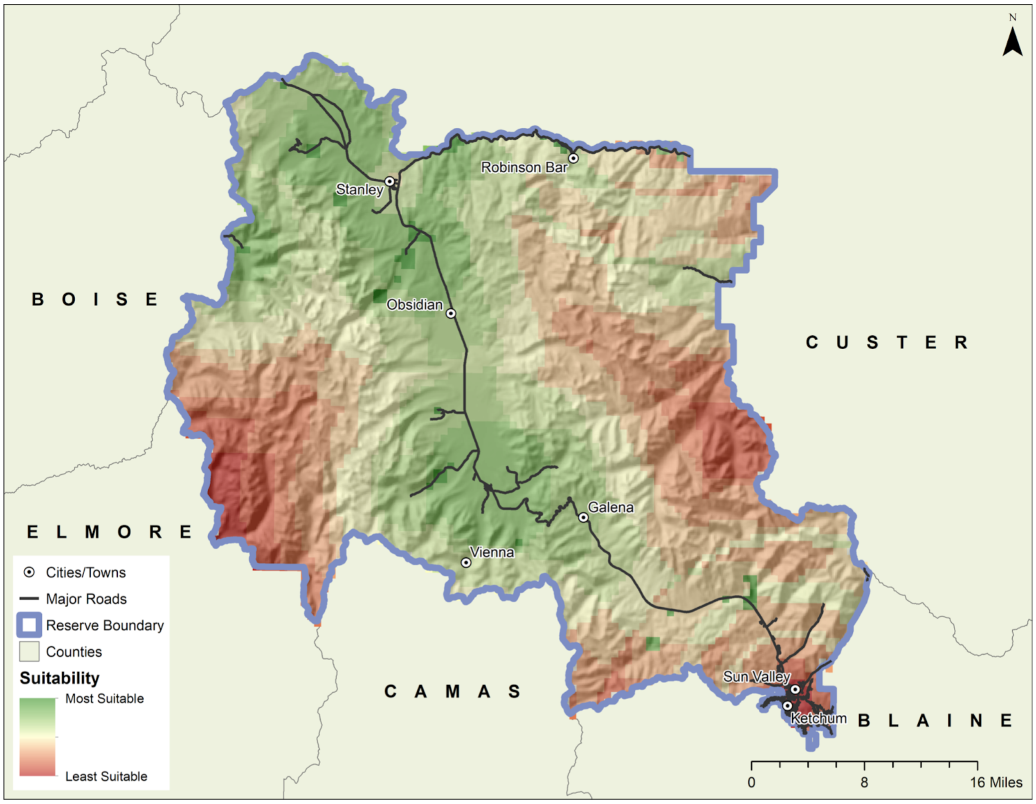



Figure 6.2. Suitability map for tourist-level astrotourism or nightscape photography.

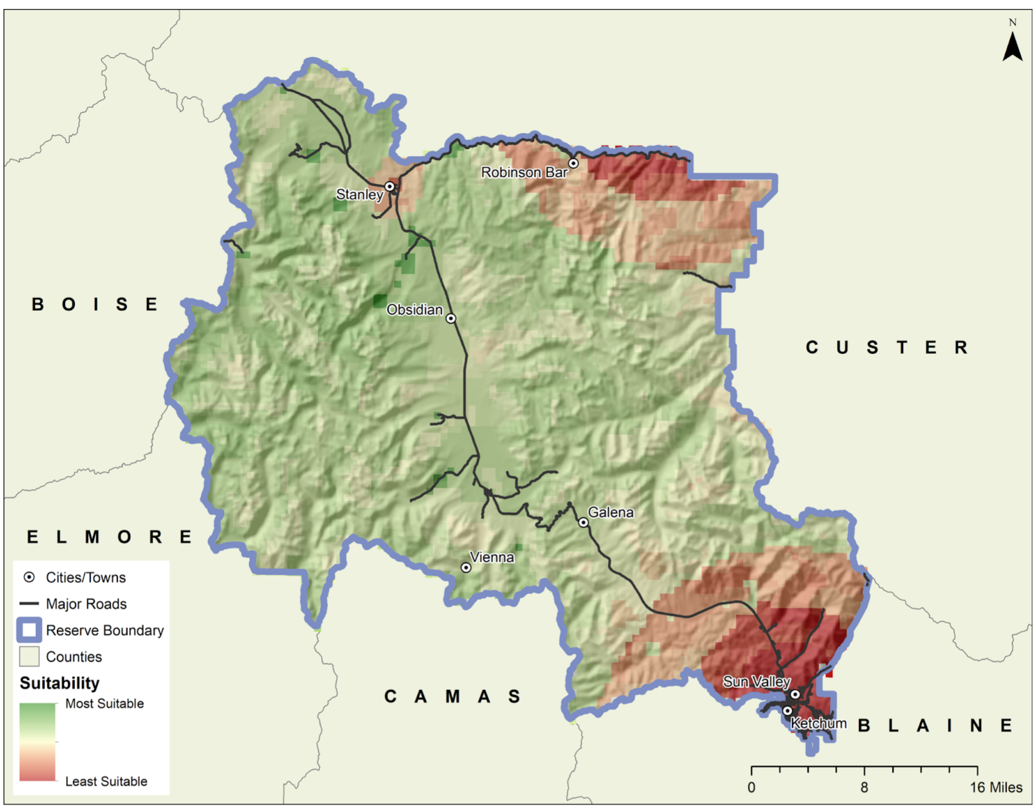



Figure 6.3. Specialist-level suitability map for astrotourism and nightscape photography.

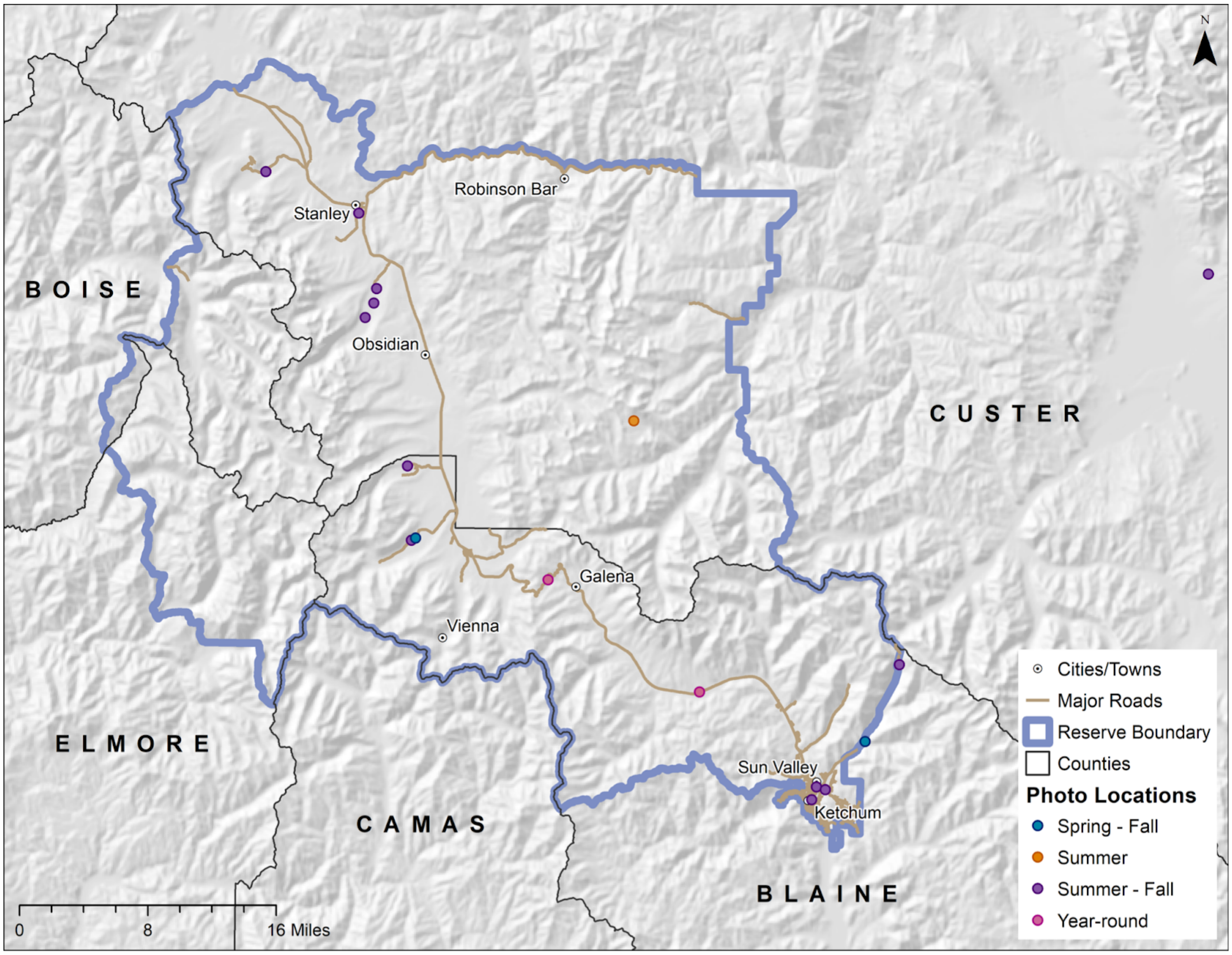



Figure 6.4. Map of the best photography locations by season in and around the reserve.

### *Specialist Suitability Map vs. Photography Locations Map*

It is important to make the distinction between nightscape photography and astrophotography. With astrophotography, it is paramount to have as little light intrusion/pollution as possible because astronomical objects and celestial events are being directly photographed. Nightscape photography is simply photographing the landscape at night and artificial lighting can often make the composition more interesting. By comparing the specialist suitability model map and the map for best photography locations on the reserve, many of the photography locations are in 'unsuitable' areas on the suitability map. The reason for this is that the specialist model took into account the preferences of astrophotographers who require the least amount of light. However, shooting at these locations can capture artificial lighting in contrast with the night sky and produce great nightscape photographs.

