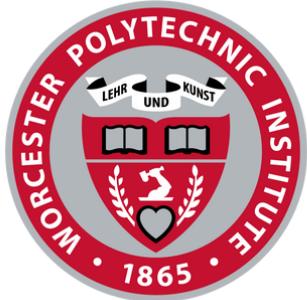




Seeking Darkness in Acadia: Examining the Possibility of a Dark Sky Park Designation



Gabe Demanche | Kyla Driscoll | Amelia McKenna | Adrienne Saucier | Ryan Thivaharaja



WPI

Acadia Dark Sky - Acadia National Park, Maine Project Center - IQP

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Dark Sky 2023

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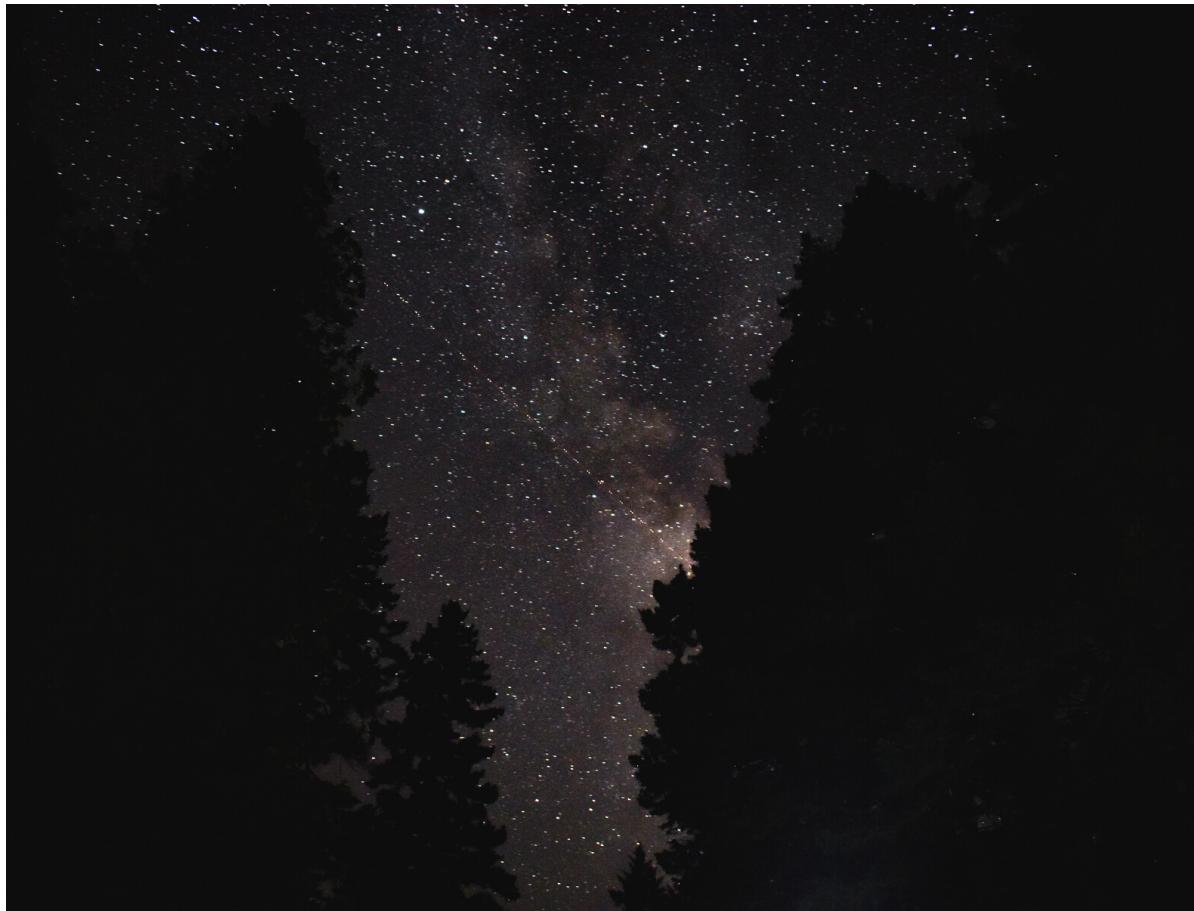
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ABSTRACT

Light pollution has harmful impacts on both natural and human made systems. Organizations such as the International Dark-Sky Association (IDA) aim to mitigate these damages. The project's goal was to assess the nightscapes of Acadia National Park and its potential of becoming an International Dark Sky Park (IDSP). To realize this goal, the team examined Acadia's compliance with IDA IDSP requirements for sky darkness quality, community outreach, and outdoor lighting through a combination of field measurements, night sky photography, and surveys. Acadia excelled in night sky quality and dedicated night sky outreach. While complete lighting compliance could not be determined, an inventory of over half the park's outdoor fixtures indicated that compliance is achievable with minimal action.

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This picture and all other night skies shown throughout the paper were taken by the team, with the help of Juliana Porto

AUTHORSHIP

This paper was written and edited as a collaborative effort by all members of the team, although each had their own specialty. **Gabe Demanche** worked primarily in ArcGIS, lighting and night sky analysis, and recommendations. **Kyla Driscoll**'s area of expertise was on research instruments and night sky analysis. **Amelia McKenna** worked in outreach and lighting requirements for the lighting inventory. **Adrienne Saucier** worked in outreach requirements and ArcGIS. **Ryan Thivaharraj**'s expertise was in lighting inventory and night sky analysis.

Whether the team was visiting lights, taking readings on the night sky, or surveying park visitors on their experiences, everyone was engaged and excited for the wonderful opportunity to learn, surrounded by the natural beauty of Acadia National Park. The team believes that through completion of this project many skills were gained and new experiences had.



EXECUTIVE SUMMARY

The United Nations defines global environmental change as long-term changes in the Earth's climate that affect the balance of ecosystems that support life and biodiversity (United Nations, 2023).

One of the often overlooked, but influential, forms of global environmental change is light pollution. A plethora of data exists measuring the darkness of the night sky. Light pollution has spread and increased over time across almost all areas in the United States (National Park Service, 2017).

Acadia National Park has a rich history of possessing some of the darkest skies on the east coast, and efforts have been made by the park and Worcester Polytechnic Institute (WPI) project teams to raise awareness of its dark skies. Acadia is one of the few national parks in the northeast with natural darkness comparable to remote western parks, offering visitors a unique and remarkable stargazing experience.

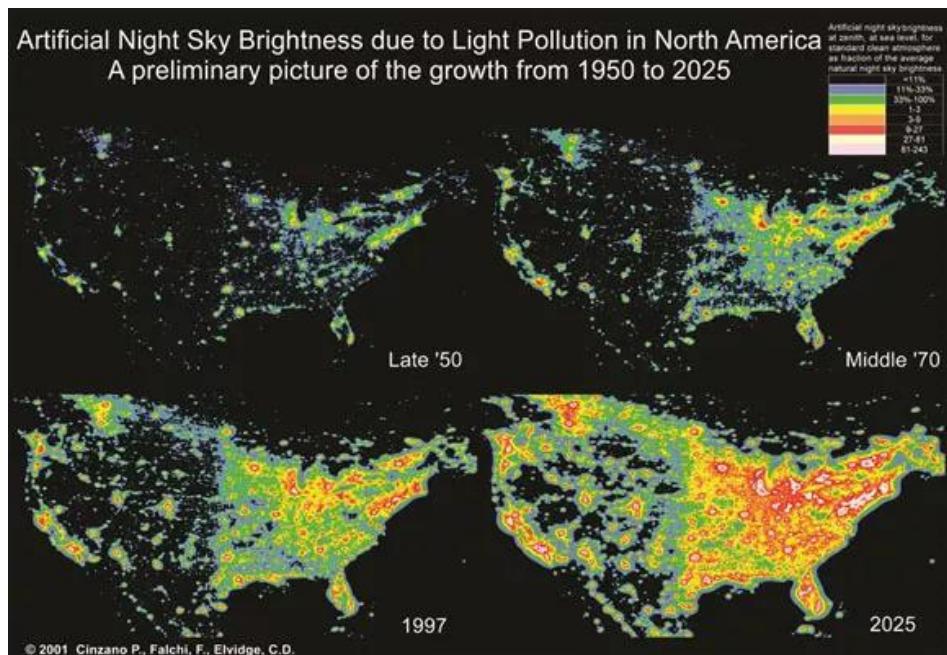


Figure A Light Pollution Across the US 1950-2025
(National Park Service, 2017)

Meeting International Dark Sky Park Requirements

With the ever-growing concern of human impact on the natural environment, this project looked to determine the effect of light pollution on the nightscape of Acadia National Park, and assess the plausibility of Acadia submitting an application to become an International Dark Sky Park. Three objectives were developed to accomplish this project goal:

Measure dark sky quality in Acadia for compliance with IDA IDSP standards

Determine which lighting fixtures in Acadia are compliant with IDA IDSP standards

Analyze current outreach efforts and collect community feedback on outreach

Sky Quality

To assess the current conditions of night skies in Acadia National Park, multiple methods to determine the impacts of light pollution on the night sky darkness were used, including collecting quantitative data about night sky darkness, taking photos to document night sky quality, and making observations of what is seen in the field.

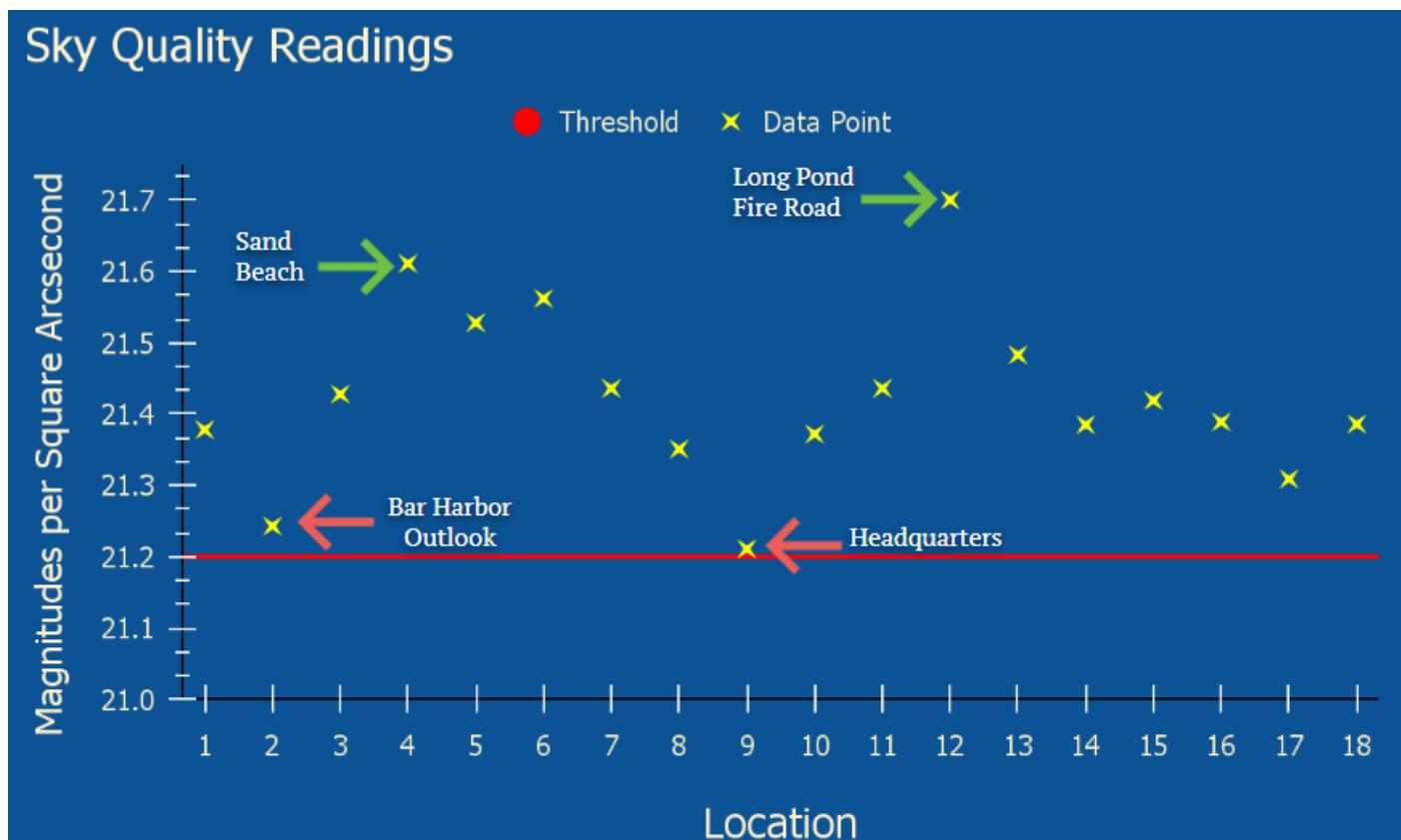


Figure B Results of sky quality readings across Mt. Desert Island

To gauge the quality of the night skies of Acadia National Park, the team conducted night sky measurements, recorded field observations, and collected photographs of the night sky. These night sky measurements were done using SQM-L recordings at eighteen different locations across Mount Desert Island. These recordings were all above the required threshold of 21.2 magnitudes per arcsecond, meeting the IDA's requirement for night sky quality. With this data, the team determined that despite pollution from artificial light sources, the skies within Acadia National Park are beautifully preserved and are of excellent quality for stargazers of any background.

Lighting Compliance

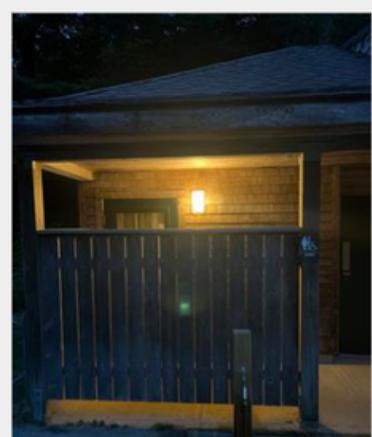
Additionally, the lighting fixtures in the park were analyzed to ensure adherence to guidelines set by the IDA and NPS. These criteria include the purpose of the light, shielding, and proper color correlated temperature (CCT). The purpose of each light should either be for safety or historical preservation; the light should be properly shielded with no uplight, backlight, or glare; and the CCT for each light should be below 3000 Kelvin, displaying a warm color. After the previous inventory from the 2016 WPI team was reviewed, fieldwork was conducted to verify the current status of all 928 external lighting fixtures. Any changes that were made by the park in the seven years that have passed since the last inventory was conducted were also noted.



Purpose



Shielding



Color

Figure C The three requirements for compliance, with example pictures

A comprehensive lighting inventory of the park was conducted to determine the lighting compliance levels set out by the IDA. This inventory, using ArcGIS, detailed several data points of each lighting fixture in the park, most importantly the CCT and shielding of each light. Only 10.9% of lighting fixtures in Acadia National Park were found to be compliant with IDA standards, not meeting the 67% compliance required to become an IDSP.

NPS System Measured Compliance of MDI

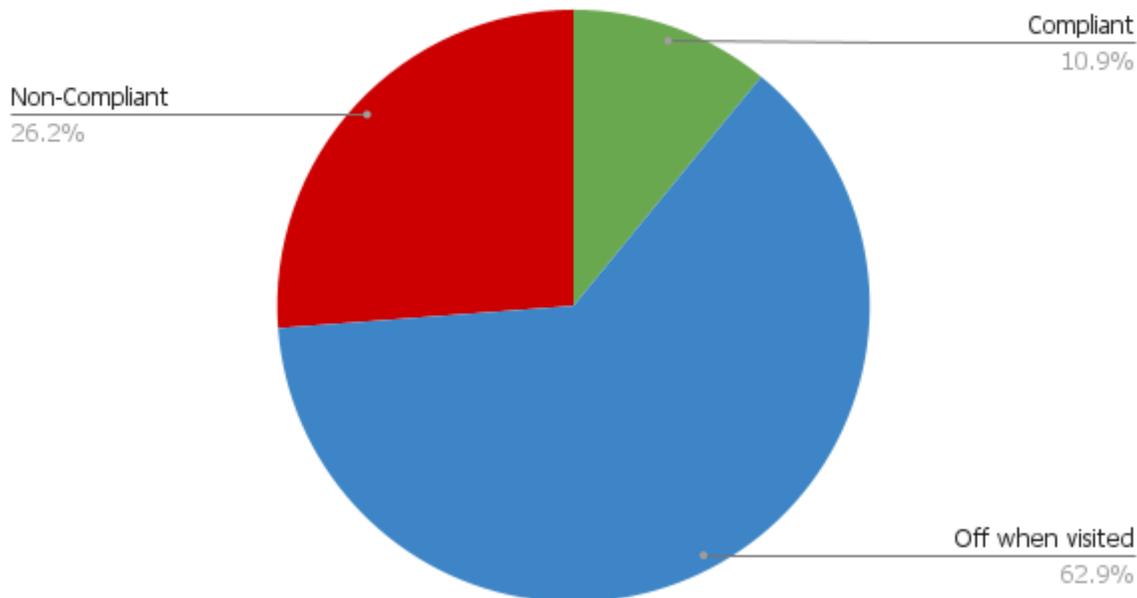


Figure D Compliancy of lighting fixtures on Mount Desert Island

Due to 63% of lights visited in the field not being operational at the time of visit, further visitation will be required to determine the compliance of these lights. All lights on Schoodic Peninsula will also need to be analyzed in any future visits.

