Dark Sky Project

The study of light pollution and its effects on Mount Desert Island for the Acadia National Park

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Table of Contents

Table of Figures

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- 3.2: Joshua Morse
- 3.3: Joshua Morse
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Abstract

The purpose of this project was to map the quality of the sky on Mount Desert Island and Schoodic Peninsula for the National Park Service. The first phase of the project was acquiring data points from across the island using a Sky Quality Meter. The second involved mapping the data using Geographic Information System software. The results of this project can be used by Acadia National Park to advise new lighting ordinance policies within the park and in major towns on Mount Desert Island.

Executive Summary

Synthetic lighting is often seen as an advance in technology and an improvement in the quality of life. Yet the use of excessive lighting is detrimental to the local environment. Large urban areas and cities emanate a vast amount of light during the night, causing sky glow. This in turn covers the dark sky and hides the view of stars, planets, and the Milky Way.

The Dark Sky Project's goal is to prevent sky glow from covering the skies of Mount Desert Island and Acadia National Park; one of the few locations left in the Northeast to still have a clear view of the sky.

The Dark Sky Project is a response to the National Park Service's Call to Action. Under the sponsorship of Acadia National Park, the team focused on point 27, "Starry, Starry Night." The point focuses on natural darkness, classifying it as a natural resource. It calls for the preservation of a natural dark sky, in an effort to restrain man-made light from intruding on such.

College of the Atlantic (CoA) and the Astronomy Institute of Maine are the only studies done on light levels on Mount Desert. In the winter of 2006/2007, two students from the CoA created a color-scale map representing the different light levels across the island using Sky Quality Meters (SQMs). The Astronomy Institute of Maine, on the other hand, used special CCD cameras and created gradient pictures of specific locations throughout the island. The Dark Sky Project based their study off of the CoA study.

There are three reasons for synthetic lighting: general illumination, security, and decorative. Light pollution is created from excessive use of this lighting. The three types

of light pollution are upward light, light trespass, and source intensity. Light pollution has detrimental effects on the ecology of an area. The physiology of humans can be affected.

Many animals are affected from excess lighting by disturbing their circadian clock. Light pollution can have several effects on humans and even be a promoter of cancer.

Following a specific calendar, the Dark Sky Project executed their study over seven weeks, starting mid June through the end of July 2013. The first steps were to assess possible locations to take readings and to test the equipment. Certain criteria had to be met in order for the locations to be valid. Key aspects such as tree coverage, weather, and the lunar calendar were closely monitored in order to get consistent readings.

The most important piece of equipment used was the Sky Quality Meter Lens USB Data Logger (SQM-LU-DL). The device is used to collect light readings of the sky, measured in magnitudes per square arcsecond. Using the meter and a Global Positioning System (GPS) device, the team was able to collect the raw data across the island.

After the collection of raw data, the next step was the creation of maps using Geographic Information System (GIS) software. Using the GPS coordinates and the SQM readings, the software can use interpolation to generate a color-coded map.

The Bortle scale is widely accepted by astronomers as a way to assess the quality of a night sky. Ranging from 1 to 9, the Bortle scale classifies different night skies from darkest to brightest respectively.

The collection of data was carried out by driving along main roads, secondary roads, and some fire roads, and taking measurements along the way. The team made sure to stop every half-mile, or as often as possible if tree coverage was too dense for proper readings.

The team was able to create various maps to represent light levels on the island. In order to compare the new results to the CoA study, the first map created used the same color scale. This proved to give a low quality representation of the data, so the team used the Bortle scale to illustrate their final results. Finally, the team created modified versions of the map. For example, a map was made marking the park boundaries.

Final analysis compares the CoA study to the WPI study. It describes the benefits from using the Bortle scale over the CoA's scale, and finally discusses certain points of interest on the island.

An important factor was the different SQMs used by the two studies. The difference in lens width was the most important difference between the two studies. Another inconsistency was the season each study was conducted. The CoA study was done during the winter, while the WPI study was done during the summer.

The reasoning behind using the Bortle scale is simple. Since astronomers and stargazers commonly use the scale, the color scheme is easily identified and understood. Additionally, the Bortle scale gave a more comprehensive representation of the data collected by the WPI team.

The team analyzed specific points of interest on the island. Bar Harbor, Northeast Harbor, Southwest Harbor, and the Somesville area were analyzed because of bright light emissions. Seawall and Sand Beach were analyzed because of their dark readings.

Finally, the team explains recommendations for future studies. Continuation of the project during the summer would be ideal in order to start a longitudinal study.

Expansion to other seasons to have a comparison between different times of the year was recommended. Additional studies were recommended. A more thorough study on Schoodic Peninsula and time-lapse studies on different parts of the island were suggested.

The Dark Sky Project met the goals they set. The collection of data and creation of maps was successful. A baseline for future studies on Mount Desert Island was created.

Chapter 1: Introduction

Light pollution is an increasing problem in the United States. Presently more than two thirds of the United States population cannot view a clear dark sky. Large cities and urban areas where lights remain lit throughout the night produce light pollution. The emitted light brightens up the sky to the point where stars and planets cannot be seen. Light pollution, by definition, is “the alteration of light levels in the outdoor environment (from those present naturally) due to man-made sources of light” (Hollan 3). The objective of the Dark Sky Project is to measure, analyze, and map light pollution.

The lightscape of the Acadia National Park is of great value and significance not only to the park itself, but to the entire Mount Desert Island area and neighboring communities. It is one of the only places in the United States where a clear, unpolluted sky can be seen, showing a vast number of stars and a clear view of the Milky Way. If proper methodologies to preserve this sight are established and maintained, Mount Desert Island will always be a place to look to the stars.

There is currently limited research dedicated to light pollution on Mount Desert Island. A study was conducted in the winter of 2006/2007 by two students from the College of the Atlantic (CoA). The students took measurements with sky quality meters (SQMs) throughout the island. The result was a gradient map showing different light levels constructed using a Geographic Information System. No comparable research has been conducted in recent years.

The project was conducted as a response to Acadia National Park's Night Sky Initiative. The Dark Sky Project created a basis for future research on Mount Desert

Island. The team outlined how to measure and document light pollution and established a stepping-stone toward preserving this unique piece of Mount Desert Island.

Chapter 2: Background

The Dark Sky Project aims to aid Acadia National Park in its mission to maintain a clear night sky. In this section, Acadia National Park's Call to Action and light pollution research is discussed. Research related to health and environmental impacts is examined. The importance of a clear night sky is described and examples are cited.

2.1 Acadia National Park

A Call to Action issued by the National Park Service includes thirty-six points. The points focus on self-improvement in preparation for the National Park's 2016 centennial. Point 27 of that plan, “Starry, Starry Night”, classifies natural darkness as a precious resource and creates a model for its protection (US National Park Service 20). A report issued in 2006 states it is the National Park Services’ mandate to

> “[P]reserve, to the greatest extent possible, the natural light scape of parks, which are natural resources and values that exist in the absence of human-caused light... [t]o prevent the loss of dark conditions and of natural night skies, the Service will minimize light that emanates from park facilities, and seek the cooperation of park visitors, neighbors, and local government agencies to prevent or minimize the intrusion of artificial light into the night scene of the ecosystems of parks” (National Park Service 57)

Natural darkness is a primary attraction of Acadia National Park. Monitoring this important aspect of the natural world is indispensable to maintain the park’s large influx of visitors. It is part of an enriching outdoor experience that cannot necessarily be found elsewhere. Astronomers frequently travel to Mount Desert Island for its dark sky. Because of the enthusiasm, an annual Night Sky Festival is hosted on the island.