## Night Sky Brightness, Elevation, and Important Points

We created three maps to better visualize night sky brightness, elevation, and important locations on the CIDSR (figures 6.5-6.7). These maps can be useful for astrotourists and astrophotographers of any experience level to learn about the region and identify places or routes of interest in and around the reserve.

| DATA LAYER | SOURCE | PREPARATION |
|---|---|---|
| **CIDSR** | Blaine County | N/A |
| **Counties** | TIGER/Line | N/A |
| **Dirt Trails** | USGS | N/A |
| **Elevation** | University of Idaho Geocatalog | Adjusted transparency so values of 0 (null) were 100% transparent rather than black. |
| **Night Sky Brightness** | New World Atlas of Artificial Night Sky Brightness (Falchi et al., 2016) | Set the maximum and minimum brightness values to +/- 0.5 standard deviation, respectively to make relatively dark but artificially lit areas near the reserve more visible. |
| **Restaurants & Hotels** | Created from data on Google Maps | Identified and marked restaurants, hotels, motels, and lodges within the CIDSR on Google Maps; downloaded the layer as a KMZ file; converted to a CSV; uploaded it into QGIS. |
| **Restrooms/ Campsites** | Sawtooth National Forest | N/A |
| **Roads** | USGS | N/A |

Table 6.2. Night sky brightness, elevation, and important point data layers, their sources, and preparation method.

### *Data Sources and Preparation*

The data layers used to create the above maps include night sky brightness, elevation, locations of restaurants and overnight stays, campsites, dirt trails, roads, the CIDSR, and counties, each projected to NAD83/Idaho Transverse Mercator (EPSG:8826). Each layer was clipped to the boundaries of Idaho (night sky brightness and elevation maps) or the CIDSR (important points map).

The points included on the points map are major locations of restaurants and hotels (in larger city centers - Ketchum, Sun Valley, and Stanley - we mapped only a few central points rather than every individual point), campsites, dirt paths, and roads. Data sources and preparation specifications for each layer are detailed in table 6.2.

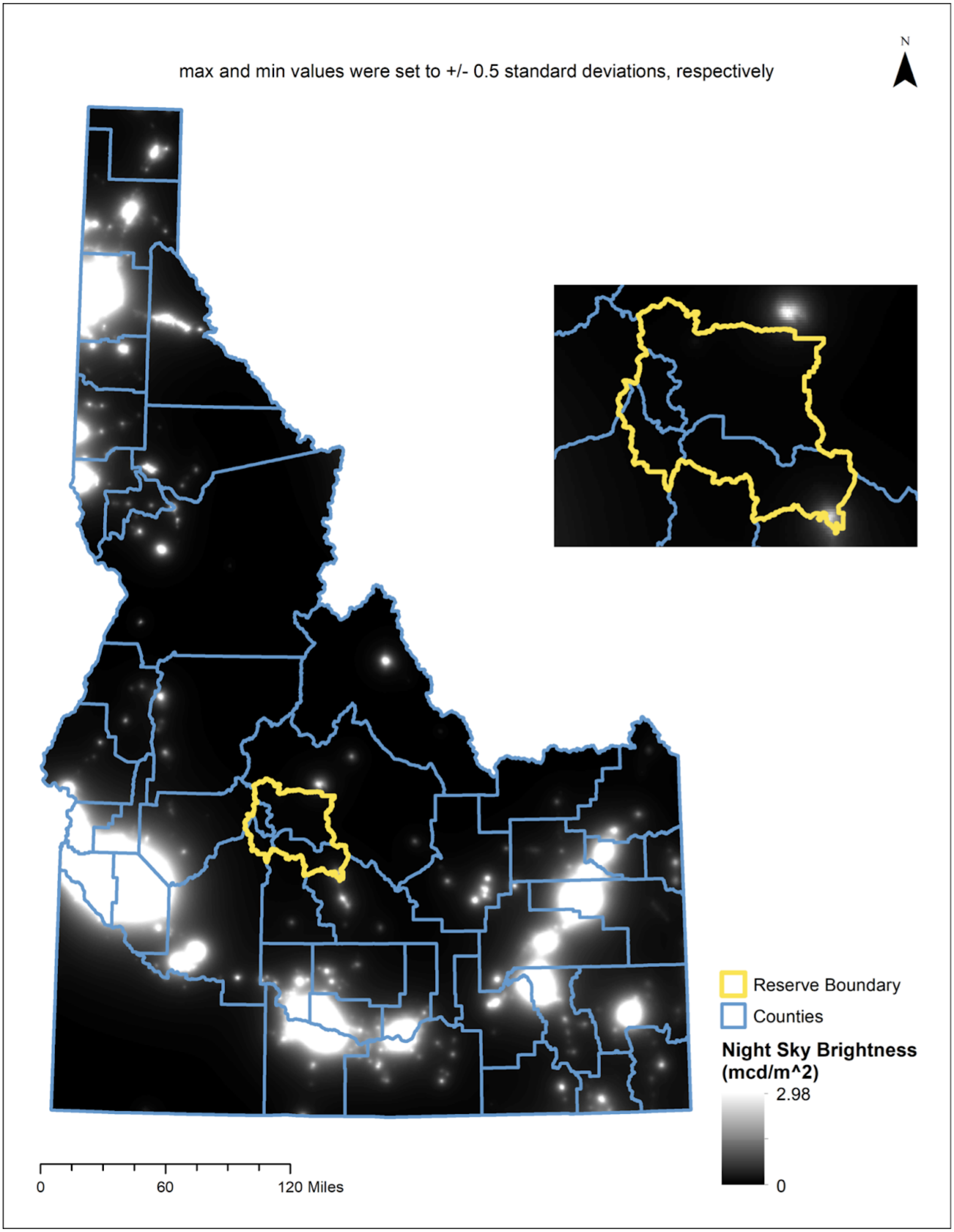



Figure 6.5. Map of night sky brightness in and around the reserve (in mcd/m2). To aid in visualization, maximum and minimum brightness levels were set to +/- 0.5 standard deviations.

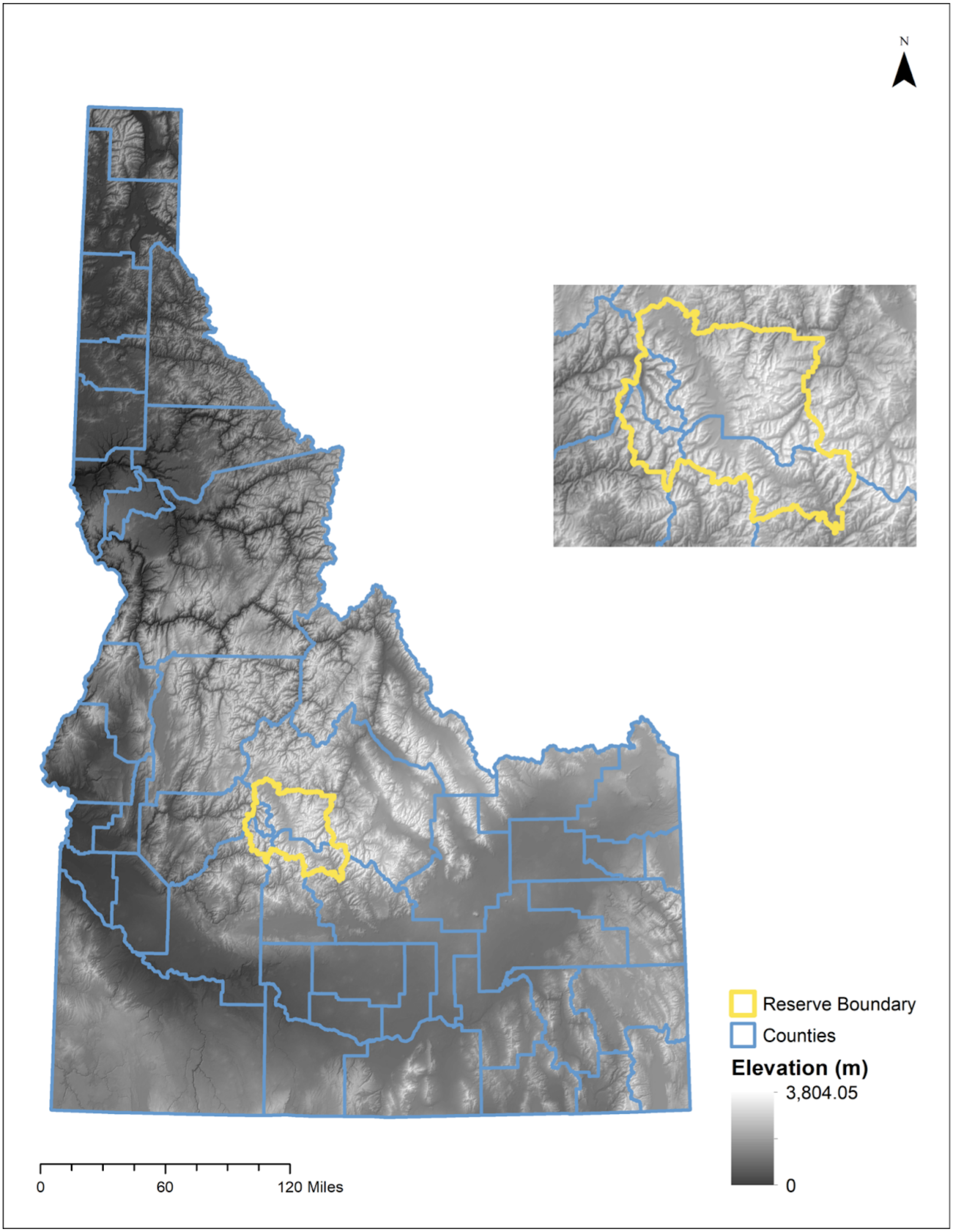



Figure 6.6. Map of the elevation (in m) in and around the reserve.