Dedicated Outreach

Without support from park visitors and the surrounding communities, it would not be possible to establish and maintain Acadia National Park as an IDSP. The requirements for outreach programs are that events must mention light pollution and the IDA in the programming, and some kind of dedicated programming occurs at least four times a year. Possible examples of outreach include star parties, museum exhibits, interpretive dark sky protection programs, educational programming, or dark skies tourism.

The team assessed the current outreach programming of Acadia National Park to determine if it completes the final requirement to become an IDSP. It was discovered that Acadia has four outreach events hosted both by itself and by its partners. However, it was also discovered that many of these events suffer from a lack of public information, which can be improved with more advertising.

Recommendations

Acadia National Park displays the necessary components to become an International Dark Sky Park, and despite the current conditions of lighting, should move forward with the application process.

Sky Quality

Both past and current teams have confirmed Acadia has a high quality of night sky darkness, and under clear conditions the Milky Way is visible to the unaided eye. In order for the park to better understand how changes over time impact the night sky of Acadia, the team recommends the establishment of a continual data collection process.

This can be accomplished through the placement of SQM-LU devices throughout the park. These devices monitor sky quality remotely and can be implemented in such a way that data is automatically uploaded for analysis. With the waterproof casing, these devices cost \$264 USD each. The SQM-LU devices would also be placed in some of the same locations that had darkness quality recordings done during this project, such as Sand Beach and Long Pond Fire Road, allowing for continuous recordings. This will help the park gain a deeper understanding of the night sky quality in Acadia National Park.

Dedicated Outreach

Acadia National Park currently has four night sky centered programs, but the marketing of these events should be improved. This can be done by following the example of other organizations, such as the International Dark Sky Association, and the Michigan State Parks Service. Both of these services promote their events on social media to improve visibility of events. These posts are accompanied by easy to navigate links to more information on events. Alternatively, posters or pamphlets on events can be posted near ranger stations or in information centers for accessibility for non social media users.



Figure E SQM-LU Device

Lighting Compliance

The team found that conducting the lighting inventory through the use of NPS provided systems was more intensive than work conducted in prior years. As such, there is work to be done to complete the assessment of lighting compliance in Acadia National Park, but the initial signs show hopeful outcomes.

In order to meet the lighting compliance requirement set forth by the IDA, the park should first complete the NPS system lighting inventory of Acadia National Park. They should then correct the color of the lighting that meets the use and shielding requirements, which will have minimal impact on park lighting choices. Upon completion of these steps, the park will have 60% compliance, and will only need to retrofit, remove, or replace 61 lighting fixtures to achieve the 67% compliance required to become an IDSP.

MDI Shielding Compliance

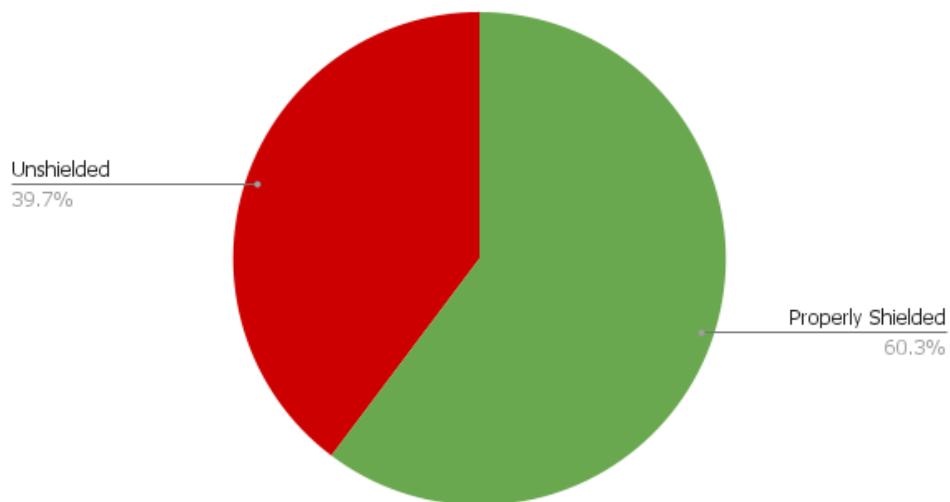


Figure F Percentage of lights on MDI that meet the shielding requirement

Conclusion

The level of dark sky quality in Acadia's nightscapes as well as the multitude of outreach events and programs meet IDA requirements. Although the lighting within the park is currently not compliant with the guidelines set out by the IDA, future changes will allow the park to reach a 67% compliance level. With these changes, Acadia National Park will be capable of becoming an International Dark Sky Park.

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1. INTRODUCTION

Human activity has impacted several facets of the natural world, with one of these aspects being the darkness of the night sky. Light pollution has become widespread with environmental and social implications. Lower quality of dark skies can impact astronomical studies, and excess lighting results cause financial burdens and an increase in environmental contamination. Light pollution also impacts mammalian activity, primarily through changes in the circadian cycle. This can cause alterations in metabolic processes and other health-related issues (Guan et al., 2022).

The National Park Service (NPS) and International Dark Sky Association (IDA) have taken initiative in addressing light pollution. The NPS has done work in national parks across the country to reduce the effects of light pollution on the night sky and environment (National Park Service 2020). The NPS's establishment of the Natural Sounds and Night Skies Division allows for a more focused approach to finding solutions to these problems. The IDA works to protect and preserve areas that fulfill the necessary criteria based on their standards to become a Dark Sky location. Along with mitigating the negative impacts of excess lighting, an official IDA park also sees numerous other benefits such as an increase in visitors and tourism during the evening and night time hours.

There is a rigorous application process required to become an International Dark Sky Park (IDSP). This application requires several qualitative and quantitative measurements regarding the quality of the night skies, the compliance of the lighting fixtures in the park following the IDA standards, and efforts taken in community outreach concerning the importance of dark night skies. Acadia National Park historically and currently has dark skies comparable to other National Parks further away from population centers. This project specifically assessed the feasibility of Acadia becoming an IDSP.



2. BACKGROUND

The aggregate impacts of human activity are changing local environments and Earth systems in fundamental ways. One of the ways humans are affecting the environment is through light pollution. This causes both health and livelihood issues for animals and humans. Actions have been taken to provide a safe haven for humanity to experience the natural world in its best possible state, such as the establishment of the National Park Service and the International Dark Sky Association. Project teams from Worcester Polytechnic Institute have played a key role in studying the night sky conditions in National Parks, such as Acadia National Park and Glacier National Park. In this section, we will explore how these issues are related to light pollution and global environmental change, as well as what is being done to prevent light pollution.



2.1 Global Environmental Change

The United Nations defines global environmental change as long-term changes in Earth's climate that affect the balance of ecosystems that support life and biodiversity (United Nations, 2023). Global environmental change disrupts all aspects of the world, from trade and business, to health and leisure.

2.1.1 LIGHT POLLUTION

One of the often overlooked, but influential, forms of global environmental change is light pollution. According to an article found in the January 19th Edition of Science, data collected over the past 12 years shows that light pollution has reduced the brightness of the dimmest stars in the night sky by 10% yearly (Falchi & Bará, 2023). This change in night darkness has impacts across both day and nightscapes.

2.1.2 CHANGES IN NIGHT SKY DARKNESS

An abundance of data exists measuring the darkness of the night sky. Some of this data has been collected by astronomers and leading researchers in the field, while additional data has been collected by citizen science initiatives and student groups, such as the work done by previous WPI project teams. Light pollution has spread and increased over time across almost all areas in the United States (National Park Service, 2017).

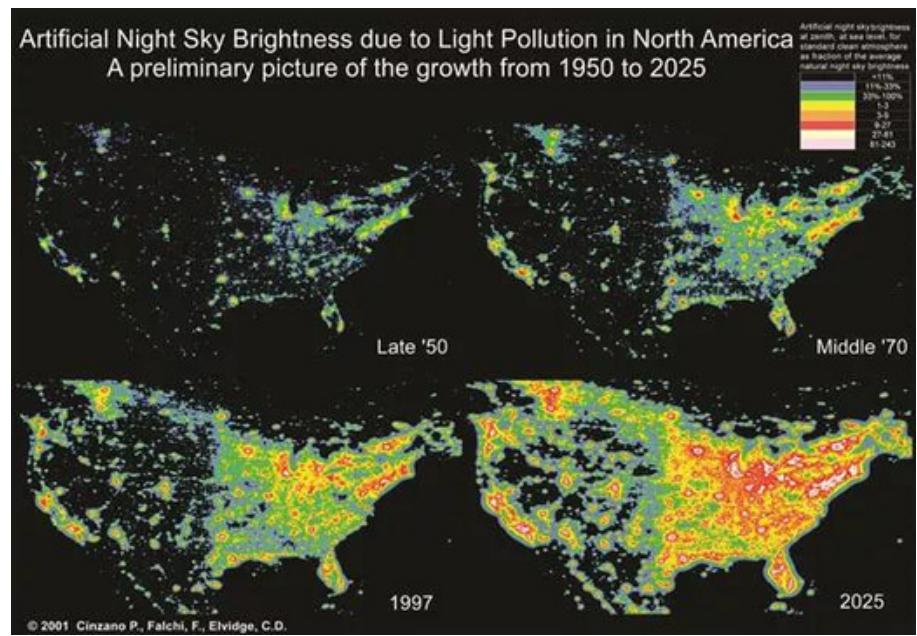


Figure 1 Light pollution data mapped from the late 1950s through 1997 and projected to 2025 (National Park Service, 2017)

These changes are caused by four main types of light pollution; glare, skyglow, light trespass, and clutter.

Glare refers to excessive brightness and can cause visual discomfort. Skyglow is the brightening of skies over populated areas. Light trespass is when light falls in places it is not needed. Clutter is the bright and confusing excessive groupings of light sources (IDA International, 2021). All forms of light pollution have detrimental effects. The dangers of light pollution vary from impacts on plants and animals to economic concerns and energy waste.



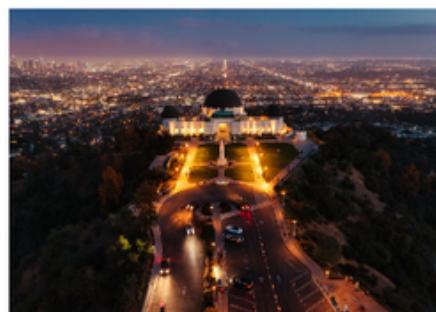
Clutter



Tresspass



Glare



Glow

Figure 2 The four types of light pollution



2.1.3 EFFECTS ON HUMANS AND ANIMALS

The impacts of light pollution can be seen across natural systems. Artificial light contributes to obesity and metabolic disorders in mammals (Guan et al., 2022). The consumption of energy is controlled by the circadian rhythm, which in turn is affected by the light and dark cycle. Artificial light causes confusion to the circadian rhythm by making it unable to distinguish night and day, and thereby when energy should be consumed or stored. This causes metabolic abnormalities. The other ways that light at night affects the metabolism is by changing the pattern of daily food intake, altering hormonal levels, and promoting inflammation. Light at night causes meal intake to occur during inactive times, leading to weight gain. Hormonal signals that are sensitive to light at night can affect metabolism and cause sleeping problems. Light at night can also cause inflammation in the brain and the liver by disturbing circadian rhythms linked via cytokine production.

Artificial light also alters the chromatic contrasts between objects and the environment around them, leading to issues regarding camouflage. This can cause prey to be more noticeable and allow predators to hunt more easily.

Artificial light can cause skyglow, which is when unused light is aimed toward the sky and reflected. Skyglow can cause an increase in ambient light by an amount of 1-4 bars (Stöckl & Foster, 2022). Nocturnal animals have a very specialized vision, working off only a few photons, ready to notice minute details, and comprehend a large amount of information on their surroundings quickly. Because nocturnal animals are used to little amounts of light, when there is an abundance of light, their eyes become overloaded, causing disorientation and difficulty distinguishing their surroundings.



Figure 3 An Eastern Meadow Vole, one of the many animals found in Acadia

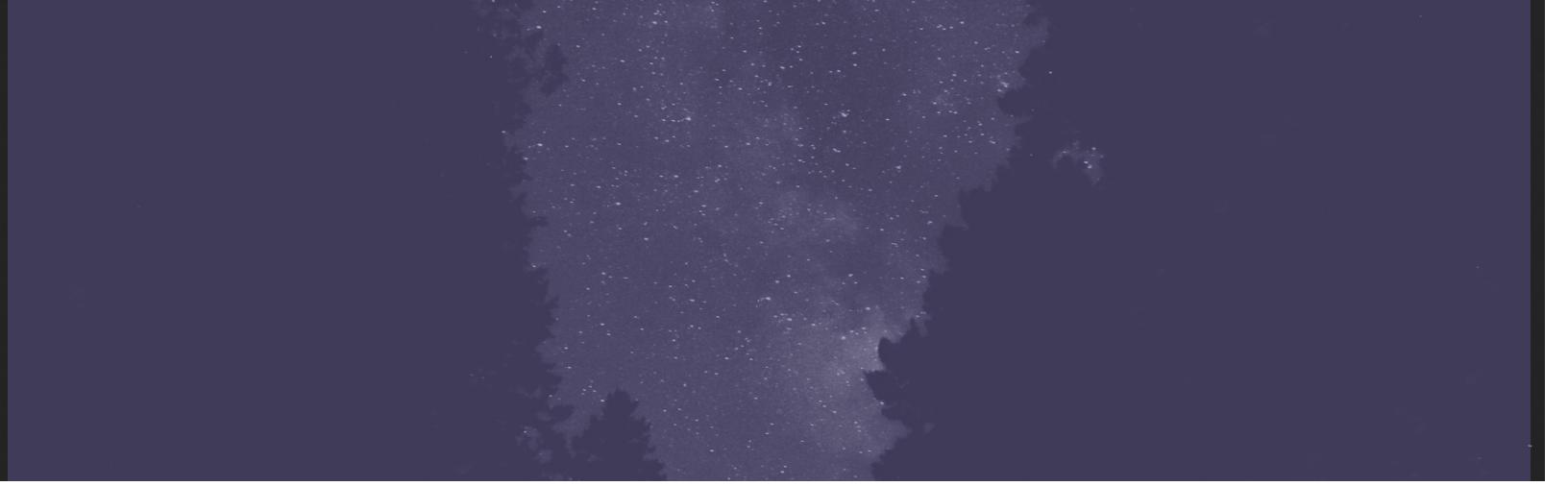
2.1.4 SOCIAL CONCERN OF LIGHT POLLUTION

Along with light pollution's changes to natural ecosystems, there are also impacts on human-made systems. One of the systems often impacted by light pollution is astronomy. Despite improvements in technology, many important discoveries, such as the discovery of the ever-expanding Universe by Edwin Hubble in 1929, would not be possible today due to light pollution (Pien Huang et al., 2023). In order for astronomers to still be able to view the cosmos, the night sky needs to remain dark. As light pollution increases, this creates issues for recreational and professional astronomers.

Light pollution also influences economic systems. As the production of energy is a costly endeavor, any light that is wasted corresponds with other wasted resources. According to the International Dark Sky Association, over 30 percent of outdoor lighting is wasted in the US alone. This waste is estimated to cost over \$3.3 billion yearly and results in the release of 21 million tons of carbon dioxide (IDA International, 2021). Outdoor energy waste is often solvable by the simple measure of shielded lighting, which prevents waste without reducing the amount of illuminated area. Along with this, new lighting technologies can reduce the cost and pollution of outdoor lighting solutions.

One common counterpoint to reducing outdoor lighting is that outdoor lighting decreases crime and increases safety. This, however, has long been found to be based on no concrete evidence, with studies dating back to the 1990s concluding that lighting and crime had no direct correlation (IDA International, 2021). A study conducted by the Chicago Alley Lighting Project proved that increased lighting led to increased crimes, as victims and property were easier to target (IDA International, 2021). Although light may make humans feel safer, this is a long-standing misconception, and the contrary that increased light promotes crime has been proven true.