Figure 1: Map of Acadia National Park (Gorp.com)

2.1.1 The Community

Public awareness and community involvement are key aspects of the National Park's new direction. Point 28 of the Call to Action, "Park Pulse", states that the National Parks will "assess the parks resources and data and present it to the public in a clear and simple way" (US National Park Service 20). The community is making an investment in the future by improving light efficiency, methods, and usage. Point 27, "Starry, Starry Night", includes a clause that urges National Parks to partner with the local community to achieve the goal of reduced artificial light (US National Park Service 20). Monitoring light pollution is currently a challenge for the National Park Service. This is especially true for smaller national parks, like Acadia, because they coexist with bustling towns like Bar Harbor.

Acadia National Park is looking at the issue of light pollution from a marketing and educational perspective. The Night Sky Initiative created in 2009 lists long-term objectives designed for this purpose. The park's outlined plans include work with the public to quantify sky brightness using SQMs, develop alternative outdoor lighting solutions, educate residents and park visitors about the value of the natural dark sky, develop community stewardship plans, and educate young residents in schools (Kelly).

Bar Harbor hosts a biennial conservation summit. In 2007, the participating organizations drafted the first Dark Sky Ordinance for Bar Harbor. The former director of The Astronomy Institute of Maine, Peter Lord, served as a consultant for the project. The end result of the project was an amendment that standardized Bar Harbor's lighting requirements (Maine Association of Conservation Commissions).

2.2 Previous Research

The College of the Atlantic research consisted of light measurements taken along the roads across Mount Desert Island. The light measurements were taken using a Unihedron SQMs. This SQM takes readings in a 42° cone above the device. Two students conducted it over two consecutive clear nights during the winter of 2006/2007. They used ArcGIS, a Geographic Information System to map and interpolate their 140 data points. The maps that were created show an easy-to-understand visual representation of the light pollution present on the island.

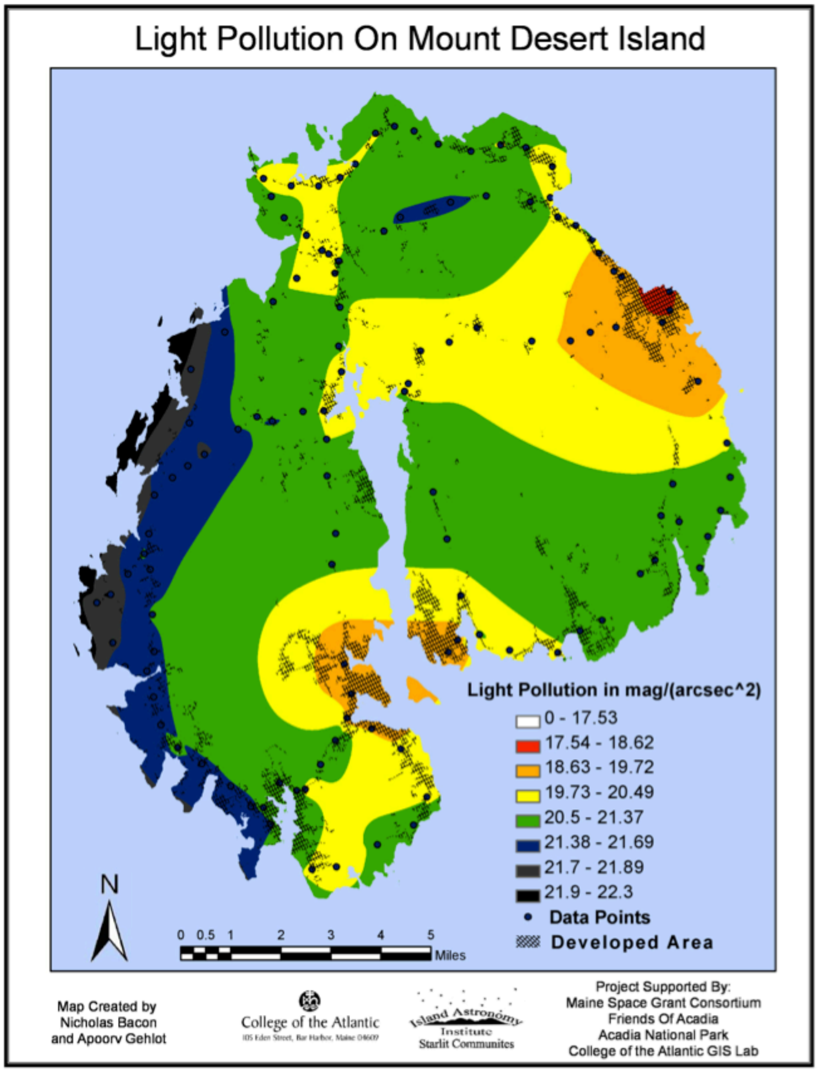


Figure 2: Light Pollution on Mount Desert Island (Bacon, Geholt)

The Astronomy Institute of Maine (AIM) conducted research consisting of light measurements taken at specific locations across Mount Desert Island. Using special CCD cameras and custom software developed by Chad Moore for the project, nightscape images showing only the artificial light data were produced. Detailed reports showing the nightscape images for each location, the readings, and weather conditions at the time of the recording were the result of Acadia National Park's effort to assess light pollution on Mount Desert Island. Preliminary data reports were submitted to Acadia National Park in 2010 to show comparisons (Astronomy Institute of Maine).

2.3 Light Pollution

Outdoor lighting is typically regulated but sometimes it is unneeded and wasteful, or even provides too much light for its purpose. The Lighting Code Handbook lists three reasons for outdoor lighting: general illumination, security, and decorative. General illumination allows pedestrians to navigate nearby areas safely. Security lighting improves the sense of safety and reduces the risk of crime. Decorative lighting enhances appearances of an area (International Dark Sky Association 7-8).

The three forms of light pollution listed in the handbook by the Institution of Lighting Engineers (ILE) are upward light, light trespass, and source intensity. Upward facing lights create sky glow. Sky glow is "the brightening of the night sky above our towns, cities and countryside" (The Institution of Lighting Engineers 1). Light trespass occurs when light from outdoor fixtures spills into unintended areas. Source intensity is the wattage, or lumen output of the bulb (The Institution of Lighting Engineers 1).