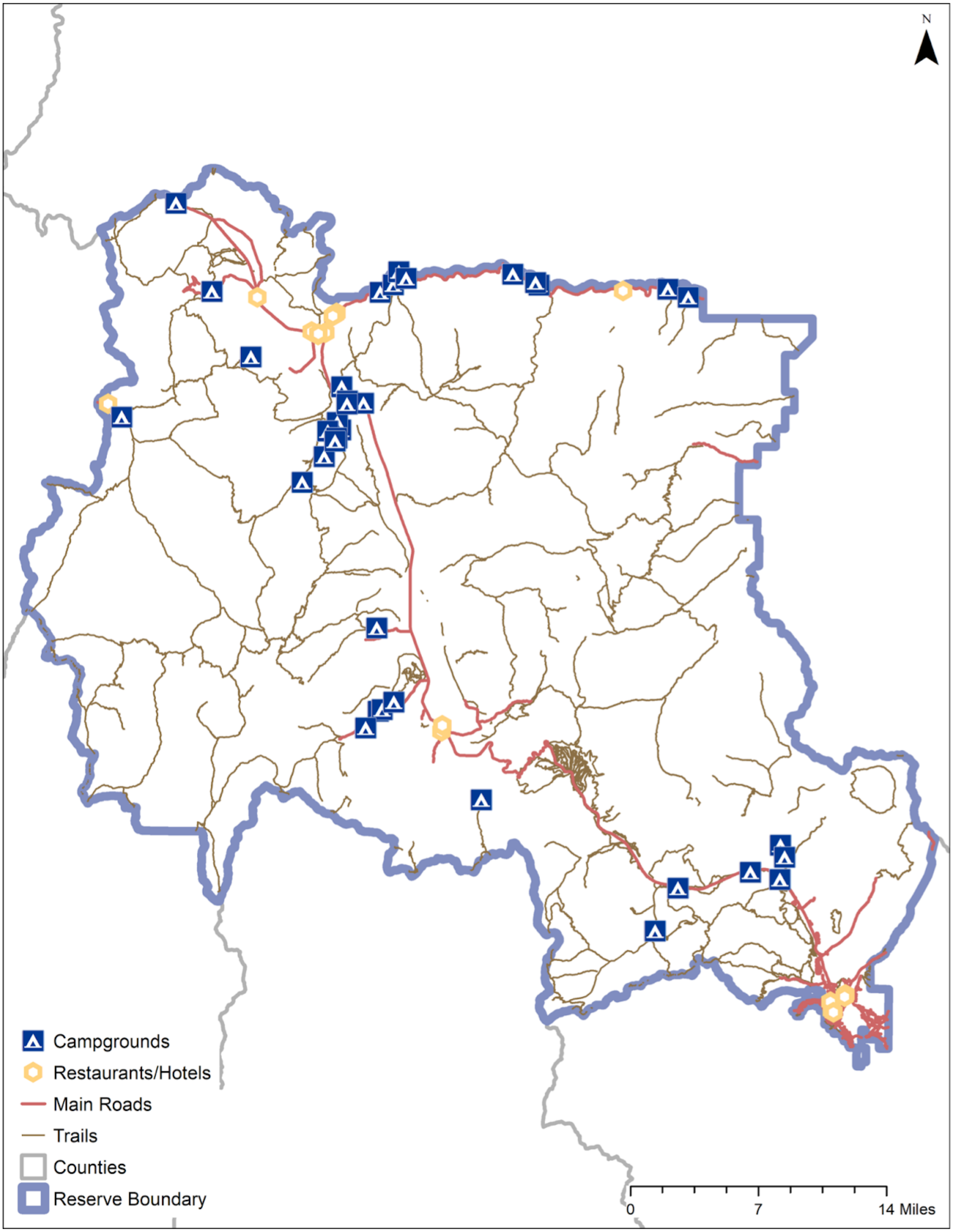



Figure 6.7. Map of important points within the reserve.

## Integration of Hospitality Industry into Astrotourism Strategy

We reached out to every hotel (including motels, lodges, inns, and cabins, but not including rentals such as Airbnbs or VRBOs) on the CIDSR via phone and/or email to ask about their interest in creating a package deal to promote astrotourism. Initially, eight hotels showed interest (table 6.3) and 14 were not interested. We then followed up with more information about specific ideas for package deals. We presented three ideas to the hotels:

1. A reduced rate for two to three days on hotel stays during key astrotourism events, such as new moons or meteor showers
2. For the hotel to offer small presentations or short hikes to night sky viewing locations in the reserve
3. To offer a discount, such as 5% off, of a hotel stay for visitors who say they are participating in astrotourism at the CIDSR

Following up with this information proved more difficult, as no hotels emailed or called back expressing interest in a particular deal. However, we are in contact with a representative of the CIDSR based in Sun Valley who is also helping us to coordinate with interested hotels. There is still a possibility that the hotels will adopt our suggestion(s) in the future.

Table 6.3. Hotels expressing interest in promoting astrotourism.

| NAME | LOCATION |
|---|---|
| **Best Western Tyrolean Lodge** | Ketchum, ID |
| **Hotel Ketchum** | Ketchum, ID |
| **Knob Hill Inn Sun Valley** | Ketchum, ID |
| **Limelight Hotel - Ketchum** | Ketchum, ID |
| **Tamarack Lodge** | Ketchum, ID |
| **Lower Stanley Country Store and Motel** | Stanley, ID |
| **Triangle C Cabins** | Stanley, ID |
| **Sun Valley Resort** | Sun Valley, ID |

## Astrotourism Guide

We created a single-page, double-sided flyer/guide about astrotourism for hotels to print in bulk for guests. The guide contains the best photography coordinates map, as well as information on the best times for photography/observing the night sky, what to bring, apps and websites to use, and additional resource links. So far, one hotel requested we send our guide to them. We also sent our guide to two representatives in Sun Valley who can help us to distribute the guide to hotels. Guide: http://bitly.ws/e9kp

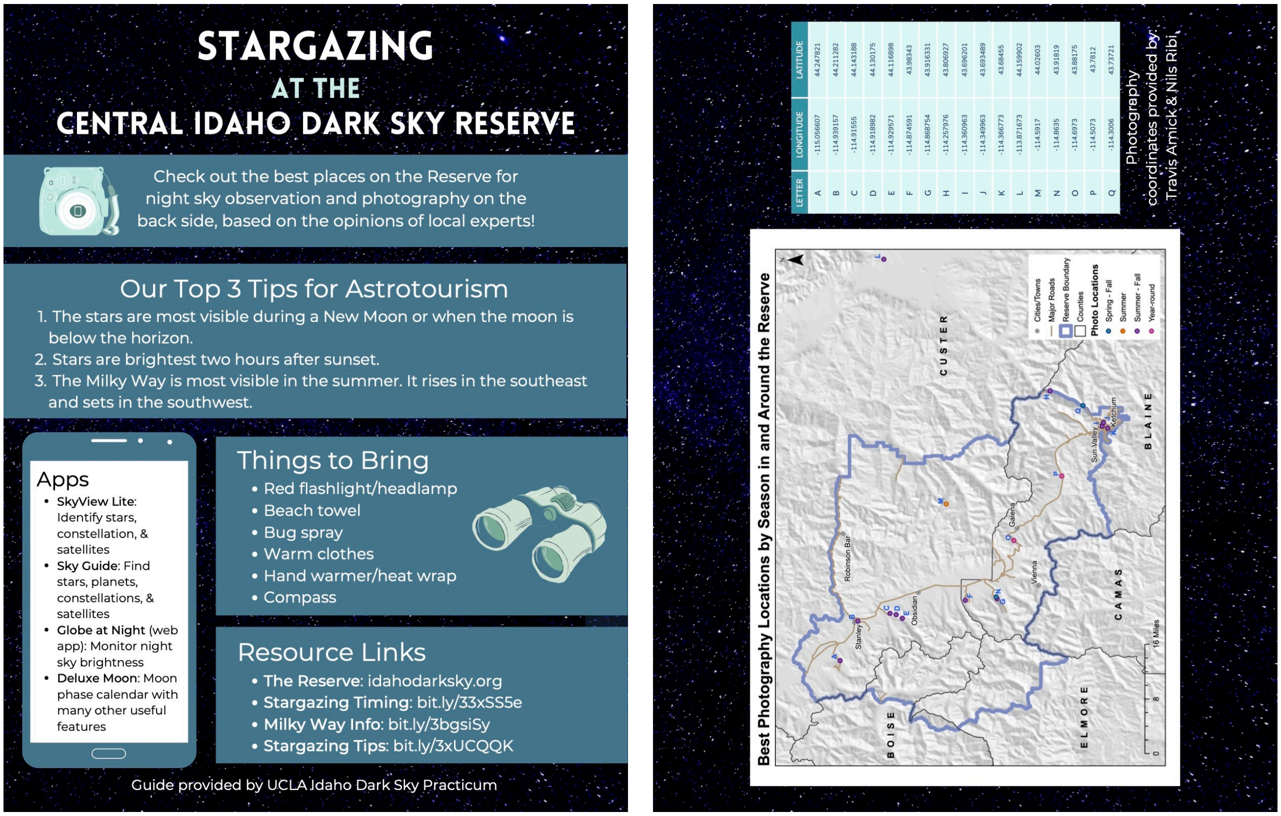



Figure 6.8. Image of the astrotourism guide created.

## Recommendations

Keeping track of annual statistics is vital to the maintenance and growth of the astrotourism sector at the CIDSR. The following suggestions can be used to add on to the existing work that our team has done in promoting astrotourism.

- Track participation of hotels in astrotourism promotion and report annually.
- Print and provide introductory astrotourism guide at visitor's centers, through the Forest Service, at hotels, and/or the Chamber of Commerce. Report the number distributed annually.
- Provide materials for novice stargazers at the CIDSR website and track usage statistics annually.
- Run an annual astrophotography and nightscape photography competition, with categories for beginners and advanced, for both resident (in-state) and visitor (out-of-state) awards.