2.2 Efforts of National Parks to Address Light Pollution

Although the National Park Service has no specific criteria for dark sky measurements and quality within national parks, under the Organic Act of 1916, dark skies are seen as a cultural, economic, and natural resource. As such, dark skies must be preserved and protected to the highest extent possible for all to enjoy. The Natural Sounds and Night Skies Division, along with other organizations, have taken the initiative to reduce light pollution and protect the night skies.

2.2.1 COLLABORATION ON A GLOBAL SCALE

The Natural Sounds and Night Skies Division's collaboration with other organizations allows for the protection of night skies to expand to a global level. This allows for the sharing of resources and information, as well as further increasing the progress made toward goals set out to reduce light pollution. The National Park Service also cooperates with different groups such as the International Dark-Sky Association and the Illuminating Engineering Society to advance lighting infrastructure that has less impact on light pollution.

A major benefit of shared global resources is the ability to access vast amounts of data collected from researchers around the world. The Natural Sounds and Night Skies Division, using the Web of Science database, created a tool used to synthesize scientific literature. This tool was able to run through over four hundred articles based on artificial light and light pollution, written both in the United States and globally. Using internationally recorded data assists the National Park Service in gaining a bigger picture of the impacts of light pollution on the night sky, the environment, and society as a whole, as well as stay up to date with the latest research done and most recent data collected (Kavanagh, 2022).



2.3 The International Dark Sky Program

The Dark Sky Program was developed to ensure a dark night sky for current and future generations (International Dark Sky Association). Six different categories exist that can be certified as part of the Dark Sky Program. These categories include Urban Night Sky Places, Dark Sky Friendly Developments of Distinction, Sanctuaries, Reserves, Parks, and Communities. In January of 2023, there were 201 certified Dark Sky locations around the world. Of these 201 locations, there are 6 Urban Night Sky Places, 6 Dark Sky Friendly Developments of Distinction, 16 Sanctuaries, 20 Reserves, 115 Parks, and 38 Communities. For a location to be certified as a Dark Sky Program official location, the International Dark Sky Association (IDA) reviews a rigorous application process. Applicants must document all specific program requirements and display large community support for dark sky protection. The IDA committee that reviews all applications is composed of previously accepted program applicants, as well as dark-sky experts (IDA International, 2021). For the purpose of this paper, International Dark Sky Parks will be most closely examined. An International Dark Sky Park identifies, restores, and protects public lands; encourages eco and astro-tourism; promotes the protection of the natural night environment, visitors' enjoyment of the dark sky (alongside its heritage), and areas for professional and amateur astronomy.

2.3.1 BENEFITS OF DARK SKY DESIGNATION

There are many benefits to the Dark Sky Program. According to a study done in Bryce Canyon National Park, which is not a Dark Sky Park but does have dark sky programming, up to 10 percent of visitors to the park were involved in formal dark-sky and astronomy programming, as well as some informal astronomy activities.

With the increase of visitors participating in evening programs, visitors nearly doubled, originally starting at 13,451 visitors and totaling 23,878 visitors afterward. This then created an increase in funds earned from visitors; before, the amount earned was \$1.1 million, and after the rise in visitors it was \$1.7 million (International Dark Sky Association, 2015).

Another benefit of the Dark-Sky program is it economically helps surrounding communities. In a study done at Galloway Forest Park located in Scotland after it became an official IDA Park, results showed that for every £1 spent to meet compliance for the Dark-Sky Park, there was a return of at least £1.93 due to the increase of tourism. This is only a partial investigation into the matter, however. There are likely more positive impacts on surrounding communities (IDA International, 2021).

2.3.2 OTHER DARK SKY PARKS OF PARTICULAR RELEVANCE

Although there are many International Dark Sky Parks across America, IDSP recognition on the east coast is more difficult to achieve due to dense population centers. Despite this challenge, Dark Sky designation is possible on the east coast. There are currently two locations in Maine that have been recognized by the International Dark Sky Association. The most recent designation was in 2021, which is also the closest location in Maine to Acadia National Park. This location is the Appalachian Mountain Club's (AMC) Maine Woods Initiative lands. It is about 300 square kilometers of land in central Maine. This land is categorized as an International Dark Sky Park and is an excellent resource while going through the process to qualify Acadia National Park as an International Dark Sky Park, as it can share information specific to Maine that other IDSP sites will not be able to provide. (IDA International, 2021).

In the next section, Acadia National Park will be specifically explored, including prior work, current outreach, and IDSP status.



2.4 Dark Sky Efforts at Acadia National Park

Acadia National Park has a long-standing history of having some of the darkest skies on the east coast, and work has been conducted by the park and other WPI project groups to share the dark skies with the community. In this section, an overview of dark sky works in the park will be covered, along with some of the specifics of how dark skies are determined.

2.4.1 PRIOR WORK

Community outreach, lighting inventory, and heat maps have been a large component of the focus in WPI's past Acadia Dark Sky projects from 2013 to 2017. The 2013 WPI project team began their work with help from a 2009 study conducted by two College of the Atlantic (CoA) students. The CoA students created a heat map of Mount Desert Island (MDI) through the use of Sky Quality Meters (SQM) in addition to geographic information system (GIS) software. The WPI groups in the years following, up to 2017, improved upon these measurements in addition

to drafting a provisional IDSP application and a community outreach program in Southwest Harbor. In 2017, (the most recent work from a WPI dark sky team in Acadia) the lighting inventory and heat maps were again updated, a cost-benefit analysis for replacing non-compliant light fixtures was created, and an outreach website was created for public education about Dark Sky Parks. They additionally focused on having Acadia qualify as an IDSP and Bar Harbor as an IDSC (Lund et al., 2017).

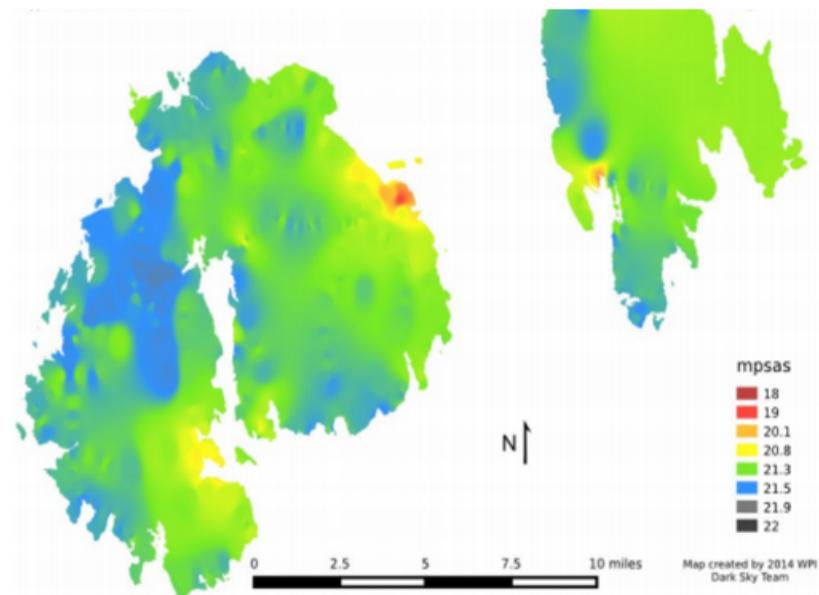


Figure 4 Heat map created by prior WPI project teams

2.4.2 CURRENT OUTREACH

Acadia hosts a plethora of events catered to the excitement of the night sky to attract visitors and nearby residents to the preservation of the night sky. Historically, the Acadia Night Sky Festival, hosted annually in late September, promotes preserving the Downeast region of the starry sky for a weekend with a “star party” on Cadillac Mountain. Alongside local astronomers, enthusiastic rangers, and professional stargazers, visitors can learn about light pollution and peer through high-powered telescopes to appreciate the constellations and Milky Way in a way they would not be able to at home (Moretto, 2012). Currently, Acadia Night Sky, formally known as Stars Over Sand Beach, is held every Thursday, engaging the public in learning about and appreciating the constellations.

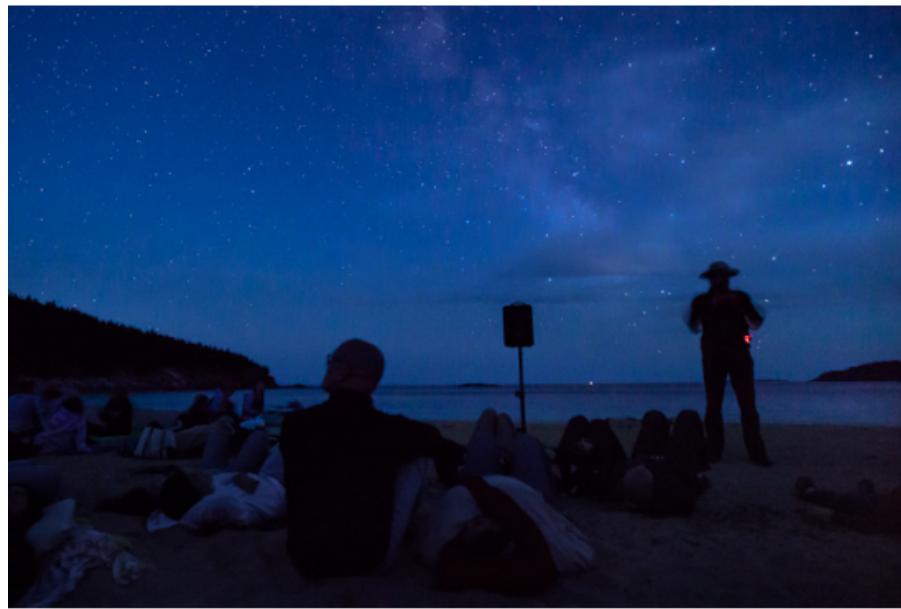


Figure 5 Acadia Night Skies event on Sand Beach

These types of events are crucial to the public's excitement and knowledge of the Night Sky Initiative, as Acadia is the only national park in the northeast that has a natural darkness comparable to the remote parks west of the Mississippi River. Acadia is a class 3 or 4 on the Bortle Scale with historically clear visibility of the Milky Way, meaning that visitors to the park at night may experience the darkest night sky they will get to see in their lifetime (Moretto M., 2012)





3. METHODOLOGY

Acadia National Park and prior WPI project teams have conducted work to conserve the darkness of night skies and move forwards towards becoming a Dark Sky Park. With the ever-growing concern of human impact on the natural environment, this project looked to determine the effect of light pollution on the nightscape of Acadia National Park and assess the plausibility of Acadia submitting an application to become an International Dark Sky Park. This project aims to answer the question: **How can the effects of light pollution towards nature and the night sky be reduced at Acadia National Park, and what steps should be taken in order to classify Acadia National Park as a Dark Sky Park?** Along with this, the IDA has several guidelines regarding the establishment of an International Dark Sky Park, which include night sky quality and lighting fixture requirements, along with community outreach and programming tailored towards increasing public knowledge and support of night sky preservation.

PROJECT OBJECTIVES

Three objectives were developed to accomplish this project goal:

Measure dark sky quality in Acadia for compliance with IDA IDSP standards

Determine which lighting fixtures in Acadia are compliant with IDA IDSP standards

Analyze current outreach efforts and collect community feedback on outreach

In addition, the flow chart shown in Figure 6 shows how these three objectives contribute towards the overall purpose of this research, and how each objective will be accomplished.

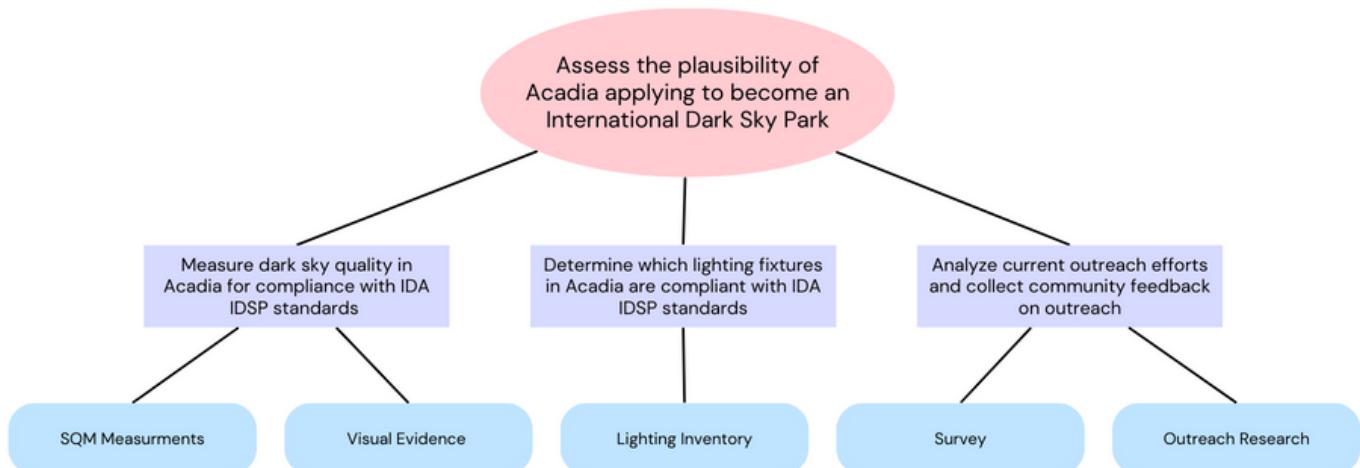


Figure 6 Flowchart showing objectives and methods to achieve the purpose

This chapter discusses the plan to gather and analyze data that assisted in completing these objectives, as well as the explanation for choosing these methods and what can be learned from their implementation. Appendix A includes a sample of the Research Instrument, Appendix B includes a Gantt Chart of the timeline of the implementation of these methods, Appendix C includes the data taken on the darkness of the night sky, and Appendix D contains the promotional outreach materials used, including the trifold pamphlet and survey poster.

3.1 Measure Dark Sky Quality in Acadia for Compliance with IDA IDSP Standards

To assess the current conditions of night skies in Acadia National Park, multiple methods were used to determine the impacts of light pollution on the night sky darkness, including collecting quantitative data about night sky darkness, taking photos to document the night sky quality, and making observations of what is seen in the field.

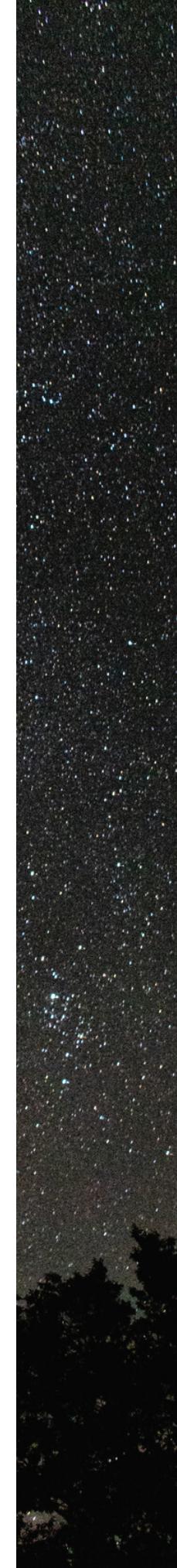
3.1.1 NIGHT SKY QUALITY REQUIREMENTS

The International Dark-Sky Association provides general criteria that qualitatively describes night sky standards. These criteria include being able to easily see the Milky Way with the naked eye, no artificial light sources causing significant interference with sky darkness, and any "light domes" in the surrounding area being at low light levels as well as having a low height relative to the horizon. To quantitatively measure these requirements, the average of the five recordings done with a Sky Quality Meter should be at least 21.2 magnitudes per square arcsecond or above.

3.1.2 NIGHT SKY QUALITY RECORDING

One crucial component of assessing sky quality in Acadia National Park was collecting data readings of the night sky darkness using a Unihedron Sky Quality Meter - L (SQM-L). These readings provided a quantitative assessment of the darkness of the night sky and allowed for Acadia's skies to be compared to IDA and National Park Service baselines and requirements.

To ensure night sky quality readings are consistent with international standards, data was collected in accordance with IDA guidelines for comprehensive and valid measurements. Data collection was done during the proper phases of the moon cycle and the time of night. All readings were taken during astronomical darkness, which is defined as when the sun is more than 18° below the local horizon (IDA International, 2018). The moon can also impact readings, so all readings were taken when the moon was below the horizon or during a new moon cycle. Another aspect of the data collection process is the clarity of the night sky and the location of readings with respect to light sources or other obstructions, such as trees or buildings. Since 2013, prior WPI research teams have established locations for collecting readings, and to further establish trends over time, these locations were reused (Lund et al., 2017). The location data was verified using GPS values recorded using a cellphone and was accurate to 1/10th of a second.





Sky quality readings were collected using Unihedron Sky Quality Meter - L (SQM-L) devices. These allow for near-instantaneous night sky darkness readings established in magnitudes per square arcsecond, which can then be compared with the IDA standard for sky darkness.