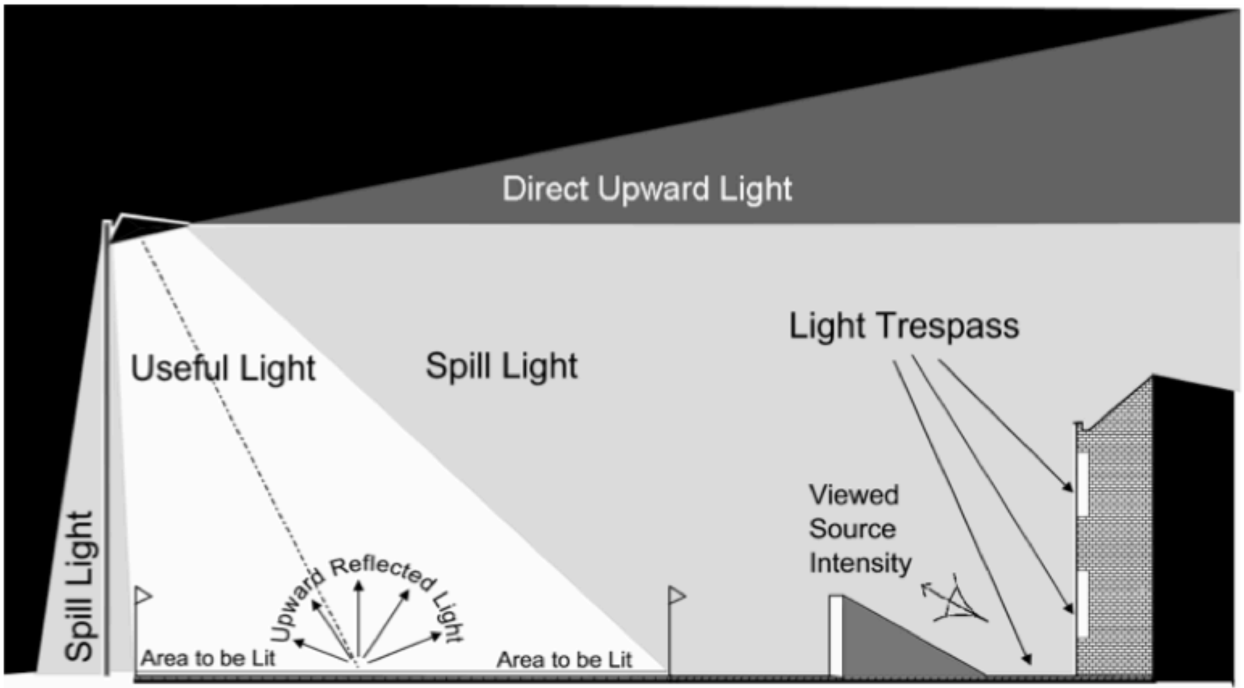


Figure 3: Illustrating lighting efficiency (Guidance Notes for the Reduction of Obtrusive Light 1)

2.4 Ecological and Physiological Impacts of Light Pollution

Light can damage organisms. Damage can occur to animals when photons hit the retinas, and when there are increased amounts of artificial lighting at night there is an increased risk of exposure (Chepesiuk A-22). Light pollution can affect plants' ability to respond to seasonal changes when the 24-hour light cycle does not match natural conditions. It disrupts behavior, breeding cycles, and migration patterns in animals (Chepesiuk A-22). In humans, long-term effects of light pollution can manifest as cancer, insomnia, and other health problems.

2.4.1 Ecological Impacts

Light pollution is associated with many ecological problems. There are two types of light pollution: astronomical and ecological. Astronomical light pollution affects the night sky. Ecological light pollution is light pollution that strictly affects wildlife (Longcore 192).

Figure 4: Illustrating the differences between ecological and astronomical light pollution (Longcore 2)

A classic example of altered behaviors can be illustrated with sea turtle hatchlings. They cannot distinguish between the bright skylines of coastal cities and the ocean. If the artificial light is brighter than the ocean light, sea turtles will leave the beach and move inland. This distraction causes many problems, including massive loss as road kill (Chepesiuk A-22).

There are many other studies of the effects of light pollution on animal behavior. One study conducted by Mark Miller addresses changes in American Robin song patterns due to increased light. The study was conducted in areas where the level of artificial light differed during the night. Miller determined that song activity increased before dawn in areas with higher amounts of artificial light during “true night” (130). In another study, foraging behaviors of beach mice were affected by artificial lighting on beaches. Mice foraged at more patches in dark areas than in light areas, and foraged fewer seeds in light areas (BIRD et al. 1437).The researchers do note that these readings reflect microhabitat level analysis and may not fully represent the problem on a large scale (BIRD et al. 1437).

Outdoor lighting utilizes brighter energy-efficient methods, such as light-emitting diodes (LEDs). These brighter lights have negative effects on the foraging behavior of certain bat species. The increased ambient light delays the emergence of bats at night. This limits the amount of time bats have to hunt (Stone et al. 2584).

2.4.2 Physiological Impacts

There are many physiological effects of light pollution in humans. Exposure to light stresses the body, and prolonged stress weakens the body’s immune response (Navara et al. 217). The Navara paper suggests that prolonged exposure to artificial light may increase the risks of cancer in exposed individuals due to a number of factors including epidermal cell damage and suppressed immune response due to stress (217). Exposure to light at night suppresses melatonin secretion by the pineal gland. Changes in melatonin levels affect immune response, metabolism, and hormone levels in the body (Chepesiuk A-26). Low nighttime levels of melatonin in the body have been linked to heart disease, type II diabetes, and obesity. Melatonin may suppress tumor growth, and the absence of melatonin due to light pollution may increase the risk of breast and colon cancers (Chepesiuk A-24, A-26).

2.5 Summary

As seen in the previous sections, light pollution is a silent but serious issue. The Dark Sky Project contributed to previous efforts to combat light pollution in Mount Desert Island and Acadia National Park.

Chapter 3: Methodology

This chapter discusses how the Dark Sky Project was executed. The team reviews the project calendar, methods for data collection and analysis, and plans for dissemination of project results.

3.1 Calendar

The Dark Sky Project followed a 7-week calendar that indicated when each phase of the project occurred.

Task	Week						
	6/17	6/24	7/1	7/8	7/15	7/22	7/29
Scout Locations							
Test Equipment							
Collect Raw Data							
Analyze/ Map Data							
Finalize Project							

Figure 5: Dark Sky Project calendar

3.2 Preparation and Equipment Testing

3.2.1 Assessing Locations

The team began the project by scouting sites for measuring light pollution. The following factors were addressed to ensure adequate coverage of Mount Desert Island:

- Popular Park Visitor Locations
- Open Sky
- Time Restrictions
- Accessibility
- Extensive Coverage

Acadia National Park attracts thousands of park visitors during the summer months (NPS Stats Report Viewer). The team designed a plan that accounted for locations park visitors typically go to view the sky. A few of these locations include Sand Beach, Thunder Hole, Cadillac Mountain, and Otter Cliffs. This information was obtained from the team's sponsor.

Measuring light levels in the night sky requires a set of parameters to obtain useful data. The most important of these parameters is to have an unobstructed view of the sky. The team surveyed areas around the island to ensure that this was not a problem. The locations were recorded via geographical positioning devices.