# Conclusion

CHAPTER 7

# Conclusion

Using satellite data to measure light pollution is advantageous when looking across large areas and for tracking light levels over time. Visible Infrared Imaging Radiometer Suite (VIIRS) Day-Night Band (DNB) data specifically, are accessible and fairly easy to use and interpret. As more data become available each year, light pollution trends will become more apparent and likely yield significance. Though this project used VIIRS data to specifically monitor light pollution trends in and around the Central Idaho Dark Sky Reserve (CIDSR), this same methodology can be applied to other Dark Sky Reserves around the world – or other places of interest – in order to monitor and protect the quality of the night sky.

A Sky Quality Camera (SQC) is a portable and cost-effective method to obtain repeat measurements of night sky quality. If older lighting fixtures that emit yellow tones of light continue to be replaced by white LEDs with peak emittance in the blue portion of the spectrum that the VIIRS instrument cannot detect, the use of an SQC to complement satellite-based measurements becomes essential for accurately measuring light pollution trends.

Lighting ordinances play a significant role in decreasing light trespass, sky glow, and light pollution in general from urbanized areas. Because light pollution can reach as far as 300 km from the source, it is important for counties and cities near the CIDSR to adopt lighting ordinances to preserve the quality of the sky within the reserve. Effective ordinances include provisions that address lumen limits, correlated color temperature (CCT) limits, and shielding requirements.

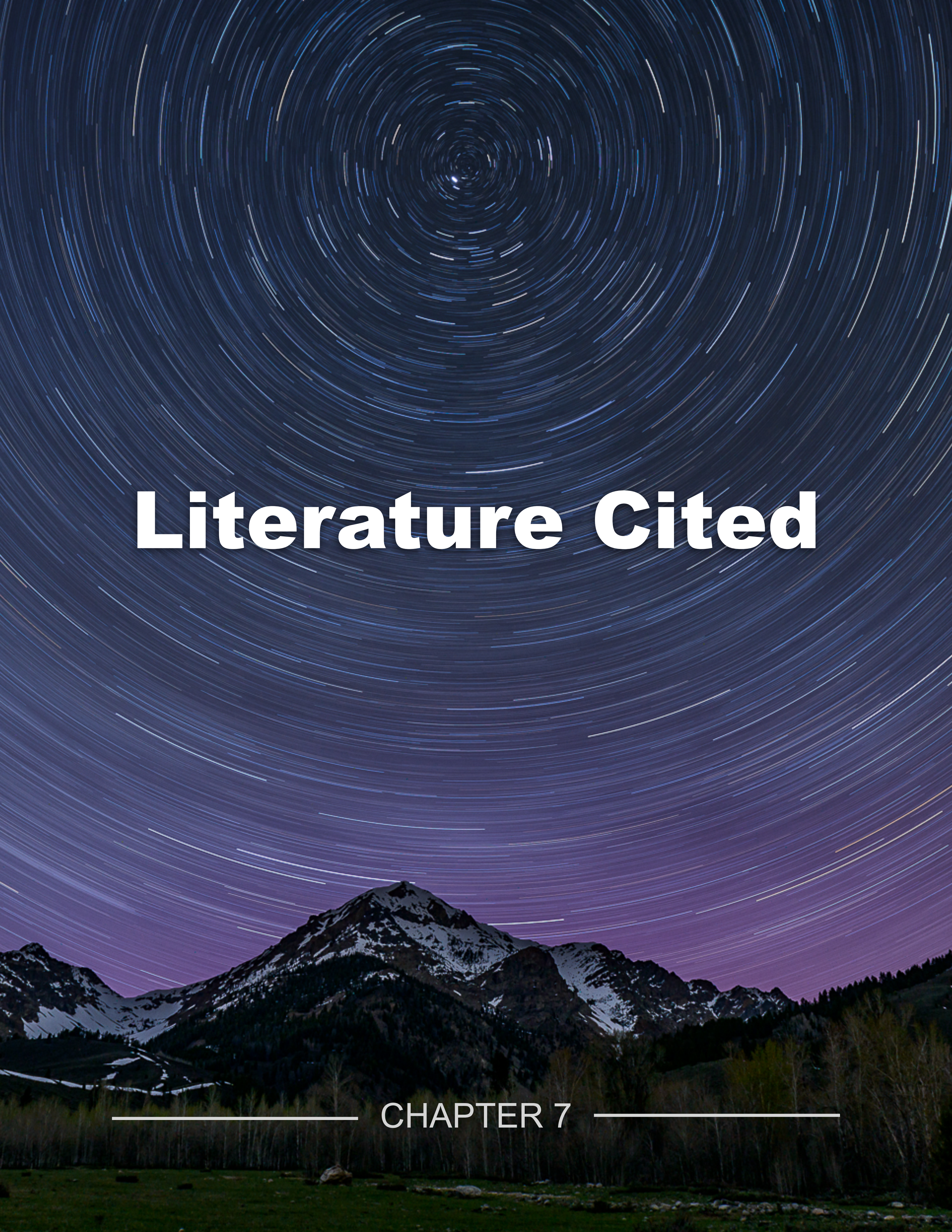
Research shows that artificial light at night (ALAN) is harmful to wildlife, but public support for dark skies can be difficult to gather. If ALAN can be mitigated for the benefit of one charismatic/ambassador species, then it can be beneficial for all species. In Idaho, such ambassador species are fish. We hope the CIDSR is able to head a case to protect fish in Idaho by reducing or removing lights that directly or indirectly shine into waterways and thus, lead to a reduction in light pollution across Idaho.

Given astrotourism is not a very well known concept, our primary goal in conducting an assessment of astrotourism potential in the reserve was to compile more information to be able to better promote dark sky opportunities and activities at the reserve. By sharing our research and maps we created, our hope is that more people come to recognize the value of dark skies, engage in forms of astrotourism, and be more aware of the consequences of light pollution.

# StoryMap

Visit our StoryMap, which summarizes the information contained in this report with interactive maps, available at https://bit.ly/darker-skies

Cover photos by Nils Ribi



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## Literature Cited


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# Appendices

# Appendix 2A: VIIRS Methodology

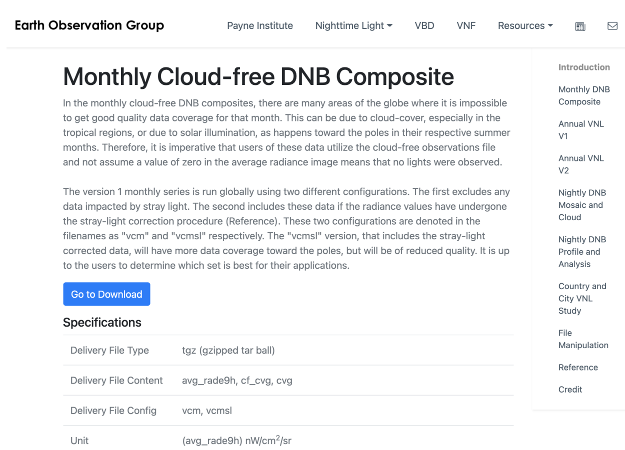
# Appendix 2A: VIIRS Methodology

## Software

- ArcGIS Pro (required)
- ArcMap (optional – all calculations listed in this methodology that were performed in ArcMap can similarly be performed in ArcGIS Pro with minor tool and/or methodological variations)
- Microsoft Excel or Google Sheets
- R Studio

## Step 1: Downloading VIIRS Raster Files

- Go to the Earth Observation Group (EOG) Website
- Scroll down to ‘**Monthly Cloud-free DNB composite**’, and press the blue button ‘**Go to Download**’
- Select **year** of interest folder
- Select **month** of interest folder
- Select ‘**vcmcfg/**’ folder
  - This folder excludes any data impacted by stray light. Some months include a vcmslcfg/ folder which includes some corrected raster data, however, this folder is not available for all months and often provides lower quality data
  - Note that the earliest available data are from April of 2012



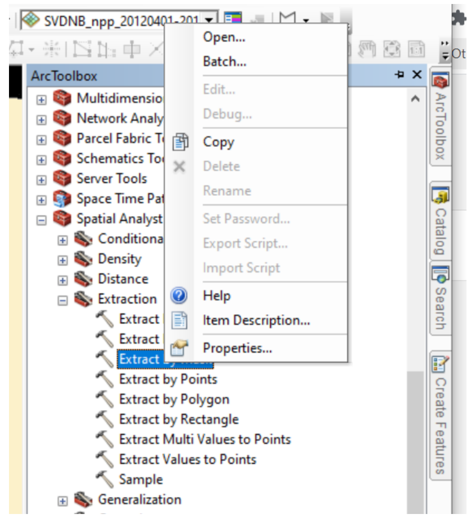

- Select file to download (**.tgz**)
  - Select file with coordinates in the name that most closely corresponds to the area of interest. For this particular project based in Idaho, we selected the file with **‘75N180W**’ in the name (the last listed file)
  - Once selected, the TAR Archive file (.tgz) will download
- Once downloaded, identify the Tag Image File (**.tif**) with the extension ‘**avg_rade9h**’
  - This is the average  Day-Night Band (DNB) radiance, while cf_cvg is the number of cloud-free observations used for the average

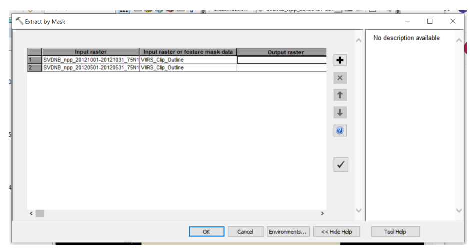
## Step 2: Convert Raster Into a More Manageable Size

(optional but recommended)

- We recommend clipping the raster files to a more manageable size before performing summed radiance calculations. For the purpose of this project, we created a simple rectangular shapefile (.shp) that conservatively covered the maximum possible extent of land we aimed to look at. This allowed for the raster to load faster and for calculations to run quicker.