Readings were taken in accordance with IDA guidelines for comprehensive and valid measurements, including the number of readings, location requirements, and recording of other related information (IDA International, 2018). All readings were taken in a series of 6, with the first reading discarded as it is prone to error due to the starting of the device. The remaining 5 readings were averaged to calculate the magnitudes per square arcsecond readings of the dark sky in that area. Along with this, the weather, sky visibility, temperature, time, and GPS location were recorded.

To collect the most accurate measure of dark sky quality possible, two SQM-L meters were used to identify outliers and ensure all data is as accurate as possible. To do this, both devices were placed side by side with their sensor points directly up in a box. This allowed for easy access to both the buttons used to take readings and the screens where measurements are displayed. It also ensured that both devices were kept still at the time of readings. An image of this setup can be seen in Figure 8. When collecting data, both devices were started at the same time, and the measurements of each device were then recorded following the process previously described. All data collected was recorded in the spreadsheet shown in Appendix C.



Figure 7 Unihedron Sky Quality Meter - L



Figure 8 SQM-L devices in the storage box

The IDA requires a minimum of 5 locations to be included in the night sky quality assessment. These locations should be places visitors are likely to stop and stargaze, as well as the brightest and darkest areas in the park. In order to best assess the night sky across Mount Desert Island, the following 18 locations were used. These locations have been used by prior teams and allow for the baseline measurements to be updated. The locations can be seen in Figure 9.

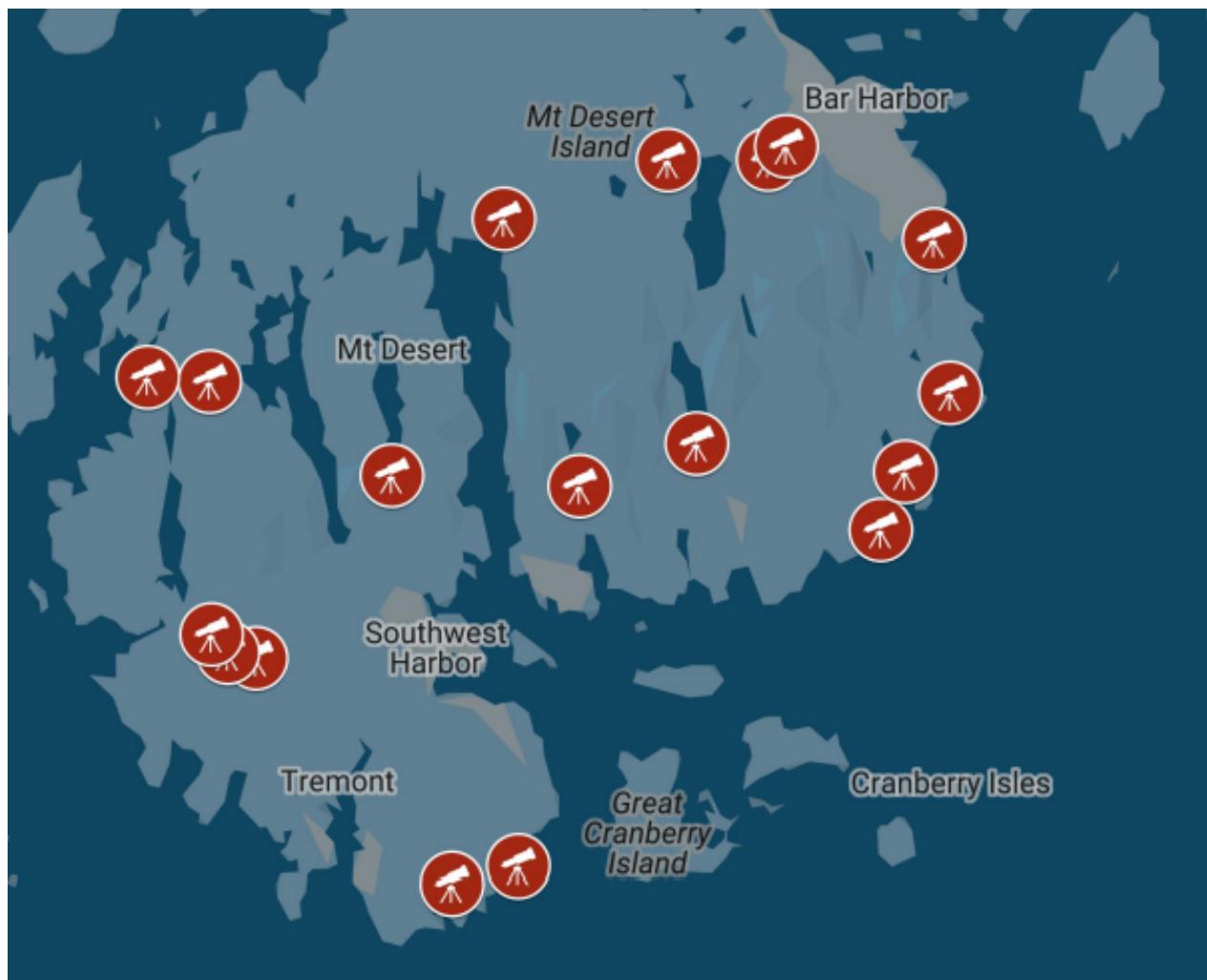


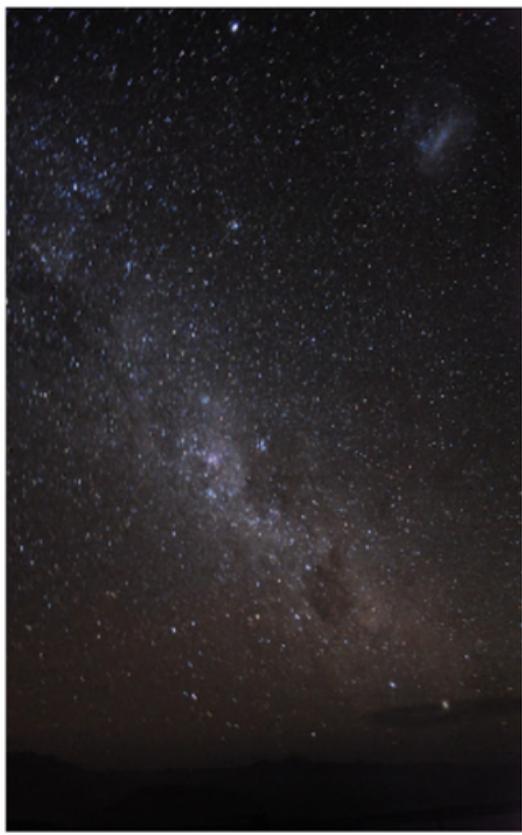
Figure 9 Locations of sky quality readings across Mt. Desert Island

3.1.3 VISUAL QUALITY ASSESSMENT

Along with the quantitative methods used to measure the dark sky quality, qualitative methods were employed. These methods included the use of field observations of the night sky and photographic evidence.



Another aspect of IDA standards for International Dark Sky Park designation is photographic evidence of night sky darkness. These photographs verify that certain light domes are visible in the night sky and verify the SQM-L readings (IDA International, 2018). To accomplish this, photographs were taken of the night sky during the SQM-L data collection process. All of the guidelines for SQM-L data collection were followed, along with additional guidelines to ensure all photos follow IDA standards. These additional guidelines include recording the camera details used, such as exposure time, ISO, and focal length (IDA International, 2018). An example of this can be seen in Figure 10.



Photographer:	Ameé Hennig
Location:	Cerro Pachón, near SOAR Telescope in Chile (GPS location if available)
Phenomenon Shown:	Milky Way, Large Magellanic Cloud
Camera:	NIKON D3000
Exposure:	17.5 sec (1/0)
Aperture:	f/3.5
Focal Length:	18 mm
ISO Speed:	1600
Special Editing:	None

Figure 10 Example of photographic evidence and additional required information

When combined, the use of photographic evidence and SQM-L readings portray quantitative and qualitative methods to produce the best assessment of night sky quality. This data can then be further analyzed to determine the quality of night skies in Acadia National Park.

3.2 Determine Which Lighting Fixtures in Acadia are Compliant with IDA IDSP Standards

As part of the process of determining if Acadia National Park is eligible to become an IDSP, the lighting fixtures in the park were analyzed to ensure adherence to guidelines set by the IDA and NPS. This was done through the use of the software provided by the Natural Sounds and Night Skies Division of the National Parks Service, and involved field visits to all lighting fixtures on Mt. Desert Island during the day and night hours. During this time, all relevant field measurements were recorded.

3.2.1 LIGHTING COMPLIANCY REQUIREMENTS

Once the lighting inventory had been completed, it was analyzed in accordance with the Dark Sky guidelines in order to determine if Acadia National Park meets the requirements to become an IDSP.

Lighting compliance is a complex system of many parts. The three main criteria lights must meet in order to be compliant can be seen in Table 1 which was compiled from the 2021 IDA guidelines.

Purpose of Lighting	The use of outdoor light at night is only prescribed for when it is strictly needed, where it is needed, and in the appropriate amount for a specific task. The purpose of outdoor light allowed under the policy must be specifically to ensure public safety. Lights can additionally be used for Historical Preservation and are to be reviewed on a case by case basis.	 Path lighting at the Jordan Pond House, which serves the purpose of safety.
Shielding of Lighting	All outdoor lighting fixtures emitting more than 500 initial lumens must be fully shielded and make appropriate use of timers and motion sensors. Any special purpose lighting under 500 lumens must also make use of proper shielding unless properly documented and used for historical preservation.	 A properly shielded fixture, often used by the park on restrooms.
Color of Lighting	Emission of short-wavelength light is limited through one of the following restrictions: Light source correlated color temperature (CCT) must not exceed 3000 K; OR Allowed lighting must not emit more than 25% of its total spectral power at wavelengths shorter than 550 nm; OR The scotopic-to-photopic (S/P) ratio of allowed lighting must not exceed 1.3.	 A warm amber light that meets the color requirements, with a CCT below 3000K. The team chose to focus on CCT of all lights, as it is the easiest to measure in the field.

Table 1 IDA lighting compliance guidelines and examples



Along with this, lighting controlled with motion-activated switches, which limits the duration of illumination to less than five minutes after activation, are exempt from the compliance requirements. The IDA has also defined compliance of signage, temporary lights, and lights emitted by park visitors, but these guidelines were not a major focus of the team's research.

In order for Acadia to become an IDSP, at least two-thirds or 67% of the lighting fixtures in the park must conform to these guidelines, with all lights properly documented in the Lighting Inventory.

Lastly, the lights were examined for compliance with National Park guidelines. The guidelines for outdoor lighting by the National Park Service are simple: restrict the use of artificial lighting in parks to areas where security, basic human safety, and specific cultural resource requirements must be met, use minimal-impact lighting techniques, and shield the use of artificial lighting where necessary to prevent the disruption of the environment and living creatures. The database was analyzed by these principles, and lighting that breached these requisites were noted.

3.2.2 LIGHTING INVENTORY DATA COLLECTION AND MANAGEMENT

The Natural Sounds and Night Skies Division of the National Park Service has developed an innovative system to use when conducting park lighting inventories. This system allows for information about all outdoor lighting within park boundaries and the immediate surrounding areas to be recorded, following a standardized protocol. The NSND system is a novel approach to the lighting inventory collection process, and our team is one of the first Institutional groups to test its effectiveness.

The data collection process involved visiting all outdoor lighting fixtures twice, assessing it once during the daylight hours and again at night. To ensure comprehensive coverage, two to five members of the team walked through areas of the park where lights had been documented by the 2016 WPI research team, or any other areas with buildings or additional structures where lights may be found.

During a daytime visit to a lighting fixture, a new luminaire entry was added to the ArcGIS field maps mobile app. The fixture's GPS location was then recorded with a maximum of a 10-meter buffer, as well as the date and time. Following this, a picture of the light and its location on the structure was taken, along with whether the light is a historical lighting fixture, its height in meters, the light's purpose or task, the luminaire type, and how many lamps there were within the lighting fixture. For full definitions and options for the described categories, see Appendix E.

Night visits were also necessary to collect data on external lighting fixtures. During a night visit, the Correlated Color Temperature (or CCT, which is the gauge of how yellow or blue a light is), as well as the lux of the light, were measured. Additionally, the type of control system it runs on, whether the light is on at night, and the backlight, uplight, and glare of the light were recorded. The OPPLE Light Master 4 Light Meter was used to measure the lux and CCT of the lights, and the data was then saved on the ArcGIS map.

For data storage, a preliminary map with a layer for luminaires was used within ArcGIS. This software was provided by Sharolyn Anderson, a member of the National Park Service Natural Sounds and Night Skies Division, and was prepared with all of the necessary fields for data collection. Maps of the park boundaries, along with the feature layer for inventorying lights, were downloaded using the Field Maps mobile app, allowing for data to be taken offline and synced once a cellular or WIFI connection was established. This information was saved to a data point on the map and uploaded to the main online map once an internet connection was established.

3.3 Analyze Current Outreach Efforts and Collect Community Feedback on Outreach

Without support from park visitors and surrounding communities, it would not be possible to establish and maintain Acadia National Park as an IDSP. The requirements for outreach programs are: events must mention light pollution and the IDA in the programming, and some kind of dedicated programming occurs at least four times a year. Possible examples of outreach include star parties, museum exhibits, interpretive dark sky protection programs, educational programming, or dark skies tourism.

3.3.1 REQUIREMENTS FOR OUTREACH PROGRAMMING

There are four main parts to the outreach requirements. These ensure that the park has a commitment to protecting the night sky.

The first is that the park has set a leadership example in the restoration of dark skies, meaning that the park has in some manner worked in dark sky restoration. This can be accomplished by working on a lighting project that doesn't negatively affect the night sky and can be publicly viewed. It can also be accomplished by working with 2 or more external partners in dark sky restoration efforts, such as universities, environmental or conservation groups, and others. Finally, this can be completed by cooperating with two or more municipalities to create lighting policies that improve sky quality in the park. In order to research this, the team looked into Acadia National Park's collaborations with other organizations on their website.

The second is that the park has a commitment to public education. This was researched by looking into Acadia's events calendar and their general website to see what information they had available to the public.

The third is that the importance of dark skies and the benefits of quality lighting must be a part of the park's interpretation and outreach programs. This can be accomplished through having dark skies being a main topic during outreach events, and having a section of the event cover dark sky awareness or the IDA. Another way this can be accomplished is through information on dark sky topics being publicized through social media, flyers, and other such media. This was researched by investigating Acadia National Park's online events calendar and articles on their website.

The fourth requirement is that dedicated outreach programs must occur at least four times a year. This was examined by once again looking at Acadia's event calendar, along with the calendars of organizations that work in conjunction with the park.

3.3.2 SURVEY ON VIEWS REGARDING ACADEIA NATIONAL PARK'S DARK SKY PROGRAMMING

To understand how the Mount Desert Island community and visitors view Acadia National Park's dark sky programming, a survey was created to gather feedback. The survey was created in Google Forms and then distributed on posters and brochures through a QR code. These posters were posted at locations within the College of the Atlantic and around Bar Harbor, as seen in Figure 11.

The brochures, as well as a paper version of the survey, were distributed at Hull's Cove Visitor Center, when two members of the team tablesat on Monday, July 24th, 2023 from 9:30 AM to 4:00 PM.

Questions on this survey cover topics such as how the participants use the park and how many participants take advantage of the dark sky programs, as well as if they would like to see more

programs than what is offered currently. To evaluate responses quantitatively, the Likert Scale was implemented for answers. An example of a question asked includes "I would like more night sky programming at Acadia National Park". Then the following options were provided for answering the question: "Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree." The full survey that was used can be found in Appendix B. The survey was completed by 148 park visitors.

Using the survey results, recommendations were provided for both current and future programming to Acadia National Park. These recommendations were created from analyzing the Likert scale survey created, as well as any other feedback participants may have for the park.