There are limiting factors when choosing sites. Time was a limiting factor in the number of sites accessed. Research time in Acadia National Park was limited, and useful light pollution measurements could only be collected at night. Taking the measurements after astronomical twilight ensured a dark sky. The Lunar cycle was another factor because the moon causes unwanted increases in light intensity. Clouds, fog, rain, or other precipitation compromised data gathering.

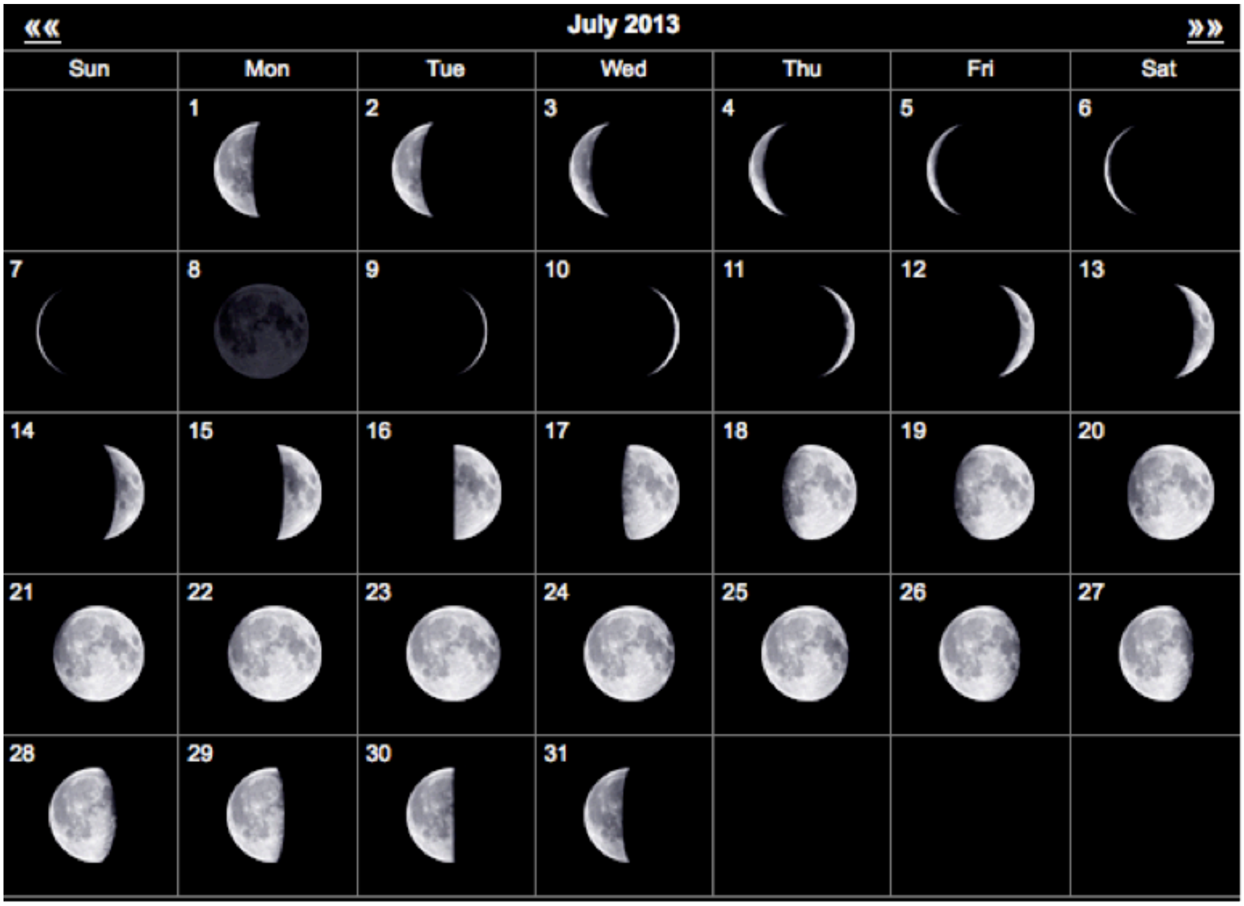


Figure 6: Lunar calendar of July 2013 (MoonConnection.com)

Acadia National Park has a wide range of natural features and ecosystems. Many of these pose problems for data collection. Rough terrain makes access difficult. The trade-off between site desirability and site accessibility was closely considered during planning. In order for the data to be useful and presentable, the team collected data in different areas on Mount Desert Island.

3.2.2 Equipment Testing

Testing was done during different nights in order to assure the equipment efficacy. For this, the SQMs were not pointed at the zenith only, but at different light sources as well. This decreased risk of malfunction. In order to test the GPS device, the team visited various locations and took coordinate readings.

3.3 Acquiring Raw Light Pollution Data

The most vital step to assess light pollution is to collect data in a consistent manner. Consistent data collection requires:

- Sky Quality Meter – Lens USB - Data Logger (SQM-LU-DL)
- Global Positioning System Device (GPS)

The most important resource utilized was the SQM. The SQM measures the intensity of light in magnitudes per square arcsecond (mpsas). This number is an average of the amount of light in a small section of sky. More information about mpsas can be found in Appendix C. To take a reading, the device should be pointed at the zenith of the sky. A reading can be taken every pre-set period of time or it can be taken manually with a computer. The reading taken is stored in the device. The data can be retrieved with a USB cable and downloaded to a computer for analysis. To ensure accuracy, three readings were taken and the average of them was recorded per site.

Figure 7: SQM-LU-DL (UIHEDRON)

In addition to the light data, several environmental and astronomical conditions were recorded. The current time, location, lunar phase, and weather conditions were of particular interest. The current time was taken from the readings of the SQM. The geographical location was determined using a GPS device that included longitude, and latitude. The GPS's precision allows future tests to take place in the same locations.

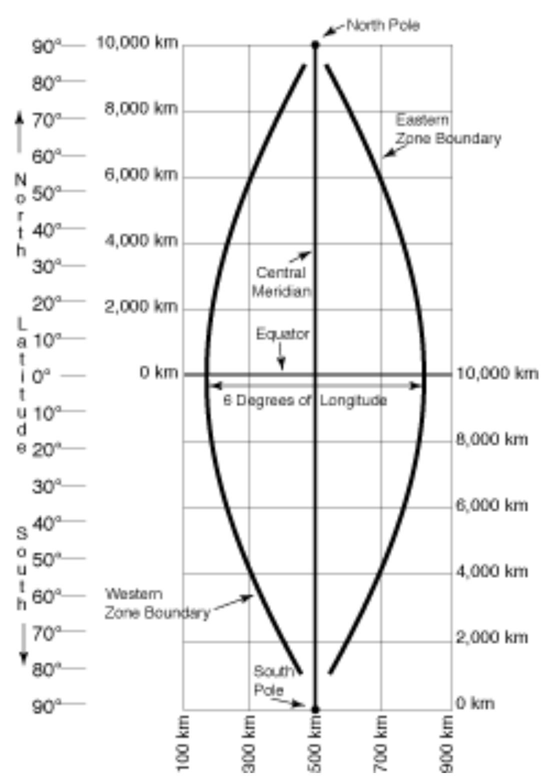
3.4 Mapping Data

After all measurements were taken, they were compiled and presented in a comprehensible fashion. Both the WPI and the CoA studies used Geographic Information System software to illustrate their results. The WPI team found a more comprehensive light emission scale called the Bortle Scale to better demonstrate their findings.