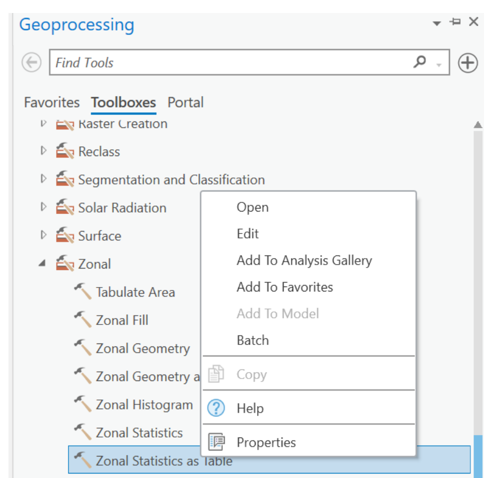
- Open a new Map file in ArcMap
- Change map projection to apply to study area
  - For the purpose of this project, we used '**NAD_1983 Idaho Transverse Mercator**'
- Add raster layers (.tif) to Layers
- Add shapefile of max extent (.shp) to Layers
  - Ensure shapefile is in the same projection as map project
- Batch Extract by Mask rasters to shapefile
  - **Tools → Spatial Analyst → Extraction →** right click **Extract by Mask** and select **Batch**
  - Under '**Input raster**', select one of the rasters to be clipped. Press the **plus sign** on the right hand side to add another raster
  - Under '**Input raster or feature mask data**', select the shapefile of which the input rasters are being clipped to. Repeat for every row of input rasters entered
  - Under '**Output raster**', select the appropriate folder destination to save in and give each raster a unique name (we recommend a name corresponding to the year/month of data and identifying the raster as a clipped version of the raw data)
  - Press '**OK**' to complete



## Step 3: Calculating Summed Radiance

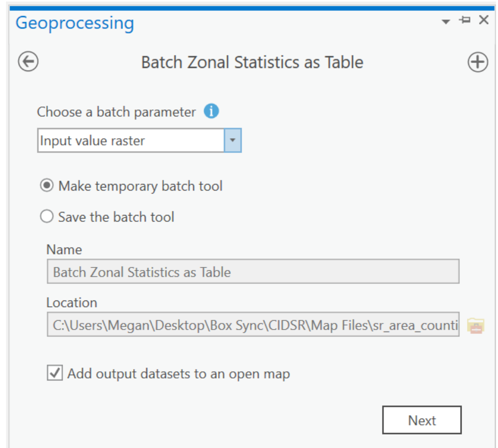
→ Note: The preceding steps must be completed in ArcGIS Pro if working with geographies of interest that overlap. For the purpose of this project, we analyzed 445 different geographic polygons that included counties, city boundaries, national parks, etc., many of which overlapped. ESRI's ArcMap is currently unable to calculate Zonal Statistics for overlapping geographies (explained at a later step), but these steps can be performed successfully in ArcMap if working with non-overlapping polygons.




- Create shapefile that includes all polygons for all locations of interest by merging separate shapefiles into a single shapefile layer
  - **Data Management → General → Merge**
- Recommendation: add a field
- Ensure the merged geographies layer (.shp) and all rasters of interest (.tif) are loaded

into ArcGIS map

- **Toolboxes → Spatial analyst → zonal → zonal statistics as table** (right click and select **Batch**)
    - Choose a batch parameter: '**Input value raster**'
    - Select '**Make temporary batch tool'**
        - '**Name**' and '**Location**' text boxes should be grayed out when this is selected
    - Check '**Add output datasets to an open map**'
    - Click '**Next**'
    - (under '**Parameters**' tab)
    - Input raster or feature zone data: **(select shapefile with geographies of interest)**
    - Zone field: **(unique field)**
        - As mentioned previously, we recommend adding a field to the geography shapefile and giving each geography polygon a unique code. For the purpose of this project, we gave each geography both a **SHP_ID** (# unique to each separate geography) and a **SHP_CODE** (# unique to each type of geography, e.g. counties, cities, reserve boundaries)
    - Batch input value raster: click the arrow which allows you to easily select all the months of years of rasters you have loaded. Click the list icon in the bottom left to select all, then click '**Add**' to add checked items
    - Output table: must be saved to a file path where no folders contain spaces or start with numbers. We recommend saving to a new folder directly onto your desktop then moving the resulting tables elsewhere once the tables have been converted to excel files
        - **Note**: in order to create a new table for every raster, you must name the output tables carefully. To avoid error, include **%Name%** in the output file name:
            - Where %Name% is written, the output table will adopt the name of the input raster file being analyzed. For example, we named our tables SR_%Name%, where SR stands for 'Summed Radiance'
    - Check '**Ignore NoData in calculations**'
    - Statistics type: '**Sum**'
    - Click '**Run**'
    - Results will be exported as tables. Need to convert the tables to Excel to be workable




- Joining tables
    - Ensure all tables of interest are loaded into ArcGIS Pro
    - **Toolboxes → Data Management → Joins and Relates → Join Field** (right click and select **Batch**)
    - Choose a batch parameter: **Join Table**

    - Select ‘**Make temporary batch tool**’
        - ‘**Name**’ and ‘**Location**’ text boxes should be grayed out when this is selected
    - Check ‘**Add output datasets to an open map**’
    - Click ‘**Next**’
    - Input table: select one of the tables (we recommend the first month/year’s table for ease, but the table selected will not affect output)
    - Input join field: ‘**SHP_ID**’ (or whatever unique field you chose for your data)
    - Batch Join Table: select all EXCEPT for the one you chose to be the join table You can’t join a table to itself
    - Join table field: ‘**SHP_ID**’ (or whatever unique field you chose for your data. This is the field that must match between tables for ease of joining)
    - Transfer fields: ‘**SUM**’
    - Click ‘**Run**’
    - An output table with sums for each month/year listed sequentially will be created
        - We recommend keeping all organized rasters in chronological order so that the resulting table lists sum fields chronologically as well. Manual confirmation may be required to ensure columns are listed chronologically, as date names will need to be applied once converted to an Excel table.
- **Toolboxes → Conversion Tools → Excel → Table To Excel**
    - Export the table as an Excel file
- Input table: select the table with the compiled joined fields
- Output excel file: Name it
- Check ‘**Use field alias as column header**’
- Leave ‘**Use domain and subtype description**’ unchecked
- ‘**Run**’
- A table with summed radiance values for all geographies of interest will be created. Further cleaning of the table may be necessary for future calculations

# Appendix 2B: Significance Testing

# Appendix 2B: Significance Testing

## R-Code

Packages, variable names, and file paths referenced are those used by our team members to perform the statistical calculations. These variables may need to be edited in order for this code to work with another user's unique set up. This code serves as a strong foundation that future researchers may use to test statistical significance of summed radiance data. Code is available on our data hub.

Note: The summed radiance data were imported into R from Excel spreadsheets, and thus it is important to format the Excel documents in such a way that the data can be imported properly into R. Again, in *Appendix 2C: Data Download,* the excel documents, containing the data for the significance tests, and their specific formatting can be viewed.

## Significance Test Results

*P-values that are significant (given a 95% confidence interval) will be indicated.

### ***The CIDSR Outer Bound***

Table A2.1.

| | P-value | | R-squared | |
|---|---|---|---|---|
| | ***Pre-2017*** | ***Post-2017*** | ***Pre-2017*** | ***Post-2017*** |
| **Jan** | 0.56421 | 0.4705 | 0.18991 | 0.28037 |
| **Feb** | 0.94258 | 0.87986 | 0.0033 | 0.01443 |
| **Mar** | 0.39301 | 0.9785 | 0.36844 | 0.00046 |
| **Apr** | 0.26996 | 0.19304 | 0.53296 | 0.65118 |
| **Aug** | 0.33656 | 0.5384 | 0.44015 | 0.21307 |
| **Sep** | 0.82015 | 0.98722 | 0.07771 | 0.00016 |
| **Oct** | 0.87316 | 0.1027 | 0.01609 | 0.80515 |
| **Nov** | 0.47818 | 0.49628 | 0.27229 | 0.50584 |
| **Dec** | 0.9133 | 0.25071 | 0.00752 | 0.56144 |

## ***Boise City***

Table A2.2.

| | P-value | | R-squared | |
|---|---|---|---|---|
| | ***Pre-2017*** | ***Post-2017*** | ***Pre-2017*** | ***Post-2017*** |
| **Jan** | 0.03635 | 0.43893 | 0.99674 | 0.59533 |
| **Feb** | 0.95832 | 0.85814 | 0.00174 | 0.02012 |
| **Mar** | 0.38422 | 0.12964 | 0.37918 | 0.75752 |
| **Apr** | 0.55646 | 0.74641 | 0.19673 | 0.06431 |
| **Aug** | 0.56317 | 0.32549 | 0.19082 | 0.45496 |
| **Sep** | 0.57609 | 0.36467 | 0.1797 | 0.40365 |
| **Oct** | 0.18045 | 0.64323 | 0.67166 | 0.12729 |
| **Nov** | 0.65666 | 0.33876 | 0.11788 | 0.43724 |
| **Dec** | NA | 0.85756 | 1 | 0.04923 |

## ***Thompson Creek Mine***

Table A2.3.

| | P-value | | R-squared | |
|---|---|---|---|---|
| | ***Pre-2017*** | ***Post-2017*** | ***Pre-2017*** | ***Post-2017*** |
| **Jan** | NA | 0.50894 | 1 | 0.24114 |
| **Feb** | 0.30099 | 0.34512 | 0.48862 | 0.42887 |
| **Mar** | 0.05671 | 0.33605 | 0.8898 | 0.44083 |
| **Apr** | 0.32301 | 0.11717 | 0.45832 | 0.77938 |
| **Aug** | 0.08108 | 0.88417 | 0.84441 | 0.03274 |
| **Sep** | 0.29055 | 0.75274 | 0.50333 | 0.06114 |
| **Oct** | 0.17574 | 0.59858 | 0.6794 | 0.16114 |
| **Nov** | 0.08624 | 0.5507 | 0.98176 | 0.20187 |
| **Dec** | 0.10919 | 0.00149 | 0.97087 | 0.99702 |