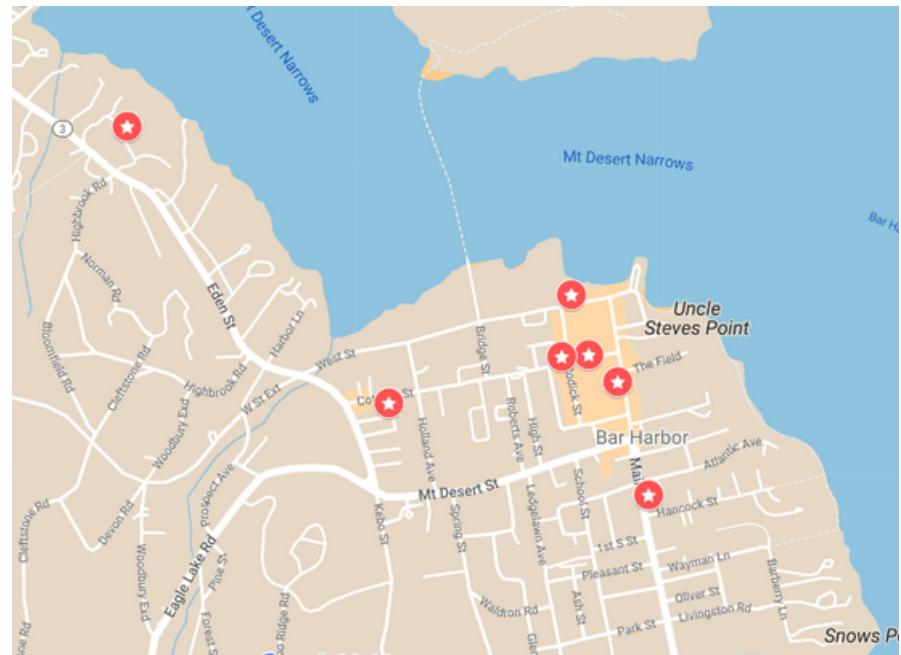


Figure 11 Locations of survey posters in Bar harbor



4. FINDINGS

The three sections of an application to become an International Dark Sky Park are dark sky quality, lighting fixture compliance, and outreach regarding light pollution. The team's research within Acadia National Park has resulted in positive findings on both the night sky quality and outreach in Acadia. During the lighting inventory, the team found that through the use of the new NPS provided system and changes in IDA standards from past years, overall compliance in the park has decreased, but can be improved without any major changes.

4.1 Dark Sky Quality in Acadia National Park

To gauge the quality of the Night Skies of Acadia National Park the team conducted night sky measurements, recorded field observations, and collected photographs of the night sky. With this data, the team determined that despite pollution from artificial light sources, the skies within Acadia National Park are beautifully preserved and of excellent quality.

4.1.1 LIGHT POLLUTION FROM OUTSIDE LIGHT DOMES

During the data collection process, the team observed light from nearby towns, cell and radio towers, and other artificial sources seeping into the nightscapes of Acadia National Park. Such light is detrimental to the quality of the night sky and has a broad range of impacts.

The strongest cause of light pollution in Acadia is the town of Bar Harbor, which is a bustling tourist community, with a lively scene and many well-lit streets and storefronts. As such, the sky glow caused by the town is visible, as shown in Figure 12. Similar impacts were noted from other light sources, such as the cell or radio towers visible from sections of Park Loop Road. However, most locations throughout the park did not have visible light pollution sources present and were of excellent night sky quality.

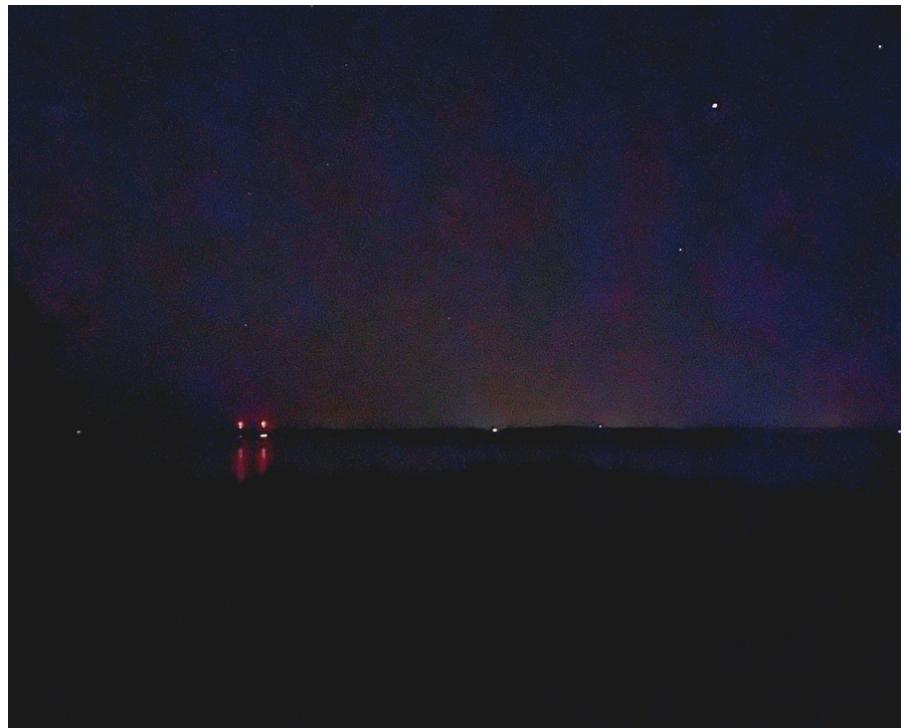


Figure 12 Sky glow caused by Bar Harbor

4.1.2 WELL PRESERVED NIGHT SKIES WITHIN ACADIA NATIONAL PARK

Despite the light pollution from Bar Harbor and other external sources, there was not a severe impact on the sky quality recordings to move Acadia away from the IDA's standards. The team collected data at 18 locations across the portion of Acadia National Park found on Mount Desert Island. These locations can be found in Figure 12.

All readings were above the IDA-specified threshold (21.2 magnitudes per square arcsecond) for Dark Sky Park designation. A chart of all readings can be seen in Figure 13. These locations align with the numbers assigned to each location, which can be seen in Appendix C.

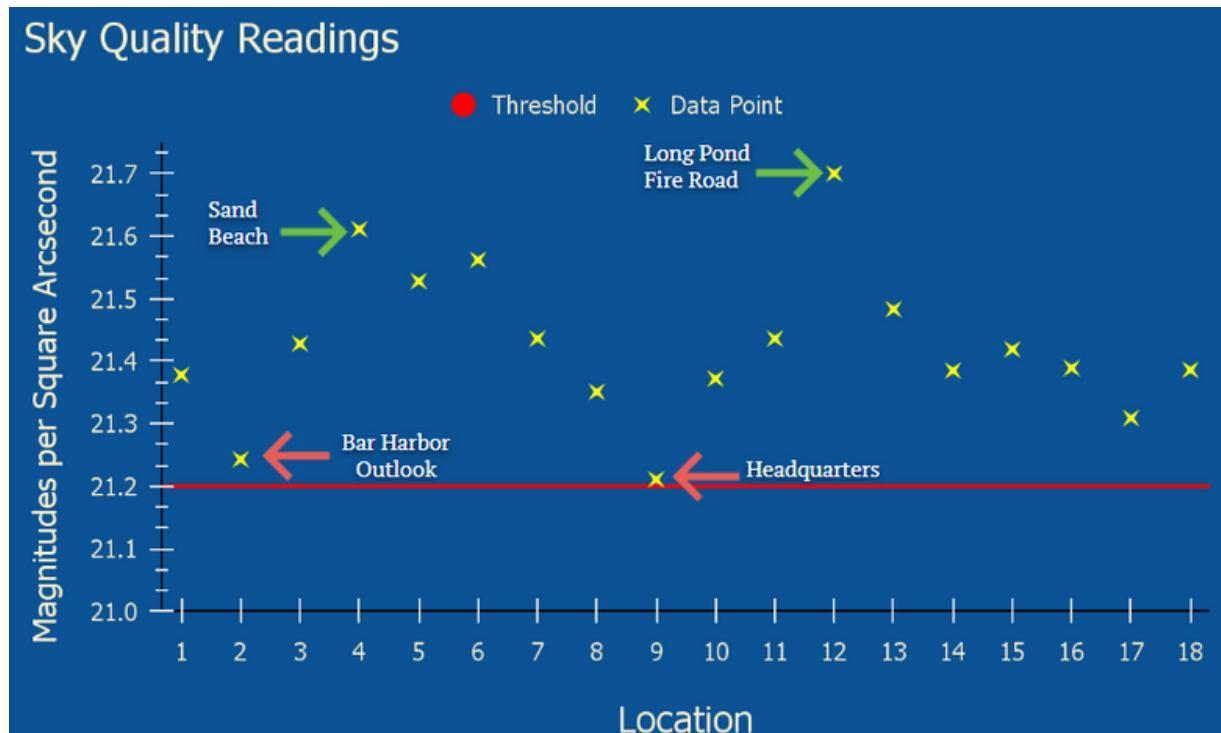


Figure 13 Results of sky quality measurements across Mt. Desert Island

As shown by this data, the night skies of Acadia National Park are well poised for Dark Sky designation. The darkest locations found from these results were Sand Beach (Location 4) and the location along Long Pond Fire Road (Location 12). These locations even have night sky quality comparable to remote IDSP National Parks of the American West, such as Zion National Park, where darkness values are on average greater than 21.5 magnitudes per arcsecond (International Dark Sky, 2021). Other locations such as the Bar Harbor Lookout on Park Road (Location 2) and the location nearest to headquarters (Location 9) have readings much closer to the minimum requirement. The team determined that this is in part due to the prevalence of outdoor lighting in these areas. Despite this, these readings were still above the specified threshold, but should be closely monitored and retested to ensure accuracy across all seasons.

Overall, the SQM readings collected show the strength of Acadia as a candidate for Dark Sky designation. A full collection of all readings, along with GPS coordinates and weather conditions, can be found in Appendix C.

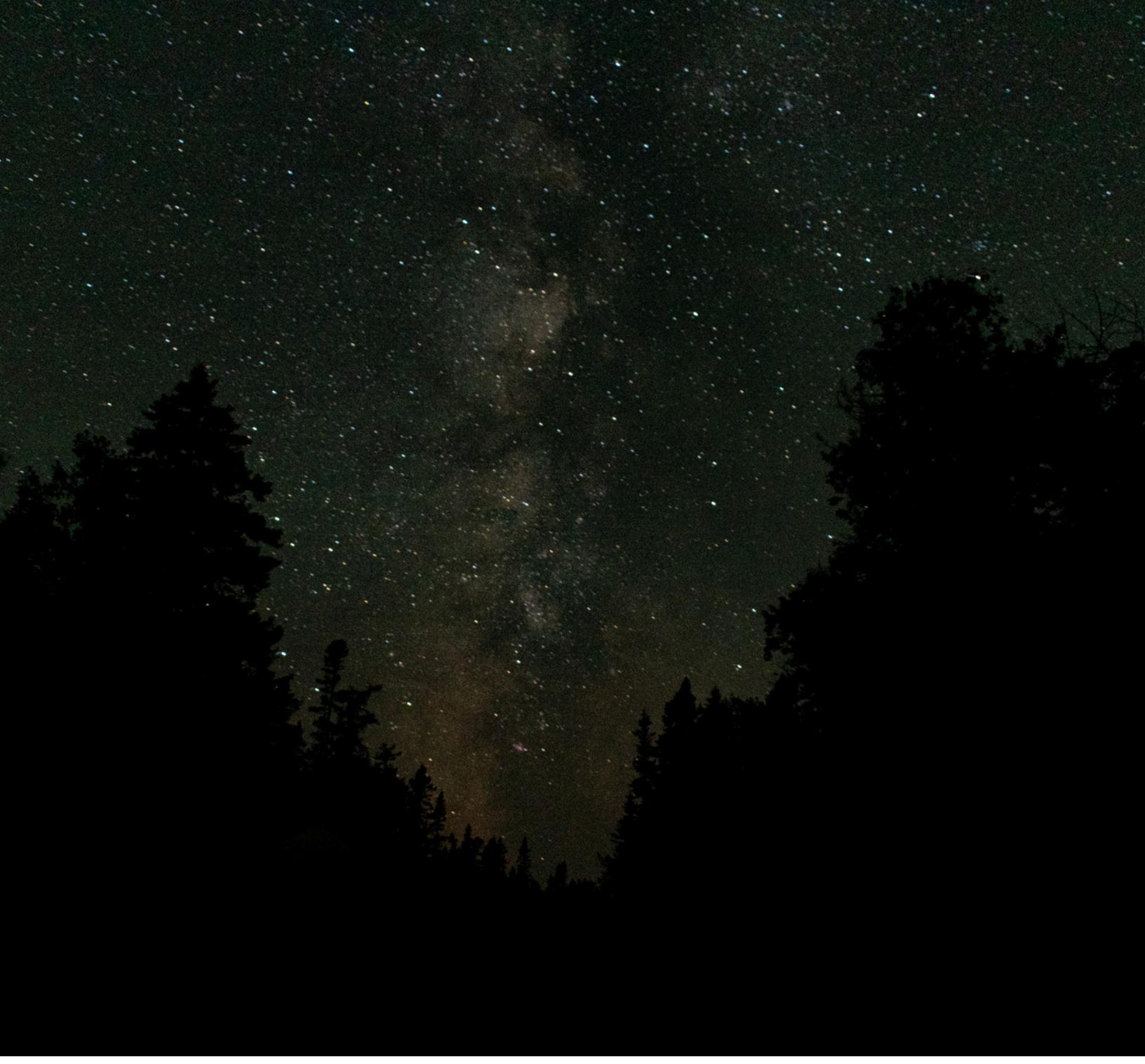


Figure 14 The Milky Way from location 16, near the Wonderland Trail Head

Furthermore, the team could not help but be awestruck by the natural beauty of Acadia's night skies. During the data collection processes, everyone noted they had never seen anywhere near the number of stars observed in the field. The Milky Way was clearly visible across the night sky, along with countless constellations. The team even observed multiple shooting stars during the time spent gazing up into the cosmos. To document the quality of darkness, the team also spent time in the field photographing the night sky. Figures 14 and 15 show a collection of the best examples of Acadia's night sky, along with a short description of the photograph and any additional information.



Figure 15 The Milky Way from location 13, located on Seal Cove Road

4.2 Lighting Fixtures of Acadia National Park

To further assess the possibility of Acadia National Park becoming an IDSP, the team also conducted an inventory of the outdoor lighting fixtures within the park. During the creation of this inventory, the team found that through the use of the new NPS provided system and changes in IDA standards from past years, overall compliance in the park has decreased, but can be improved without any major changes.

4.2.1 COMPLIANCE OF OUTDOOR LIGHTING FIXTURES

The team collected data on lighting fixtures across the Mount Desert Island portion of Acadia National Park. Based on the last inventory, collected in 2016, the park has 929 outdoor lighting fixtures. For this project, 458 lighting fixtures were accounted for, along with their relevant metrics and location in the park. Once all data points were accounted for, each fixture could be individually analyzed. Attributes of the recorded lights were compared to IDA and National Park guidelines, and could then be categorized as compliant or non-compliant.

NPS System Measured Compliance of MDI

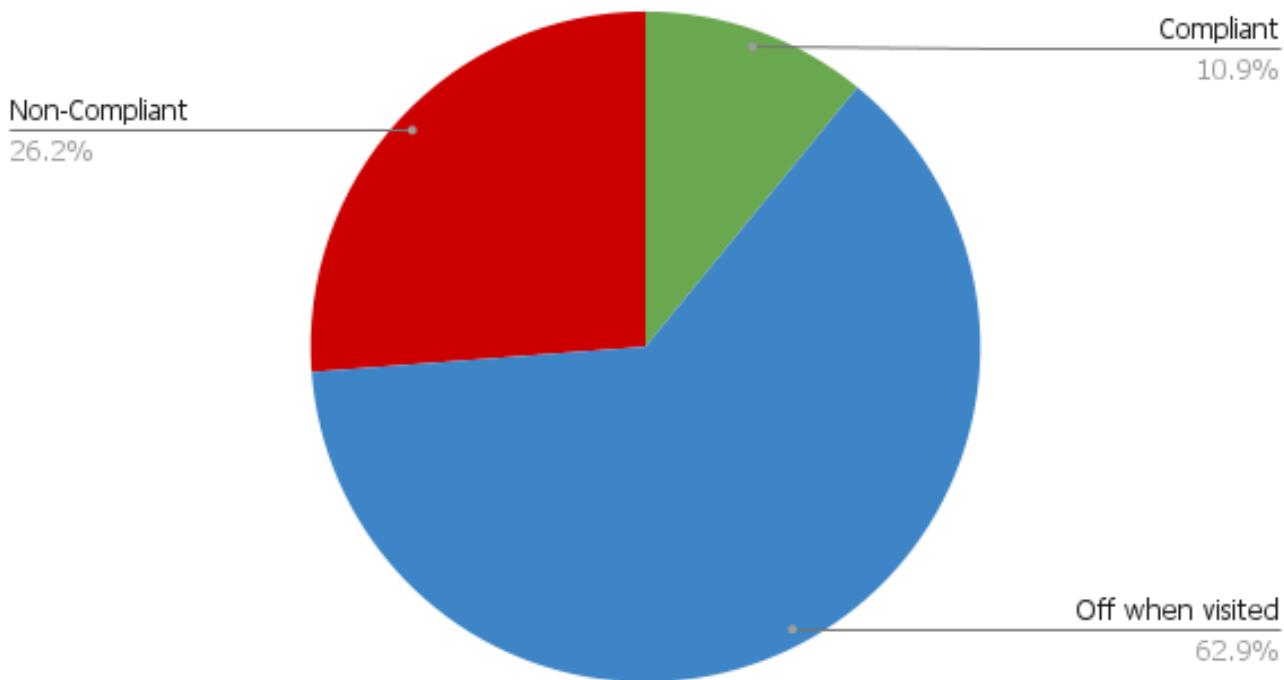


Figure 16 Compliance of all lighting in Acadia on Mt. Desert Island

The major issue found with the new system was its requirement of lighting fixtures to be on when visited in order to collect all required fields. 63% of lights were non operational when visited. This resulted in 268 lights on Mount Desert Island being unconfirmed for compliance. Of the 37% of lights that were operational when visited, only 11% met all 3 IDA requirements for compliant lighting. An overall breakdown of lights on Mount Desert Island can be found in the Dashboard Deliverable.