3.4.1 Geographic Information System

The College of the Atlantic has a dedicated Geographic Information System lab. The lab uses a ArcGIS as the primary software. It is the same software used to create the map from the previous study. The team used it to create the final maps.

The state of Maine uses the Universal Transverse Mercator (UTM) coordinate system instead of decimal degrees. UTM treats each six-degree band of longitude as a flat two-dimensional coordinate plane. Vertical position is not a factor. Decimal degrees are longitude and latitude coordinates. The GPS unit the team used measures in decimal degrees. Software tools were used to project points onto the UTM coordinate system. This projection is saved as a shape file and serves as the base layer for the maps. The ocean or shoreline was used as a mask to show only the desired land area. The points are then overlaid and interpolated. (National Geodetic Survey)



<u>Figure 8: UTM coordinate system diagram (MapTools)</u>

The spatial analysis software uses an Inverse Distance Weighted (IDW) interpolation tool to determine cell values from the location-dependent data points. Locations are specified by the teams collected GPS coordinates. The dependent data points are the values from the SQM. Layers can be added to enhance the image. Layers include Park boundaries, bodies of water, roads, contours and shadows, and the points themselves. Colors and value scales can be customized to create the desired visual gradient. (Environmental Systems Research Institute)

3.4.2 Bortle Scale

John E. Bortle established the Bortle scale in 2001. It was first addressed in a *Sky & Telescope* article as a way for amateur or beginner astronomers and stargazers to judge the quality of the night sky. The scale ranges from class 1: “An excellent dark-sky site” to class 9: “Inner city sky.” (Bortle 126) The scale provides a standard for astronomers to use to assess the quality of a night sky (Bortle 126).

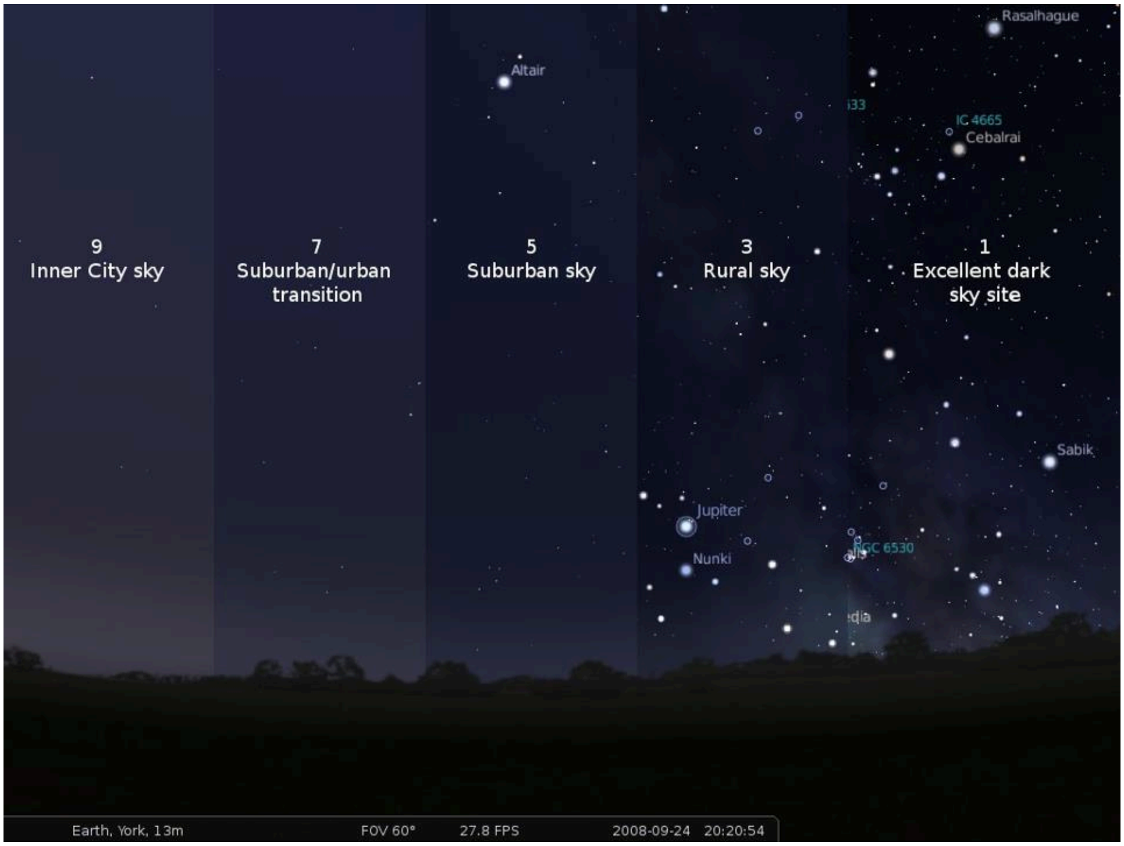


Figure 9: The Bortle Scale (Filmer)

There is an approximate comparison between the Bortle Scale and the scale used by the team. The latter scale uses magnitudes per square arcsecond. The scale is illustrated in Figure 9,with sky brightness readings of greater than 21.90 comparing to a class 1 sky on the Bortle scale (Madawaska Highlands Observatory) . The scale ends with sky brightness readings of less than 18.38 comparing to a class 9 sky (Madawaska Highlands Observatory).

Color Magnitude	Bortle Class	Sky Brightness mag/arcsec^2	Sky Brightness Artifi./Natural
7.6 - 8.0	1	>21.90	<0.01
7.1 - 7.5	2	21.90 - 21.50	0.01 - 0.11
6.6 - 7.0	3	21.50 - 21.30	0.11 - 0.33
6.3 - 6.5	4	21.30 - 20.80	0.33 - 1.00
6.1 - 6.3	4.5	20.80 - 20.10	1.00 - 3.00
5.6 - 6.0	5	20.10 - 19.1	3.00 - 9.00
5.0 - 5.5	6,7	19.1 - 18.00	9.00 - 27.0
<4.5	8,9	<18.00	>27.0

Figure 10: Comparison of Bortle Scale to mag/arcsec^2 (Madawaska Highlands Observatory)

3.5 Summary

The dark sky team aimed to measure light on Mount Desert Island. The team took measurements across the island, and later presented the results to the Acadia National Park. This created a baseline for future standardized research on Mount Desert Island.

Chapter 4: Results

In this chapter, the collection of data is explained. The final maps are presented and a comparison between the previous study and the present one is made. Finally, a brief analysis of the team's findings is explained.