## ***Grand Teton National Park***

Table A2.4.

| | P-value | | R-squared | |
|---|---|---|---|---|
| | ***Pre-2017*** | ***Post-2017*** | ***Pre-2017*** | ***Post-2017*** |
| **Jan** | 0.46567 | 0.99157 | 0.28551 | 7e-05 |
| **Feb** | 0.73882 | 0.81435 | 0.06821 | 0.03447 |
| **Mar** | 0.73099 | 0.60889 | 0.07237 | 0.15297 |
| **Apr** | 0.22729 | 0.20848 | 0.59709 | 0.6265 |
| **Aug** | 0.48858 | 0.45269 | 0.26155 | 0.29954 |
| **Sep** | 0.1436 | 0.87244 | 0.94998 | 0.01627 |
| **Oct** | 0.86508 | 0.90632 | 0.04424 | 0.00878 |
| **Nov** | 0.33891 | 0.8874 | 0.43704 | 0.01268 |
| **Dec** | 0.27851 | 0.11263 | 0.52054 | 0.78742 |

## ***Yellowstone National Park***

Table A2.5.

| | P-value | | R-squared | |
|---|---|---|---|---|
| | ***Pre-2017*** | ***Post -2017*** | ***Pre-2017*** | ***Post-2017*** |
| **Jan** | 0.42632 | 0.81128 | 0.32911 | 0.03561 |
| **Feb** | 0.92435 | 0.88192 | 0.00572 | 0.01394 |
| **Mar** | 0.715 | 0.72484 | 0.08122 | 0.07571 |
| **Apr** | NA | 0.15032 | 1 | 0.72196 |
| **Aug** | 0.91298 | 0.94404 | 0.00757 | 0.00313 |
| **Sep** | 0.03264 | 0.83638 | 0.99737 | 0.02677 |
| **Oct** | 0.68189 | 0.97332 | 0.22959 | 0.00071 |
| **Nov** | 0.44374 | 0.92196 | 0.30943 | 0.00609 |
| **Dec** | 0.92994 | 0.26848 | 0.00491 | 0.53512 |

# Appendix 2C: Additional Figures

# Appendix 2C: Additional Figures

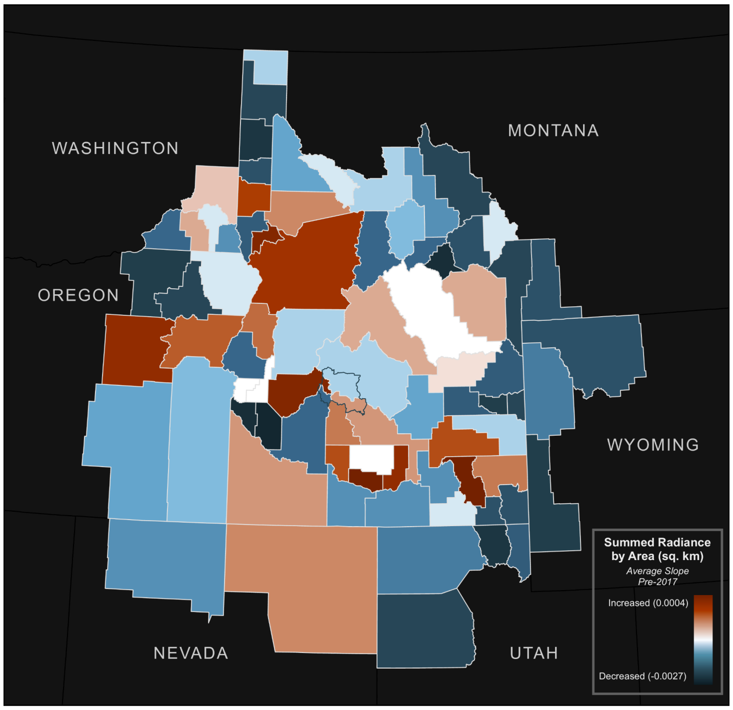



Figure A2.1. Average slope of summed radiance by area (km2), pre-2017.

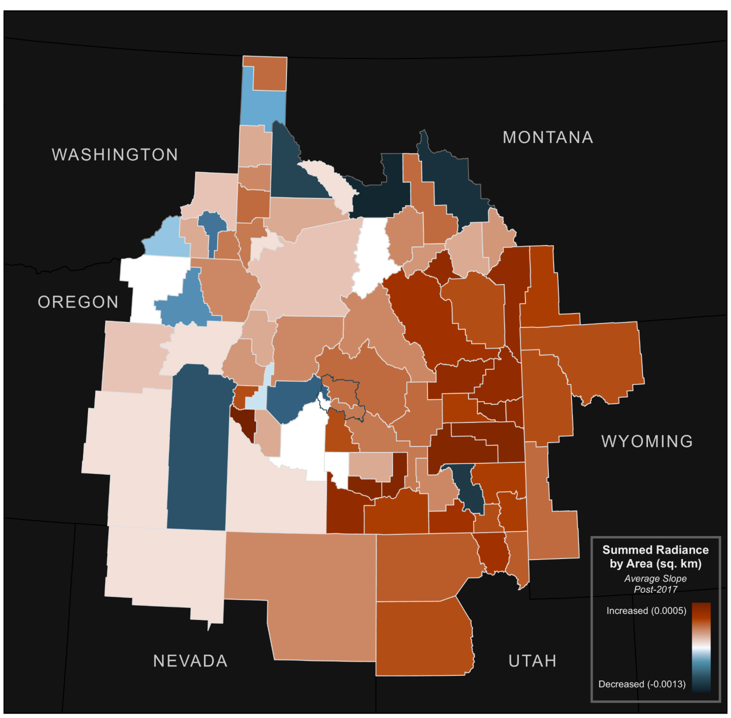



Figure A2.2. Average slope of summed radiance by area (km2) post-2017.

# Appendix 3A: Instructions for Use of Sky Quality Camera (SQC)

# Appendix 3A: Instructions for Use of Sky Quality Camera (SQC)

## Before the Field

- Charge all batteries; plug-in charger is in the Pelican case.
- Check that the Sky Quality Meter (SQM) is working and that you have a backup 9V battery
- Check that you have a SD data card with enough space.
    - Images are 25-30 MB each.
    - Never delete images from SD card unless they are backed up first.
- Check battery is working in remote shutter release
    - Check for backup battery in Pelican case
- Check settings on camera
    - File format set to 'RAW'
    - Lens set to MF (not AF)
    - In Manual mode, ISO is set to 1600
    - Auto White Balance (AWB) is enabled

## Checklist for the Field

☐ Camera (including lens and lens cap)
☐ Remote shutter release
☐ Sqm
☐ Camera batteries
☐ Compass (or Compass app on phone)
☐ Level (or level within Compass app on phone)
☐ Tripod
☐ Tripod mounting plate (either on the tripod or on the bottom of the camera)
☐ Headlamp and flashlight (with red lenses if possible, but not necessary unless you will be out with other astrophotographers)

## In the Field

- Connect the camera to the tripod securely and carry them together to the imaging site
- Record the latitude and longitude of the imaging site to as many decimal points as you can get (GPS on mobile phone works, record all the numbers)
- Extend the legs out all the way and set up the tripod so that the camera will be level
- Tilt the camera back so that the lens is facing straight up
- Orient the tripod so that the top of the camera is facing due north
- Use the compass to ensure the camera is facing north
- Use the level (mobile phone placed on top of the lens cap works well) and level the camera in all directions. It is good to practice with the settings and knobs on the tripod ahead of time so that you are familiar with the adjustments.
- Take a few measurements with the SQM and record them for comparison later (always discard the first measurement and average the next 3)
- Turn the camera on
- Check that the ISO is 1600 and the aperture is 2.8
- Decide on an exposure time
    - If the SQM is >19.5 and there is no direct glare, try 120 seconds
    - If the SQM is >19.5 then there is glare, try 60 seconds
    - If the SQM is <19.5 start at 30 seconds

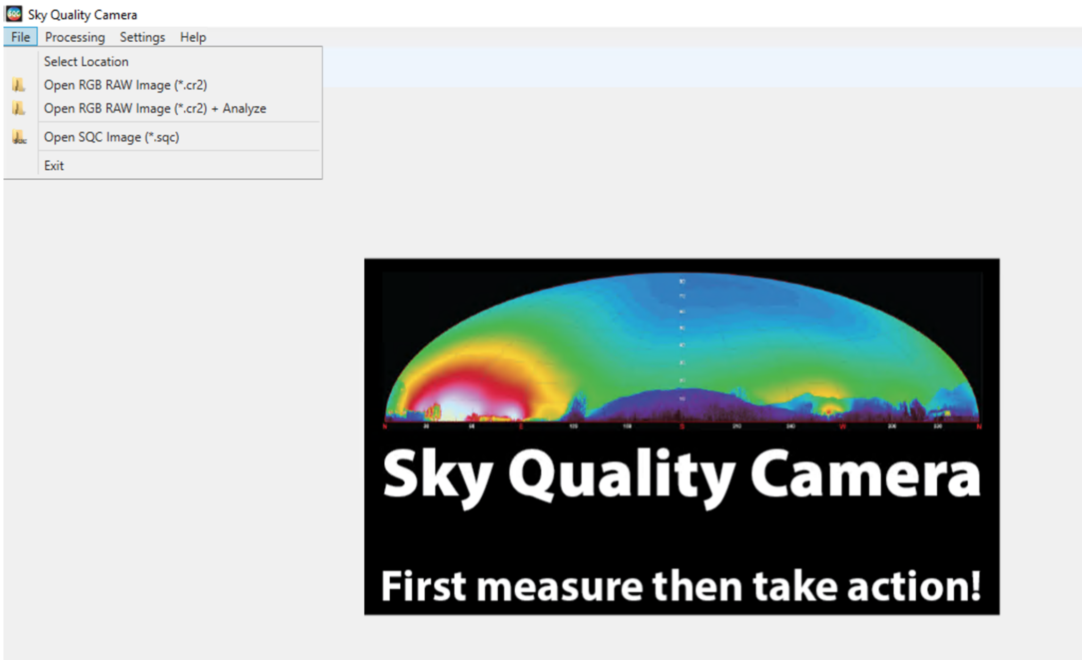
    - The goal is to get the longest exposure without saturating the sensor
    - The saturated areas of the image will flash when you view the image after taking it
    - If you have no saturation at all, take a longer exposure, until you get to 120 seconds, which is long enough
    - If you have large areas saturated, take a shorter exposure until the saturated areas are negligible
- For long exposures (>30 seconds), program the remote shutter release (‘long’) for the number of seconds of the exposure.
- Attach the remote shutter release
- TAKE OFF THE LENS CAP
- Get everyone to crouch down below the plane of the lens of the camera
- Turn off all lights
- Hit the ‘start’ button on the shutter release (assuming > 30 second exposure)
- Stay still for the whole exposure (it will click) then wait for the camera to do the white balance (another period the same duration as the exposure)
- The image will show up on the LCD screen when it is done
- Use the arrow button to the right of the screen to view the image
- Write down the image number (be sure it is the image number) **and** the exposure duration in field notebook along with the SQM readings
    - This is very important because numbering gets off, you have to figure out what image was where based on the exposure times
- Review image to see if there is any area flashing that has been saturated
- Take another image, either longer or shorter, based on assessment of the saturation
- Level the camera and take images in each of the four cardinal directions (get everyone behind the camera during the exposure)
- Write down the direction and image number each time