MDI Shielding Compliance

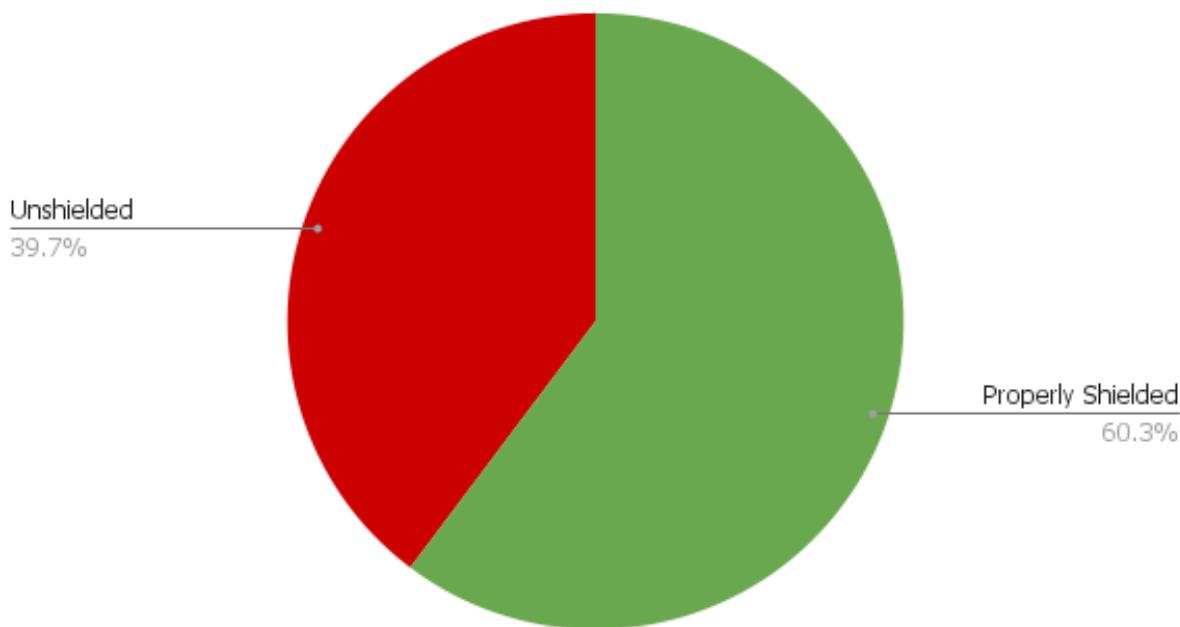


Figure 17 Percent of lights properly shielded on Mt. Desert Island

If the team were to exclusively examine the shielding compliance of the lights found on Mount Desert Island, 60% of lights met the proper shielding standards. This means that 49% of lights on Mount Desert Island will only require changes in CCT in order to become compliant with IDA standards. One important note about field measured CCT is that the Opple Light Master 4 used by the team on night inventory visits, although certified by the IDA, is known to be inaccurate when measuring lights below 4000k. This means that the 47 lights that were measured to be between 3000k and 4000k have a potential to meet IDA guidelines if remeasured with higher quality equipment.

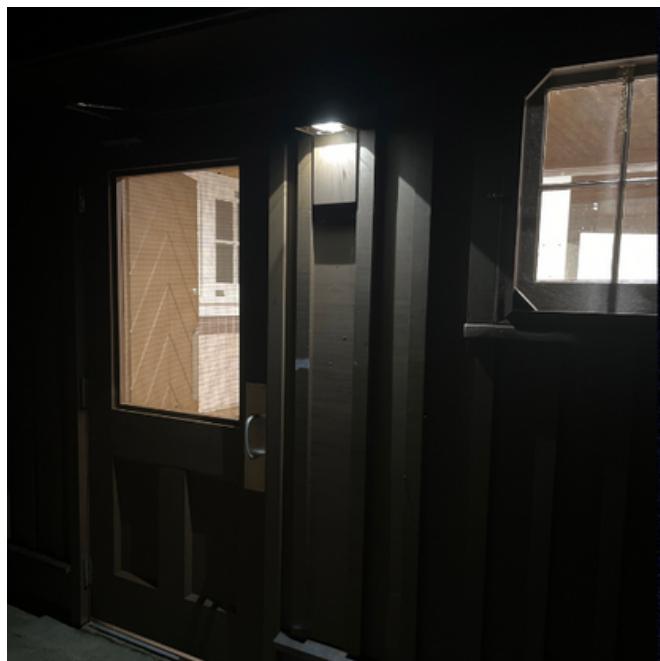


Figure 18 Properly shielded light that does not meet the CCT requirement





4.2.2 IMPACT OF OTHER LIGHTING SOURCES

The team additionally observed that interior lighting has an impact on the nightscapes of Acadia. In one specific instance, the team observed interior lighting fixtures at Jordan Pond House, which, due to brightness and inadequate shielding, had a major impact on outdoor light pollution. Readings taken with the SQM meter from the Jordan Pond House observation deck confirmed these results, with an average reading of 18.1 magnitude per arcsecond, which is well below the IDA guidelines for Dark Sky designation.



Figure 19 Light trespass caused by interior lighting at the Jordan Pond House



4.2.3 IMPLICATIONS OF THE NATIONAL PARK SERVICE LIGHTING INVENTORY SYSTEM

The newly provided ArcGIS based inventory system provided by the Natural Sounds and Night Sky Division of the National Parks Service was found to hold parks to a higher standard than is required by the International Dark Sky Association. The NPS system requires collection of many additional data fields not required by the IDA, such as the backlight, uplight, glare, and trespass of all lights. Additionally, the NPS system requires both day and night visitation to all fixtures in the park. This allows for the park to have a better understanding of the lighting fixtures in the park, as this process is more accurate and informative. The team found that the NPS system results in a much lower compliance percentage upon completion of initial visits to lights. This is largely due in part to the need for lights to be operational when values are collected. Many lights in the park are often not operational, which is in fact beneficial for dark sky quality.

Overall, the new NPS Inventory System is more accurate, informative, and allows for parks to collaborate on lighting projects, setting a baseline standard across all National Parks.



4.3 Dark Sky Outreach on Mount Desert Island

The team also assessed the current outreach programming of Acadia National Park to determine if it completes the final requirement to become an IDSP. It was discovered that Acadia has a plethora of outreach events hosted both by itself and by its partners. However, it was also discovered that many of these events suffer from a lack of public information, which can be improved with more advertising.

4.3.1 ACHIEVEMENT OF OUTREACH REQUIREMENTS

One of the requirements to become an IDSP is that Acadia National Park must host dedicated programming at least 4 times a year. Historically, Acadia National Park has conducted several programs involving the night sky. An example that is still in practice today is Acadia's Night Sky program. During this evening event, rangers guide participants to different stargazing locations throughout the park. It was established in July 2020 and replaced Stars Over Sand Beach, a separate event that ran exclusively at Sand Beach three nights per week, in 2021. Currently, Acadia's Night Sky program occurs two nights per week from June to September.

The Schoodic Institute is a nonprofit organization that works in partnership with Acadia National Park in order to promote education and conservation. It also hosts a multitude of educational and research events. It has held night sky events in conjunction with the park, such as Of Asteroids, Comets, and Meteors... and Close Encounters; a nighttime event that includes a laser-guided tour of the sky as well as the opportunity to view the stars through a telescope. Welcome to the Milky Way is an additional evening event where the Milky Way is explored, along with an explanation of the concerning effects compromising its viewing. Both of these events have been recorded as occurring in 2023. The Acadia Star Party, a popular event in the past known to be hosted on Cadillac Mountain, is currently being hosted by the Schoodic Institute in 2023 and allows visitors to gaze at constellations and planets visible in Acadia during the fall season.

The next requirement is that the importance of dark skies and the benefits of quality lighting must be a major part of the park's interpretation and outreach programs. In 2022, the event A Walk through the Stars was created and occurred every Saturday from August to September. This event focused on Acadia's commitment to Dark Sky preservation. Currently, the Park does not offer this event, but due to the other events that focus on the topics of the night sky and the benefits of proper lighting, such as the Acadia Night Sky Festival, Acadia meets this requirement.

Another outreach requirement is that Acadia National Park must have a commitment to public education. This has been clearly shown through the amount of events that the park holds, with both night sky events and general education programs led by rangers. Acadia's website is also very informative, with information on dark skies and a range of other topics. Their collaboration with the Schoodic Institute, whose primary goal is to research and educate the public about their findings, also supports this commitment.

The last requirement is that Acadia National Park acts as a leader in dark sky restoration. Acadia has succeeded in this due to their work involving external partners in dark sky restoration efforts. Over the years, Acadia National Park has worked with Worcester Polytechnic Institute to improve Acadia's lighting inventory, measure the quality of the night sky, and to put forward recommendations on improving the quality of the sky within the park. Acadia has also worked with the Schoodic Institute to educate the public, as seen in their collaborative events, confirming that this requirement has been met.

4.3.2 SURVEY RESULTS

148 survey responses were generated from posters posted around Bar Harbor alongside table sitting at the visitor center. Trends in answers include low knowledge about dark sky events, resulting in low attendance, which in turn can affect community support on Acadia becoming an IDSP. These claims are supported by the question “I have heard of night sky programming before this questionnaire” (Figure 20) having a response of 39.5% (or 58/147) of disagreement and 19.7% (or 29/147) of strong disagreement, which totals to over half of respondents, in addition to the question “How many night sky programs have you attended?” (Figure 21) resulting in 92.5% (62/67) of respondents selecting zero events.

I have heard of night sky programming at Acadia National Park before this questionnaire.

147 responses

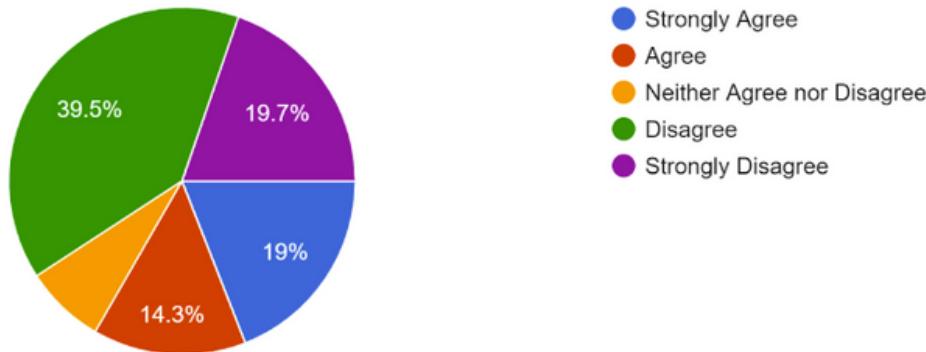


Figure 20 Question “I have heard of night sky programming at Acadia National Park before this questionnaire” from Acadia National Park Dark Sky Programming Survey Summer 2023.

How many night sky programs have you attended?

67 responses

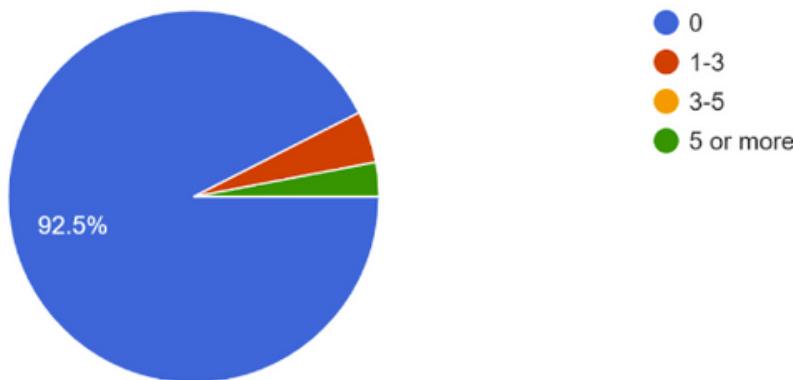


Figure 21 Question “How many night sky programs have you attended?” from Acadia National Park Dark Sky Programming Survey Summer 2023.



It is clear that Acadia park goers are interested in these types of events with the question “I would like more night sky programming at Acadia National Park” (Figure 18) resulting in 47.6% (70/147) of respondents agreeing with this statement and 31.3% (46/147) of respondents strongly agreeing – an overwhelming amount of support.

I would like more night sky programming at Acadia National Park.

147 responses

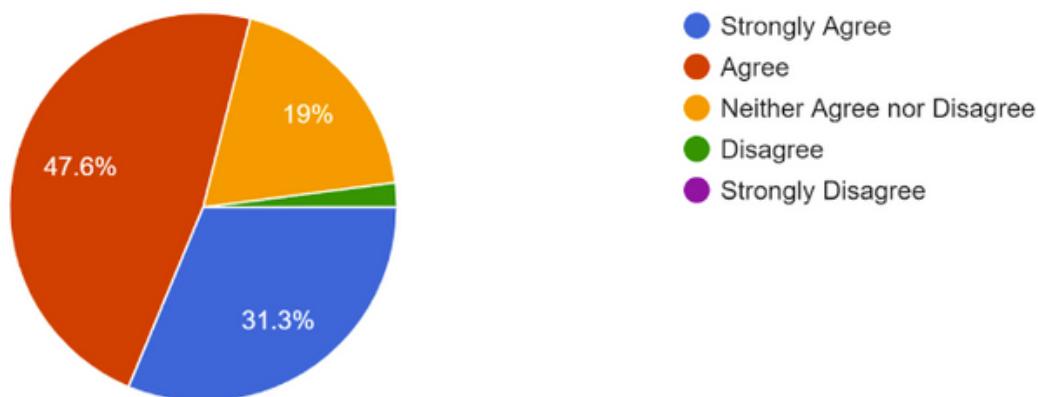


Figure 22 Question “I would like more night sky programming at Acadia National Park” from Acadia National Park Dark Sky Programming Survey Summer 2023.

During table sitting, many park goers asked where Acadia hosts their dark sky events. In addition, many people who had previously been to dark sky parks lit up with excitement when they saw the table, and told us how happy they were that Acadia was considering becoming an IDSP. Clearly, the Acadia community cares deeply about these issues.

Interesting suggestions from park goers include “education on night sky and light pollution without attending programs i.e. signs around the park. ... More programs for youth on education and possible careers.” and “...Signage at the top of mountains asking people who park up there to have all their lights off”. From these suggestions, our team can infer that people would like to be reminded of night sky efforts in dark sky locations and help to contribute to preserving Acadia’s night skies.



Figure 23 Table sitting at the Hulls Cove Visitor Center



5. RECOMMENDATIONS

Acadia National Park displays the necessary components to become an International Dark Sky Park, and, despite the current conditions of lighting, should move forward with the application process.

5.1 Continual Measurement of Night Sky Quality

Both past and current teams have confirmed Acadia has a high quality of night sky darkness, and under clear conditions the Milky Way is visible to the unaided eye. In order for the park to better understand how changes over time impact the night sky of Acadia, the team recommends the implication of a continual data collection process. This can be accomplished through the placement of SQM-LU devices throughout the park. These devices monitor the sky quality remotely and can be implemented in such a way that data is automatically uploaded for analysis.



Figure 24 SQM-LU device and remote mounting system

Additionally, the park should promote citizen science initiatives, such as Globe at Night, which allow for park visitors to monitor and record the quality of night skies in Acadia. This would promote night sky protection and increase visitor education on the night sky.

5.2 Completion of Lighting Inventory and Improvement of Lighting Compliance

The team found that conducting the lighting inventory through the use of NPS provided systems was more intensive than work conducted in prior years. As such, there is much work to be done to complete the assessment of lighting compliance in Acadia National Park, but the initial signs show hopeful outcomes.