4.1 Collection of Data

Sky quality readings were collected by traveling across the island using main roads in a personal car. The team traversed all of the island's primary roads, many secondary roads, and some fire roads. The team stopped approximately every half-mile to create a data point. If persistent tree cover did not allow this, the team stopped as often as possible. At each stop the average of three readings was recorded using the SQM. GPS coordinates were recorded in decimal form. The data was later compiled in Microsoft Excel. The data was collected during night hours after moonset. The team spent seven nights collecting data to assure a more detailed map than the previous study. The new maps show the resolution from over 200 data points versus CoA's 140 points. The figure below shows the roads from the original CoA study (Grey), and the roads added for the WPI study (Red).

Figure 11: Dark Sky Travel Path

4.2 GIS Maps

Below are the resulting maps the Dark Sky Project created. It is worthy to note that although the Bortle scale represents the values with more light as white, the team sought to use a dark red to ease visualization.

The map below shows the data points collected by the Dark Sky team using the color scale from the CoA study. The color scale used in the previous study is clearly unrepresentative of the new data collected.

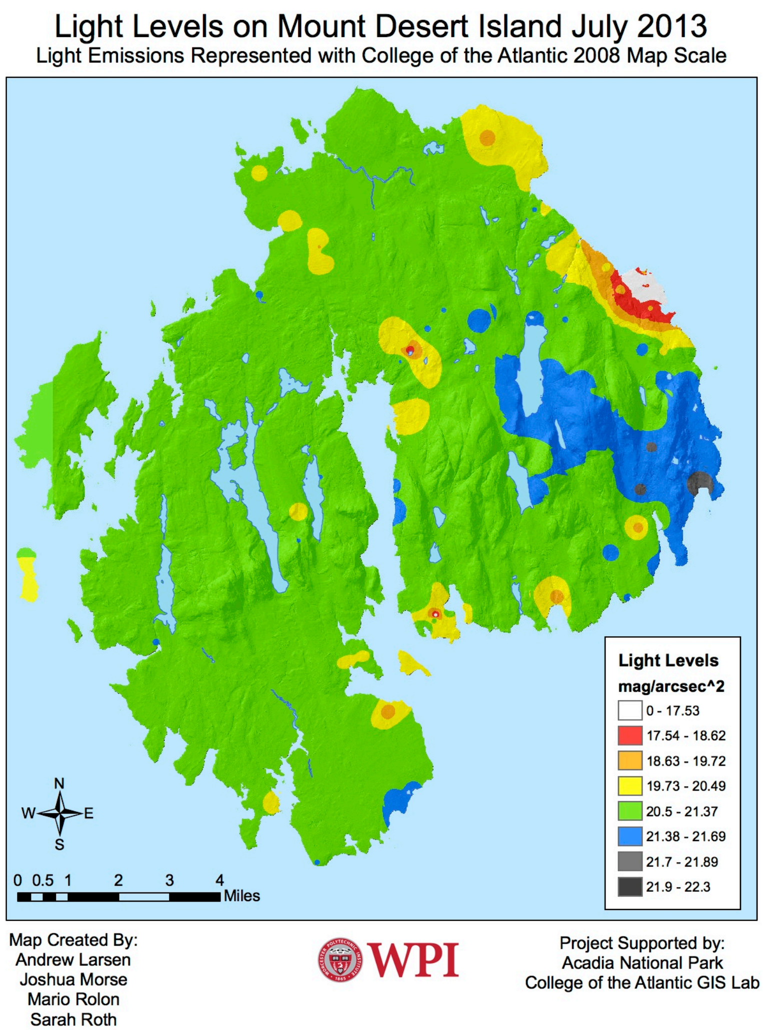


Figure 12: Dark Sky Map With College of the Atlantic Color Scale

Below is the Dark Sky Project's final map. The scale used was the Bortle scale. Additionally, developed areas are shown.

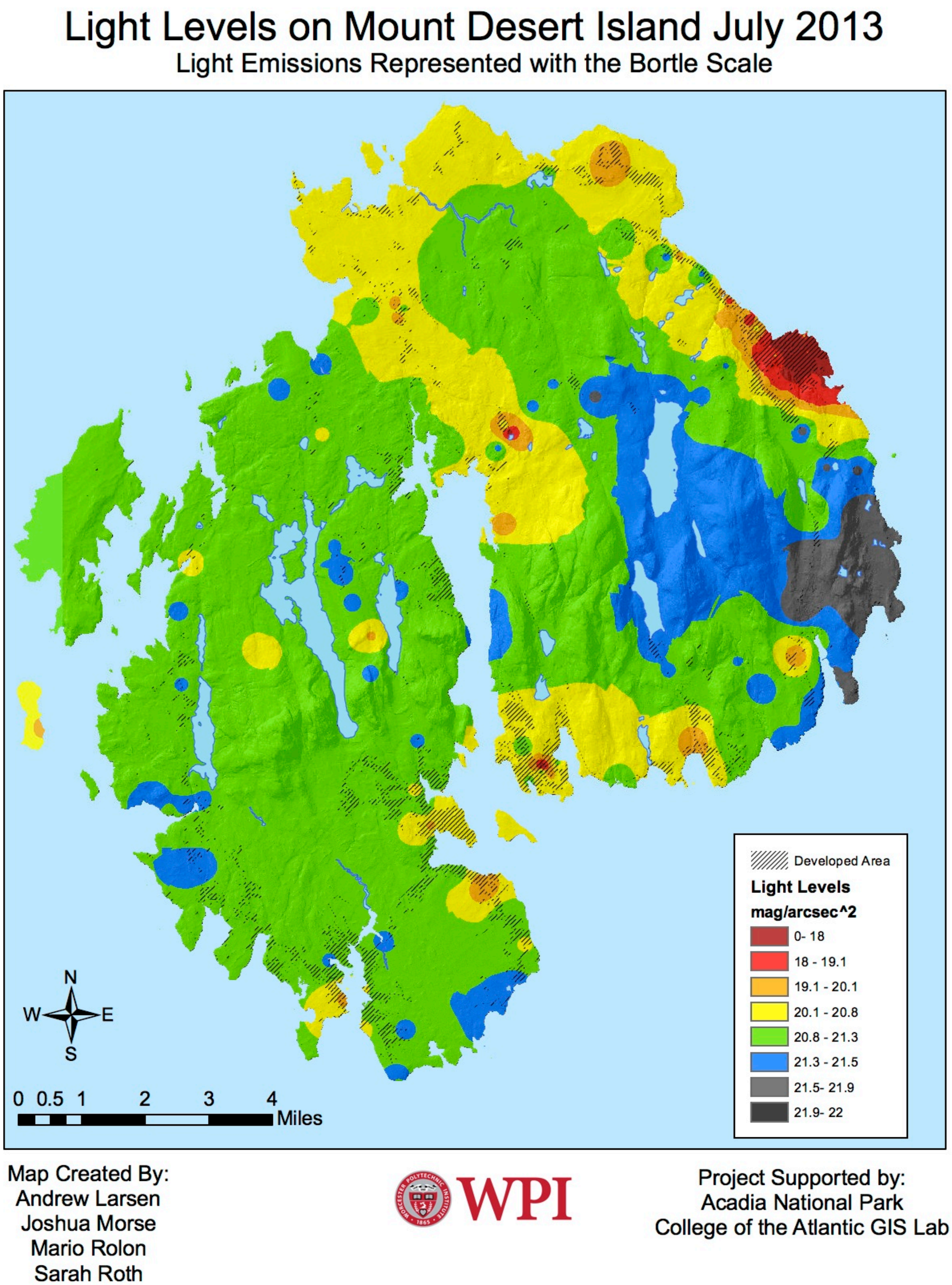


Figure 13: Dark Sky Final Map of Mount Desert Island

Schoodic Peninsula is shown on the map below. The Bortle scale was used for this map as well.