# Appendix 3B: SQC Program Instructions

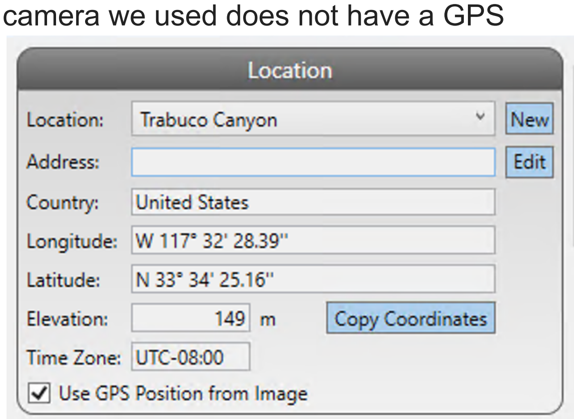
# Appendix 3B: SQC Program Instructions

1. Open the SQC program


2. Open RGB RAW from File menu

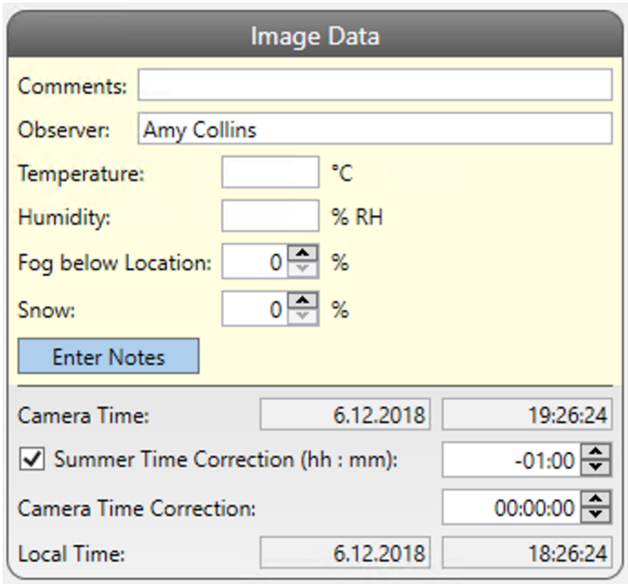



3. Create a new location or select an old location. GPS position was not used because the camera we used does not have a GPS

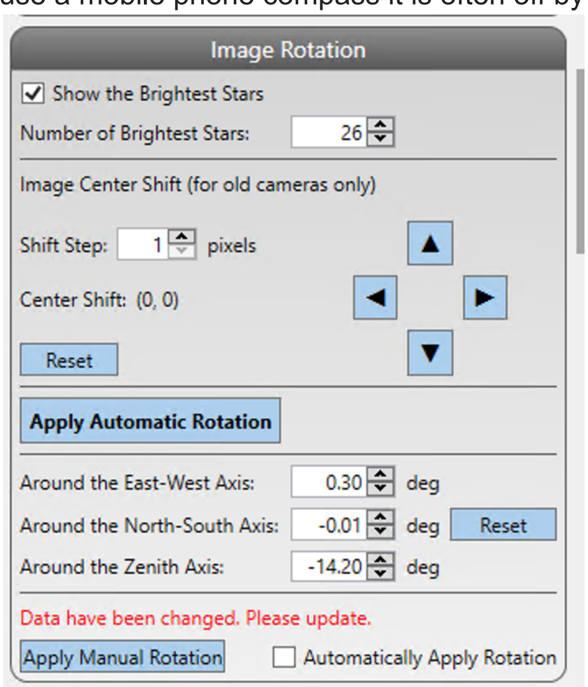



4. Update image information. Put anything you want in the comments to help remember details of interest. Probably pick one or two people to archive as the observers. Temperature, humidity, fog, and snow are important for astronomical observations so

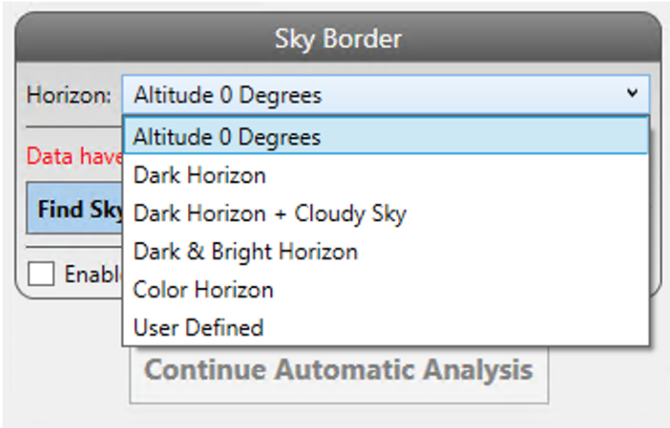
you should fill them out. The time adjustments are needed if the camera clock is off. With any luck, you do need to use them, but if the clock is off by any amount, you will

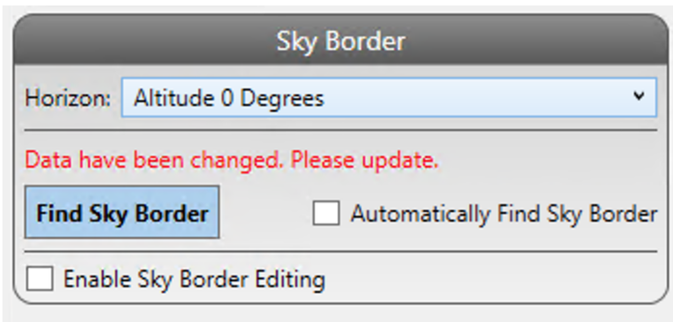



5. Skip ‘Image Brightness’ and go to ‘Image Rotation’. Click on ‘apply automatic rotation’. If the numbers for the E/W axis or N/S axis are more than a few degrees it means you might have the location and/or time incorrect. Go back and check those. The zenith correction is how accurately you lined the top of the camera up with the north pole. If you use a mobile phone compass it is often off by up to 15º, like this example

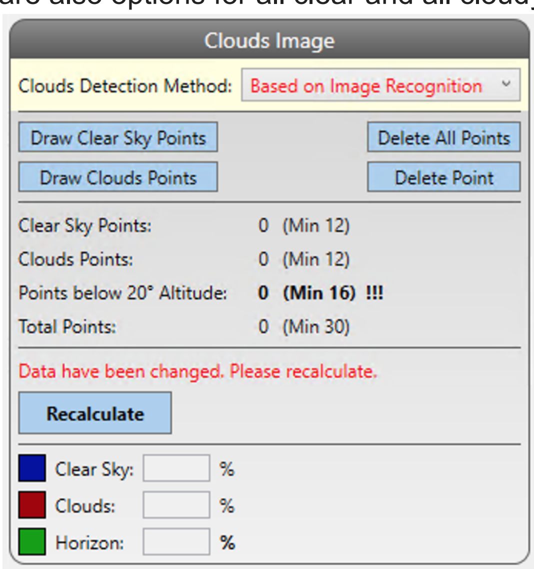



6. Set the sky border. For our purposes, we could ignore the light below the trees/horizon, since it was very dark. Dark Horizon or Dark Horizon + Cloudy Sky for the remote locations are good options, but can always be played around with. Then click ‘Find Sky Border’

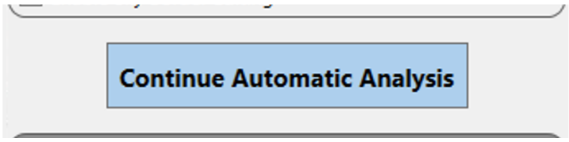


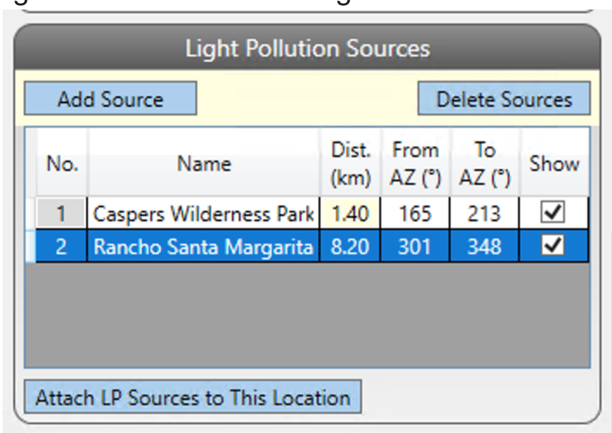

7. Provide training points for clear sky detection. Go to the 'Clouds Image' section and click on 'Draw Clear Sky Points.' Then click randomly on a bunch of places above and below 20º that are clear sky. Then click on 'Draw Clouds Points' and do the same. There are also options for all clear and all cloudy in the drop-down menu