Figure 25 Team member Amelia conducting a day visit to a light in the Blackwoods Campground

5.2.1 ADDITIONAL VISITATION TO LIGHTING FIXTURES

The team was able to inventory all lighting fixtures on Mount Desert Island during the daytime. When these lights were revisited during the night, over 58% of lights were not operational at the time of visitation. All of these lights will require night visits to be reconducted, ideally by someone with access to the controls of the lighting to ensure they are always on when visited. Upon completion of the Mount Desert Island inventory, the park should conduct a similar inventory of the lighting on the Schoodic Peninsula. There are an estimated 451 lights on the Schoodic Peninsula that will require both day and night visits to gauge their compliance.

In addition to these required visits, the park should conduct revisits to lights whose CCT was measured below 4000k with a higher quality spectrometer. This will ensure that the readings taken are the best representation of the outdoor fixtures in Acadia, and may improve overall compliance.

5.2.2 COMPLIANCE IMPROVEMENT

In order to meet the 67% lighting compliance required to become an International Dark Sky Park, Acadia National Park will need to make changes to some of the park's lighting.

The largest improvement in compliance can be achieved through the correct lighting color for lights that meet the proper use and shielding requirements. Using the current and prior inventories, the team was able to estimate that at most the park will need to correct the color of 467 lights. This number may be lower if visits to lights that were non operational and lights found on the Schoodic Peninsula yield favorable results.

Correction of color can be done through the lifespan of the lights, most simply by replacing bulbs with compliant colored alternatives. Other lights, such as LED lights and other more complex fixtures will require additional correction measures, such as applying new lighting filters or reprogramming units to adhere to guidelines.

Once the color correction has been conducted on all lights that meet proper shielding and use requirements the park will achieve 60% compliance. This is a large improvement on the current compliance of 10.9% and an improvement on the last compliance found in 2016 to be 39% (due in part to less strict requirements from the IDA and difference in methods).

In order for the Park to become 67% compliant, as required by the IDA, they will need to further improve compliance by 7%. This will involve the replacement, retrofitting, and removal of up to 61 lights in Acadia National Park. The first focus should be on the removal of temporary lights, such as those found at Wildwood Stables. Following this, the park should remove or replace damaged lights throughout the park with new, compliant options.

In order to meet the lighting compliance requirement set forth by the IDA, the park should first complete the NPS system lighting inventory of Acadia National Park. They should then correct the color of the lighting that meets the use and shielding requirements, which will have minimal impact on park lighting choices. Upon completion of these steps, the park will have 60% compliance, and will only need to retrofit, remove, or replace 61 lighting fixtures in order to achieve the 67% compliance required to become an IDSP.



Figure 26 Light that would only require change in CCT



5.2.3 LIGHTING MANAGEMENT PLAN

Once the park has an accurate representation of the lighting compliance across the park, a comprehensive lighting management plan that describes the park's lighting goals should be created, along with a plan to achieve 90% compliance 5 years after becoming an IDA IDSP, and 100% compliance 10 years after becoming an IDA IDSP. This will ensure the park adheres to IDA guidelines and all lights in the park are as minimally impactful as possible on the night sky.

5.3 Improved Advertising of Dark Sky Outreach

Acadia National Park has a multitude of Night Sky centered programs, but the marketing of these events should be improved. This is because, as supported by verbal confirmation by park goers during table sitting in addition to survey results as described in section 3.3.2, people are interested in dark sky events but struggle to find accessible information on them. This can be done by following the example of other organizations, such as the International Dark Sky Association, and the Michigan State Parks Service. Both of these services promote their events on social media to improve visibility. These posts are accompanied by easy to navigate links to more information on events. Alternatively, posters on events or pamphlets can be posted near ranger stations or in information centers for accessibility for non social media users.

Additionally, websites such as Acadia Night Sky Festival must be updated regularly to avoid further confusion to potential visitors with outdated information. For the NPS website, clearer advertising of events alongside their current display on the calendar could be a helpful improvement. One potential improvement is to show events happening during the current week in Acadia on the main page of Acadia National Park's section, and create a display of weekly recurring events. By improving these promotions of night sky programming, Acadia will be able to provide education on the night sky to a broader, more diverse, group of visitors.

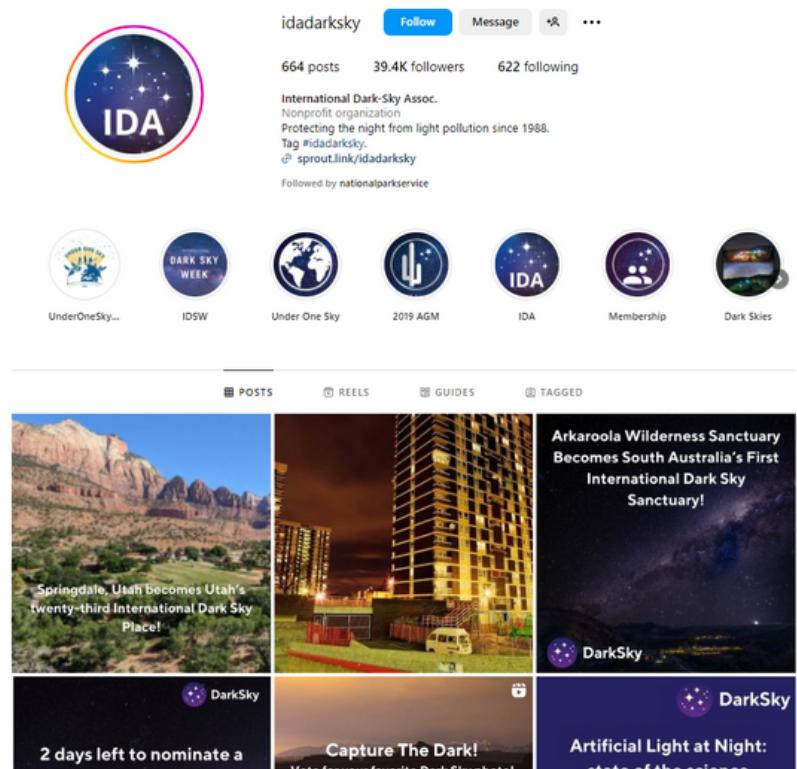
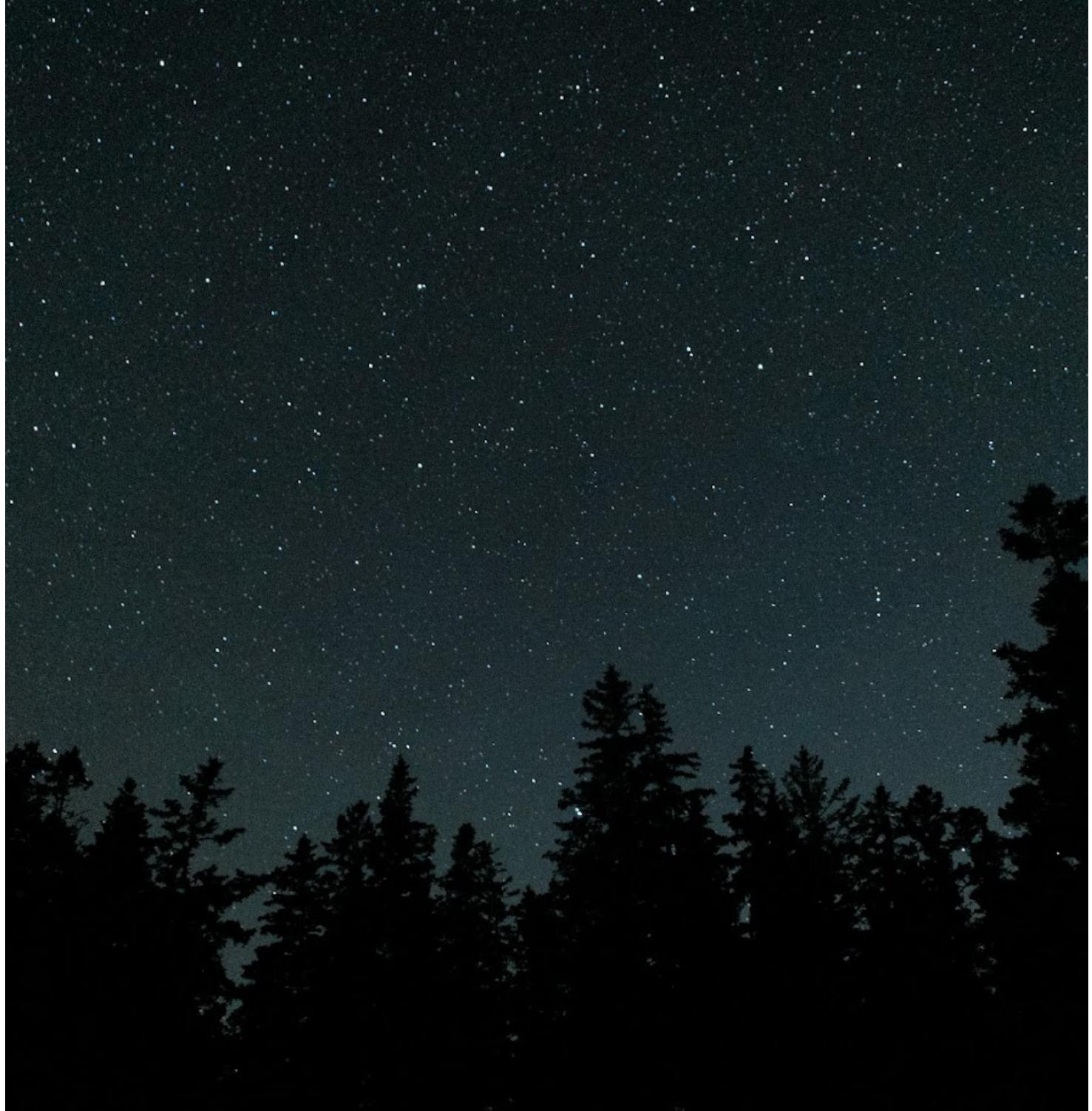


Figure 27 IDA Instagram, advertising Dark Sky events

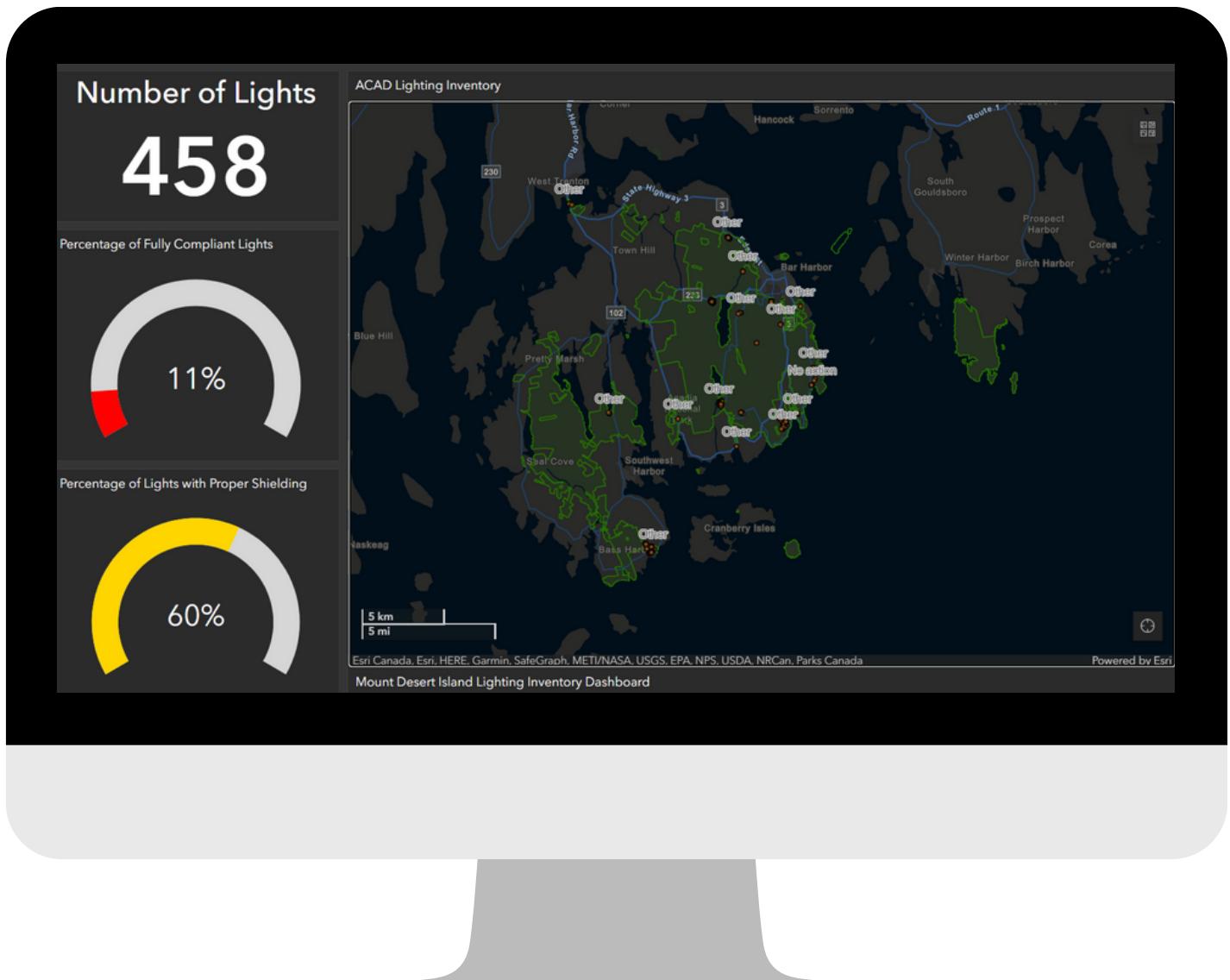


6. WEB BASED DELIVERABLES

In order to best present the materials created by the team, the Lighting Inventory Dashboard and Night Sky Photograph Collection have been included as web based deliverables.

6.1 Lighting Inventory Dashboard

Upon completion of the Mt. Desert Island portion of Acadia, using the NPS lighting inventory, the following dashboard was created to display the results and findings.



The dashboard allows for a user to view different areas of the park and see the compliance ratio by zooming in on any part of the map. This will then display the overall compliance as well as shielding compliance in the area, along with the number of lights. Clicking on a light will display all collected information about the light as a pop up.

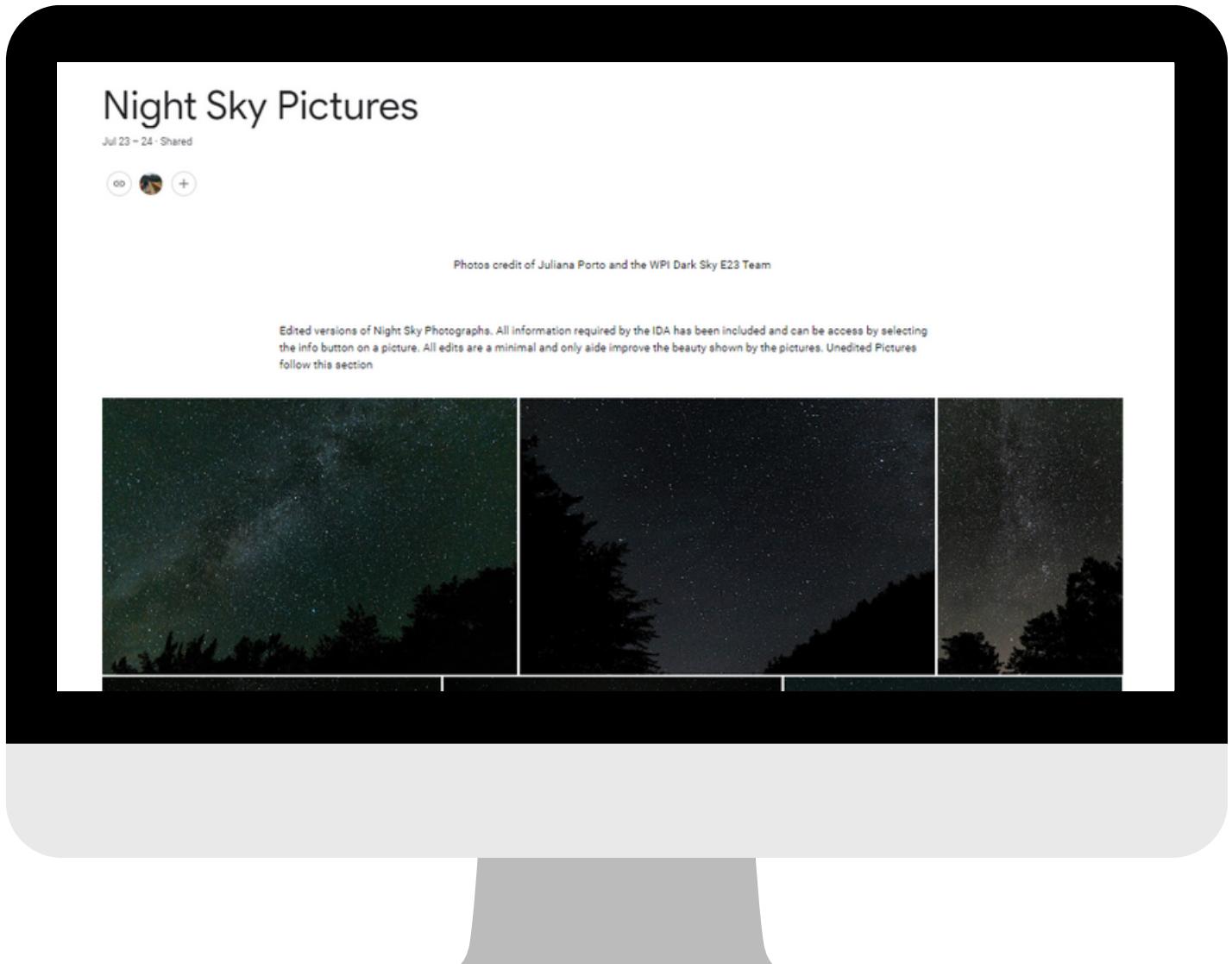


To view the dashboard, scan this QR code or go to:

<https://tinyurl.com/5ypnwaya>

6.2 Night Sky Photography Collection

In order to provide a qualitative display of the night skies of Acadia National Park, the following photo collection was created.