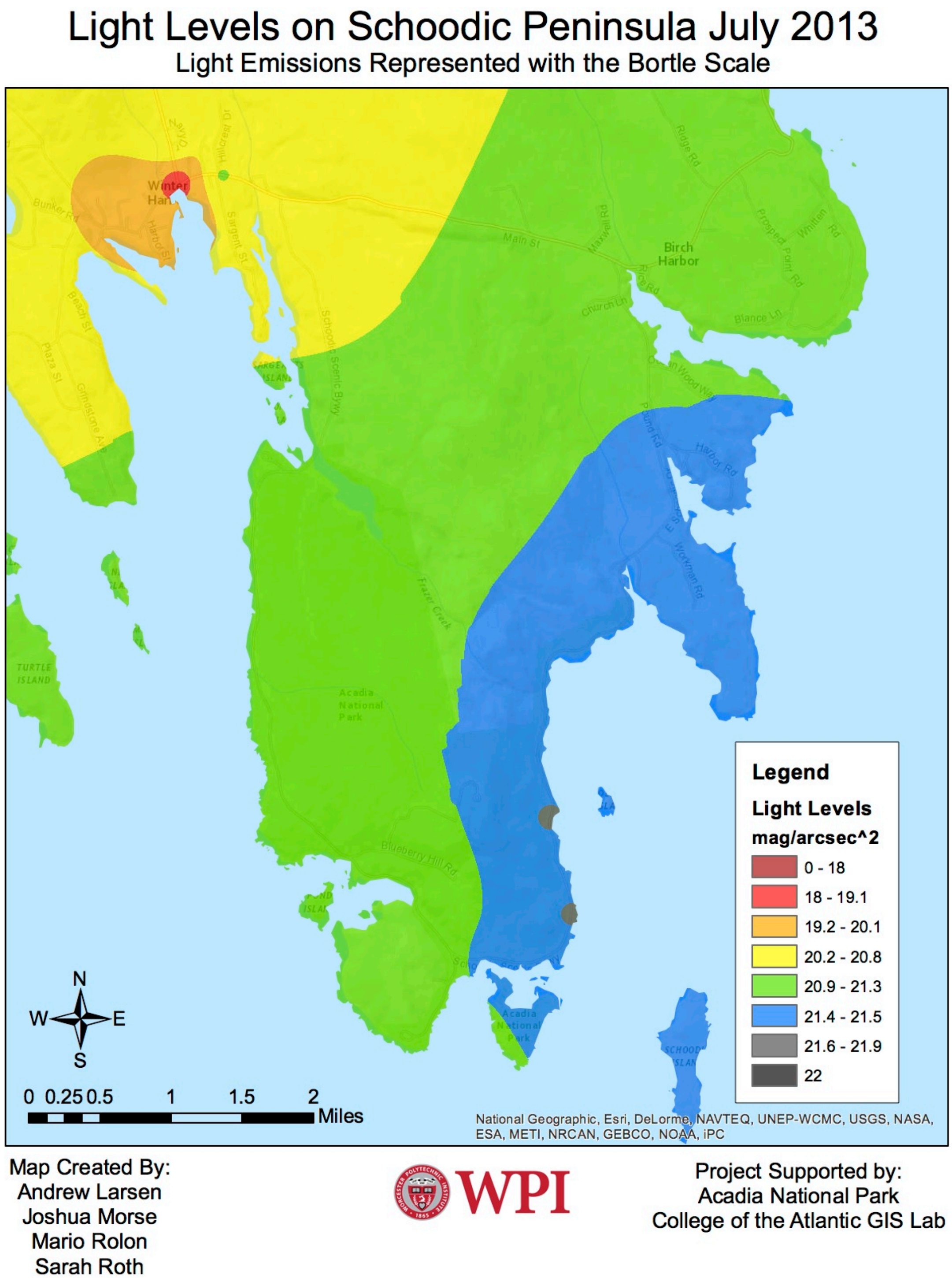


Figure 14: Dark Sky Final Map of Schoodic Peninsula

Below is a variation of the final map. The Acadia National Park boundaries are shown. For more extra maps, see Appendix D.