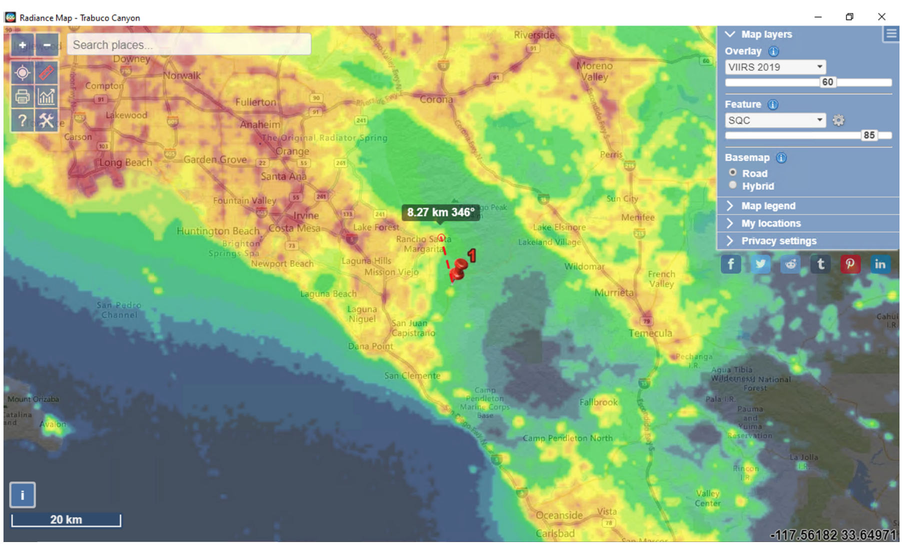

8. We can set many other options, but for now, leave them at the defaults and go back to click on Continue Automatic Analysis'



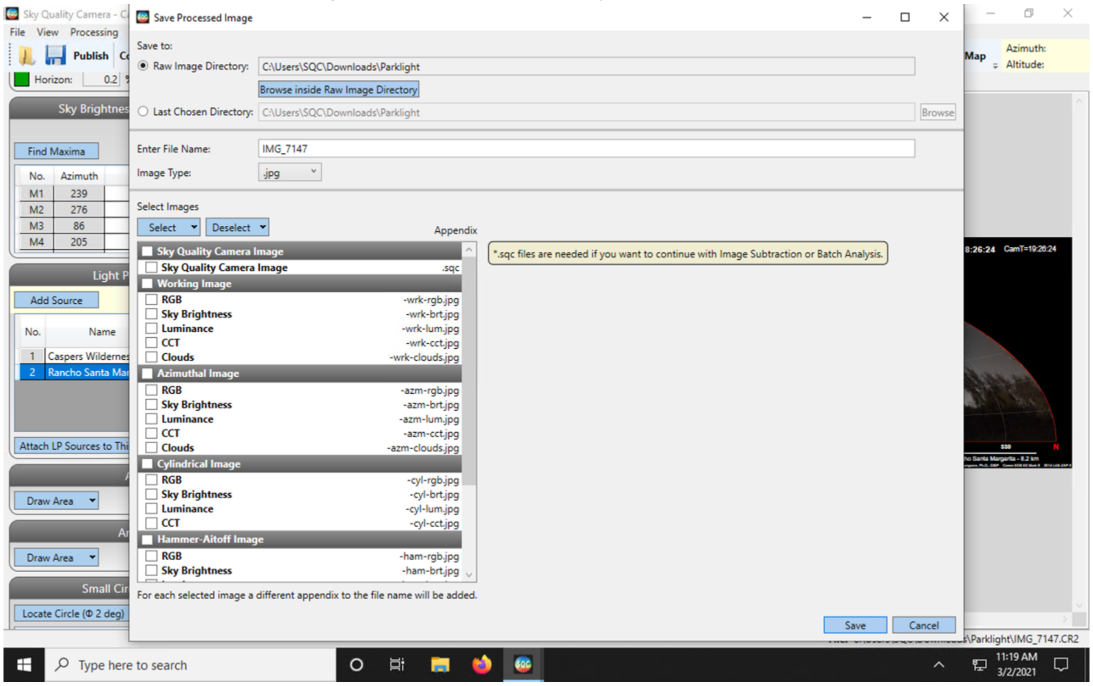

9. Add light pollution sources. Get to the map to write down these sources, by clicking on ‘radiance map’ in the upper right. Then use the measure tool in the radiance map to figure out distance and angle.




| No. | Name | Dist. (km) | From AZ (°) | To AZ (°) | Show |
|---|---|---|---|---|---|
| 1 | Caspers Wilderness Park | 1.40 | 165 | 213 | ☑ |
| 2 | Rancho Santa Margarita | 8.20 | 301 | 348 | ☑ |



10. Save the results, including the .sqc file, which you can reopen next time



## Appendix 3C: Prediction Simulation Notes

# Appendix 3C: Prediction Simulation Notes

## Lamp Color Prediction Parameters

- Selecting current White LED/MH (0-100%)
    - Using astronaut images (https://citiesatnight.org/index.php/maps/) to approximate proportion of white LEDs
        - ISS007-E-16534 (general area of the reserve) has picture from 2003.10.07, perhaps 10% white LEDs
        - ISS038-E-15125 (east of Twin Falls) has picture from 2013.12.12, perhaps 50% white LEDs
        - ISS034-E-3529 (west of the reserve) has picture from 2013.01.20, perhaps 20% white LEDs
        - Based on the images, can use a current White LED/MH of 20%
    - The CIDSR 2020 Annual Report
        - Stanley converted all of its lights to Lumican 2200 K lights (emit no blue-white spectrum light)
        - Sun Valley has rule that lights cannot exceed 3000 K, lighting must be in compliance by 2025
        - Blaine County – some light fixtures were grandfathered in

## Selecting Target Years

- 2031, 2041, 2051 (10, 20, and 30 years)

## Lamp Power Prediction Parameters

- Selecting Lamp Quality/Power Change/Year
    - No dramatic change likely to occur in the area, but perhaps in Boise or other nearby light pollution sources not under ordinances
    - According to National Park Service (NPS), light pollution increased 6% annually in the U.S. from 1947 to 2000 https://www.nps.gov/subjects/nightskies/growth.htm
    - IDA found that global light pollution is increasing at rate of 2% annually https://www.darksky.org/five-years-of-satellite-images-show-global-light-pollution-increasing-at-a-rate-of-two-percent-per-year/
- Simulations
    - 2031/2041/2051 White LED changing to 100% only
        - Realized while completing each simulation that the same result would come of each year
    - 2031 LP 2% only
    - 2041 LPr 2% only
    - 2051 LP 2% only
    - 2031 LP 6% only
    - 2041 LP 6% only
    - 2051 LP 6% only
    - 2031 LP 2% and 100% LED

    - 2041 LP 2% and 100% LED
    - 2051 LP 2% and 100% LED
    - 2031 LP 6% and 100% LED
    - 2041 LP 6% and 100% LED
    - 2051 LP 6% and 100% LED
- Do simulation sequences with 2051 2% only and then 2051 2% and 100%

# Appendix 6A: Reclassification Tables

# Appendix 6A: Reclassification Tables

Table A6.1. Restaurants/hotels reclassification values

| OLD VALUES | NEW VALUES |
|---|---|
| 34,379 - 44,566 | 1 |
| 25,975 - 34,379 | 2 |
| 18,336 - 25,975 | 3 |
| 10,441 - 18,336 | 4 |
| 0 - 10,441 | 5 |

Table A6.2. Main roads reclassification values (tourist model)

| OLD VALUES | NEW VALUES |
|---|---|
| 27,071 - 37,033 | 1 |
| 18,841 - 27,071 | 2 |
| 11,911 - 18,841 | 3 |
| 5,631 - 11,911 | 4 |
| 0 - 5,631 | 5 |

Table A6.3. Night sky brightness reclassification values

| OLD VALUES | NEW VALUES |
|---|---|
| 0.04 - 0.07 | 1 |
| 0.02 - 0.04 | 2 |
| 0.01- 0.02 | 3 |
| 0.005 - 0.01 | 4 |
| 0.002 - 0.005 | 5 |
| 0.0007 - 0.002 | 6 |

Table A6.4. Main roads reclassification values (specialist model)

| OLD VALUES | NEW VALUES |
|---|---|
| 0 - 5,631 | 1 |
| 5,631 - 11,911 | 2 |
| 11,911 - 18,841 | 3 |
| 18,841 - 27,071 | 4 |
| 27,071 - 37,033 | 5 |

Table A6.5. Small dirt paths reclassification values

| OLD VALUES | NEW VALUES |
|---|---|
| 4,951 - 9,160 | 1 |
| 1,857 - 4,951 | 2 |
| 0 - 1,857 | 3 |

# Appendix 6B: Raster Calculator Expressions

# Appendix 6B: Raster Calculator Expressions

## Astrotourism Suitability for Tourist Model Calculation

The following calculation was input into the Raster Calculator Tool to create an astrotourism suitability raster for tourists:

(((Float("buffer_final") / 1) * 0.2) + ((Float("road_reclass") / 5) * 0.2) + ((Float("rest_reclass") / 5) * 0.2) + ((Float("reclass_nsb") / 6) * 0.40)) * 17

## Astrotourism Suitability for Specialist Model Calculation

The following calculation was input into the Raster Calculator Tool to create an astrotourism suitability raster for specialists:

(((Float("buffer_final") / 1) * 0.1) + ((Float("road_rev_rec") / 5) * 0.1) +  ((Float("rec_trail") / 3) * 0.1) + ((Float("rest_reclass") / 5) * 0.1) + ((Float("reclass_nsb") / 6) * 0.6)) * 20