The photo gallery allows for a user to view the images taken by the team during night sky data collection. All images have IDA required info listed. Images are included both in edited and unedited form.



To view the images, scan this QR code or go to

<https://photos.app.goo.gl/TukqckBu4rqyt2Wu7>

7. CONCLUSION

Global environmental change is a major issue that is affecting many aspects of day-to-day life caused by humans. One often overlooked form of global environmental change is light pollution. Energy is wasted when lights are being powered, and not all light is useful. About 30% of outdoor lighting is wasted in the United States. Besides sustainability issues, there are also major health issues that can be associated with light pollution.

Although there is not much legislation on the matter, the National Park Service is attempting to reduce light pollution. One way to accomplish this within a park is to work towards becoming an International Dark Sky Park certified by the International Dark-Sky Association. There is a list of requirements to meet, including specific levels of dark sky quality and a minimum of 67% of lighting fixtures being compliant towards the standards set by the IDA. An IDSP must also have significant outreach events detailing the importance of the night skies and reduced light pollution.

This project evaluated the feasibility of Acadia National Park becoming an IDSP by recording data points of the quality of the night sky, assessing the current community outreach events on the

importance of night skies, and conducting a lighting inventory of all lights in the park located on Mount Desert Island.

Findings from this project included a high quality of dark skies, with all locations used for recordings having a level of quality above the value of 21.2 magnitudes per square arcseconds, and the Milky Way being clearly visible to the naked eye. The park also held outreach events and programs detailing the importance of dark sky preservation. However, the compliance in lighting was only found to be at around 11% when analyzed with the three IDA requirements.

The level of dark sky quality in Acadia's nightscapes, as well as the multitude of outreach events and programs, both meet IDA requirements. Although the lighting within the park is currently not compliant with the guidelines set out by the IDA, future changes will allow the park to reach a 67% compliance level. The park will then be able to design a lighting management plan to eventually reach 100% compliance of all lighting fixtures, satisfying IDA guidelines. With these changes, Acadia National Park will be capable of reaching the designation of an International Dark Sky Park.

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APPENDICES

Appendix A: Timeline

	Week 1 Jun 18	Week 2 Jun 25	Week 3 Jul 2	Week 4 Jul 9	Week 5 Jul 16	Week 6 Jul 23	Week 7 Jul 30
Determine quality of night skies in Acadia							
Collect SQM-L Readings	Red				Red		
Collect photographic evidence	Red				Red		
Assess the outdoor lighting in Acadia National Park							
Daylight visits to all lights in the park	Blue	Blue	Blue	Blue	Blue		
Night visits to all lighting locations				Blue	Blue		
Analyze Acadia with respects to IDA standards							
Analyze night sky data					Green	Green	
Analyze current community outreach				Green	Green		
Analyze lighting inventory			Green	Green	Green		
Recommend actions and next steps							
Compile data and analysis to support a new application				Purple	Purple	Purple	

Appendix B: Research Instrument

The following study is being done to evaluate Acadia National Park's Night Sky Programming. This study is being performed by the Dark Sky Interactive Qualifying Project Team from Worcester Polytechnic Institute. This team consists of 5 undergraduate students who are working towards assisting Acadia National Park as they strive to complete an International Dark Sky Park Application. Your input will provide knowledge upon what should be improved upon as well as suggestions for future programming. Additional information about the details and benefits of this program will be provided as you complete the survey.

Your participation in this survey is voluntary and you may withdraw from this study at any time. You may be eligible to participate if you are 18 years or older. This survey will take approximately 10 minutes to complete. Your privacy is of our utmost concern, so we will not ask any personal information from you. Any participation in this survey will benefit Worcester Polytechnic Institutes Interactive Qualifying Project Dark Sky Team in their Night Sky research. There are no risks to taking this survey.

Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

For more information about this research or about the rights or research participants, or in case of research-related injury, contact: gr-darksky-e23@wpi.edu.

Additionally, one may also contact IRB Manager Ruth McKeogh: Tel. 508-831-6699, Email: irb@wpi.edu, as well as the Human Protection Administrator Gabriel Johnson: tel. 508-831-4989, Email: gjohnson@wpi.edu.

CONSENT QUESTIONS

1. Do you consent to participate in this survey? (If yes, then 2; if no, then submit)

- a. Yes
- b. No

2. Are you 18 years or older? (if yes, then 3, if no, then submit)

- a. Yes
- b. No

STUDY DESCRIPTION

As light pollution is ever increasing, Worcester Polytechnic Institute, in partnership with Acadia National Park, is working towards qualifying the park as an International Dark Sky Park. This means that in Acadia National Park one can clearly see the stars of the Milky Way with the naked eye. This has many benefits for both humans and wildlife, as light pollution causes many problems for mammals. These problems include obesity and metabolic disorders, disrupts Circadian Rhythms (the 24-hour cycle that mammals generally follow), as well as makes seeing at night a challenge since the eyes are overloaded with information. Part of this application process is advocating the importance of the night sky to the community, as well as providing programming for visitors to enjoy the night sky. An example of this would be the Night Sky Festival as well as Acadia Night Sky held every Thursday evening during the summer. In the following sections, we will be asking questions regarding current night sky programming, as well as any future programming that could be implemented.

GENERAL NIGHT SKY QUESTIONS

Please answer the following questions as they pertain to you.

3. I can see the stars with the naked eye where I live.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

4. I can see the Milky Way with the naked eye where I live.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

5. In an ideal world, I would want to see the stars more clearly where I live.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

6. I feel as if light pollution is a large issue in our current world.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

NIGHT SKY PROGRAMMING QUESTIONS

Please answer the following questions as they pertain to you.

7. I have heard of Night Sky Programming before this questionnaire.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

8. How many night sky programs have you attended?

- a. 0
- b. 1-3
- c. 3-5
- d. 5+

9. I would have liked more information on the effects of Light Pollution at Acadia National Park during the program.

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly Disagree
- I did not attend a program

10. I would like more night sky programming at Acadia National Park.

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly Disagree

11. If there was new Night Sky Programming at Acadia National Park discussing the impacts of Light Pollution, I would be likely to attend.

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly Disagree

12. I am more likely to attend a dark sky program if it is an event catered to my children.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree
- f. I do not have children

13. I am more likely to attend night sky programming if it is an event catered to adults.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

14. I am more likely to attend night sky programming that is for those using a telescope to observe the night sky.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

FUTURE PROGRAMMING QUESTIONS

15. For future programming, I would like to see more information sessions sharing the best places to stargaze.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

16. For future programming, I would like to see more tours of stargazing locations.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

17. For future programming, I would like to see more information sessions regarding International Dark Sky Parks.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

18. For future programming, I would be interested in seeing a presentation sharing the process of how Acadia National Park is working towards International Dark Sky Park Recognition.

- a. Strongly Agree
- b. Agree
- c. Neither agree nor disagree
- d. Disagree
- e. Strongly Disagree

19. Do you have any other suggestions for us?

- a. TEXT BOX

20. By submitting this form, you acknowledge that you have been informed about and consent to be a participant in the study described above. Please ensure that your questions are answered to your satisfaction before submitting.

Note: This survey was conducted via Google Forms, an online form system. It was distributed to participants via QR code in visitor centers as well as on bulletin boards around Acadia National Park.

Appendix C: SQM Data Collection

Below are the spreadsheets used for data collection during the SQM-L data collection process. All recordings were done after the moon had set below the horizon.

Date: June 22, 2023

Location Number	Latitude	Longitude	Time	SQM Readings					Average SQM	Median SQM	Cloud %	Air Temp	Moon Phase
1	44.37541 N	-68.23382 W	11:17 PM	21.34	21.31	21.31	21.28	21.29	21.306	21.31	0	54 F	Waxing Crescent
				21.48	21.46	21.47	21.42	21.42	21.45	21.46			
2	44.37843 N	-68.22886 W	11:24 PM	21.16	21.15	21.15	21.15	21.15	21.152	21.15	0	54 F	Waxing Crescent
				21.34	21.32	21.33	21.34	21.34	21.334	21.34			
3	44.36001 N	-68.18840 W	11:42 PM	21.37	21.36	21.36	21.36	21.36	21.362	21.36	0	53 F	Waxing Crescent
				21.51	21.49	21.49	21.49	21.49	21.494	21.49			
4	44.32912 4 N	-68.18317 1 W	11:53 PM	21.54	21.54	21.58	21.53	21.54	21.546	21.54	0	53 F	Waxing Crescent
				21.67	21.67	21.7	21.67	21.67	21.676	21.67			
5	44.31435 N	-68.19628 W	12:07 AM	21.41	21.41	21.41	21.41	21.4	21.408	21.41	0	53 F	Waxing Crescent
				21.65	21.66	21.65	21.64	21.64	21.648	21.65			
6	44.30213 N	-68.20312 W	12:17 AM	21.49	21.49	21.49	21.49	21.49	21.49	21.49	0	52 F	Waxing Crescent
				21.64	21.64	21.63	21.63	21.63	21.634	21.63			
7	44.31972 1 N	-68.25405 5 W	12:30 AM	21.36	21.36	21.34	21.34	21.35	21.35	21.35	0	52 F	Waxing Crescent
				21.52	21.53	21.52	21.52	21.52	21.522	21.52			
8	44.31247 N	-68.28560 W	12:50 AM	21.31	21.29	21.29	21.28	21.28	21.29	21.29	0	53 F	Waxing Crescent
				21.42	21.41	21.41	21.41	21.41	21.412	21.41			
9	44.36626 N	-68.30215 W	1:01 AM	21.12	21.11	21.11	21.09	21.09	21.104	21.11	0	53 F	Waxing Crescent
				21.32	21.31	21.3	21.34	21.32	21.318	21.32			
10	44.37533 N	-68.26084 W	1:10 AM	21.35	21.33	21.32	21.31	21.31	21.324	21.32	0	53 F	Waxing Crescent
				21.44	21.42	21.42	21.41	21.41	21.42	21.42			

Date: July 24, 2023

Location Number	Latitude	Longitude	Time	SQM Readings					Average SQM	Median SQM	Cloud %	Air Temp	Moon Phase
11	44.33291 N	-68.40388 W	12:03 AM	21.38	21.38	21.38	21.38	21.37	21.378	21.38	0	68 F	Waxing Crescent
				21.5	21.49	21.49	21.5	21.49	21.494	21.49			
12	44.33205 N	-68.38713 W	12:17 AM	21.72	21.72	21.68	21.66	21.68	21.692	21.68	0	68 F	Waxing Crescent
				21.71	21.71	21.7	21.71	21.71	21.708	21.71			
13	44.28262 N	-68.38639 W	12:47 AM	21.49	21.48	21.41	21.38	21.42	21.436	21.42	0	66 F	Waxing Crescent
				21.54	21.53	21.52	21.52	21.54	21.53	21.53			
14	44.27937 N	-68.38183 W	12:56 AM	21.34	21.3	21.3	21.31	21.31	21.312	21.31	0	66 F	Waxing Crescent
				21.46	21.46	21.46	21.45	21.46	21.458	21.46			
15	44.27772 4 N	-68.374173 W	1:04 AM	21.37	21.37	21.36	21.36	21.35	21.362	21.36	0	66 F	Waxing Crescent
				21.48	21.48	21.48	21.47	21.47	21.476	21.48			
16	44.23365 8 N	-68.320358 W	1:31 AM	21.29	21.3	21.41	21.3	21.29	21.318	21.3	0	64 F	Waxing Crescent
				21.43	21.45	21.54	21.45	21.43	21.46	21.45			
17	44.23704 0 N	-68.302236 W	1:40 AM	21.24	21.32	21.23	21.22	21.23	21.248	21.23	0	64 F	Waxing Crescent
				21.37	21.38	21.37	21.36	21.37	21.37	21.37			
18	44.31376 N	-68.33669 W	2:12 AM	21.35	21.34	21.35	21.3	21.31	21.33	21.34	0	64 F	Waxing Crescent
				21.46	21.46	21.45	21.42	21.42	21.442	21.45			

Appendix D: Outreach Materials

This appendix includes the promotional outreach material used to share the survey found in Appendix B along with the tri fold informational pamphlet distributed at the Hulls Cove Visitor Center.

PROMOTIONAL POSTER



TRIFOLD PAMPHLET



Dark Sky Parks

An IDA International Dark Sky Park (IDSP) is a designated area that possesses exceptional or distinguished qualities characterized by pristine, unobstructed views of the night sky and a nocturnal environment that is deliberately safeguarded. This protection is primarily aimed at preserving the park's scientific, natural, educational, cultural heritage, and facilitating public appreciation and enjoyment of its unique celestial wonders.

Thank you!

If you enjoyed this information and want to help our team or just learn more scan the QR code below ↓



Worcester Polytechnic Institute

Dark Sky Research Project

In collaboration with Acadia National Park

Summer 2023



Who are we?

We are a research team from WPI studying the impact of light pollution on the nightscape of Acadia National Park. We aim to assess the possibility of Acadia becoming an International Dark Sky Park (IDSP) by establishing dark sky quality measures, evaluating lighting fixture compliance, and engaging in community outreach. Our research will provide valuable insights to support the evaluation of Acadia's eligibility as an International Dark Sky Park.

DARK SKIES IN ACADIA

Since 2013, students from WPI have worked together with Acadia National Park to evaluate the night skies across Mt. Desert Island. The ultimate goal of this research is to qualify Acadia as a IDSP.

The National Parks Service works to preserve and protect the nightscapes of Acadia National Park and share its wonder with visitors. Events such as Acadia Night Sky at Sand Beach help visitors enjoy the beauty of Acadia's skies.

WHAT'S NEXT?

During our time here in Acadia, we hope to measure Dark Sky Quality and to conduct an inventory and evaluation of the outdoor lighting within the park. With this information, we can provide advice to the park along with sharing our findings with the Mt. Desert Island community and park visitors.



WPI

Photo by Dulcey Lima on Unsplash
Photo by Evan Leith on Unsplash
Photo by Jackson Hendry on Unsplash
Photos by WPI Dark Sky 2023

Appendix E: ArcGIS Data Dictionary

Below is a dictionary of all of the data fields and options used to fill out information about lights in the field. Definitions were compiled from ArcGIS.

Data field	Options
DAYVISIT	Date
HISTORIC	Yes No Unknown
HEIGHT (m)	Single
TASK	EntranceEgress Parking Pathway Wayfinding Signage Decorative Area Roadway Stage Flag Interpretive Monument Hazard Other Unknown StreetLighting

Luminaire Type	Wall Pole-Post Suspended Bollard Ceiling Ground Tree Other
NUMBER of LAMPS	Small Integer
TYPE of LAMP	CFL LED Metal Halide Other Unknown Incandescent LPS HPS Halogen MercuryVapor OLED
CCT	Integer
LAMP PART NUMBER	String
LUMINAIRE CONTROL	Switch Timer Photo Computer Motion

LUMINAIRE CONTROL	Other
	Unknown
	Multiple
NIGHTVISIT	Date
LUMINAIRE OPERATING AT NIGHT	Yes
	No
	Unknown
RATE GLARE	None
	TaskArea
	BeyondTaskArea
RATE BACKLIGHT	Unknown
	Negligible
	Moderate
	Severe
RATE UPLIGHT	Unknown
	Negligible
	Moderate
	Severe
Recommended Action	Retrofit
	Replace
	Remove
	No action
	Other
Damage	NoVisibleDamage
	Damage
	Inoperable

	None
Trespass	TaskArea
	BeyondTaskArea
Shielding	No shielding
	Some shielding
	Fully shielded
Lux	Integer