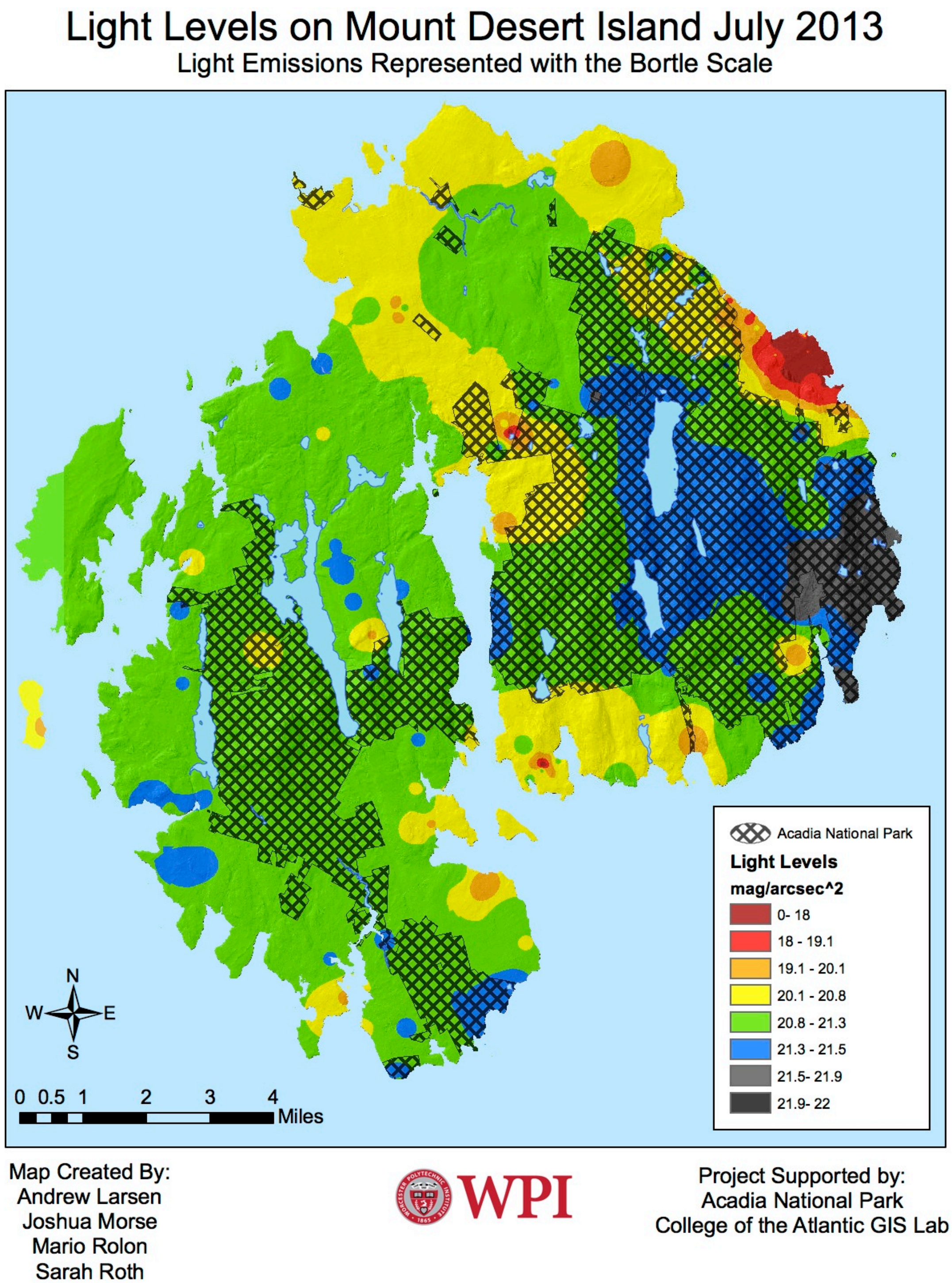


Figure 15: Dark Sky Final Map With Acadia National Park Boundaries

4.3 Analysis

This section discusses how the two studies were compared, how the Bortle scale map illustrates light emissions better than the CoA scale, and points of interest on the island.

4.3.1 Lens Difference

The results of this study cannot be directly compared to the results of the previous COA study. The WPI study utilized a SQM-LU-DL with a 20 degree lens. The previous study used a SQM with a 42 degree lens. Readings taken with a narrower lens pointed at the zenith will return darker readings. The SQM from the previous study utilized a wider lens and would have returned brighter readings under the same conditions.

Despite the previous study's SQM that uses a wider lens, it acquired darker readings from the west side of the island. The WPI team believes this occurred because the west side of the island has dense tree cover over the roads. There are limited locations to take readings even using a 20 degree lens. If a reading was taken with a 42 degree lens on a road with tree cover, part of the field of view would include tree cover and it would return a darker reading.

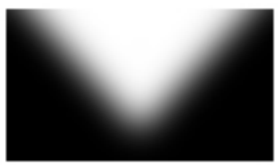
Model	SQM	SQM-LU-DL
Interface	 Handheld / Display	 USB
FOV	 Wide	 Narrow

Figure 16: Sky Quality Meter lens comparison (UNIHEDRON)

4.3.2 Season Difference

The studies were conducted during different seasons. This set of data was taken in the summer and the previous set was taken in the winter. While the studies cannot be directly compared, certain assumptions can be made using the maps and population differences on the island between the winter and summer. The west side of the island contains less light pollution in the winter than it does in the summer. The team believes this is due to the large influx of park visitors and summer residents the island receives during the summer.

4.3.3 Reasoning for the Bortle Scale

The CoA study generated two maps, one with data points and developed areas indicated, and one without. The CoA study contained 140 data points that did not allow for accurate data interpolation in certain areas by the mapping software. Limited road access was a factor. This produced a map with a low resolution and inaccurate interpolation, especially within the park's boundaries.

The WPI study collected 201 data points on Mount Desert Island. This allowed for more accurate interpolation. This study showed that the park is significantly darker than it was shown in the CoA study. This can be attributed to the higher resolution data interpolation, as well as lens differences, rather than lighting ordinances. The side by side comparison using the CoA color scale revealed that their scale was not a good fit for the WPI team's data.

The WPI team chose the Bortle Scale to represent the new data. The Bortle scale reveals a more detailed and comprehensive representation. Using this scale, the interpolation of the data points was more indicative of the quality of the sky throughout the island.

Using the Bortle scale allowed for standardization of future studies. Because the Bortle scale is used widely among stargazers and astronomers, the maps can be compared to studies from other locations. Lastly, the Bortle scale has an easy-to-understand color scheme. It is designed so that amateur stargazers can identify sky qualities.

4.3.4 Points of Interest

Bar Harbor is the brightest source of light on the island. There are many street lights on the main roads. West Street, Main Street, and Cottage Street all contribute a large amount of spill light. There are many businesses that utilize decorative lighting well after closing time. Geddy's restaurant is a good example of bright decorative lighting, which sports a large illuminated moose located on the roof. Most of the spill light in Bar Harbor is from decorative lighting and inefficient security lighting. There is a large area for improvement.

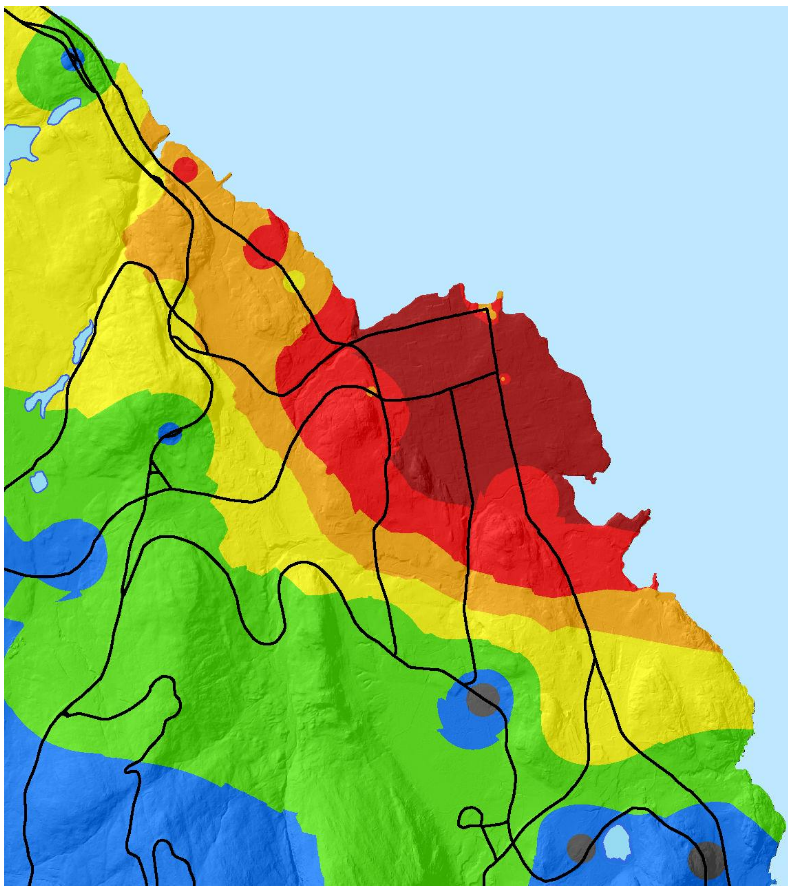


Figure 17: Bar Harbor

Northeast Harbor and Southwest Harbor are other large contributors to sky glow on the island. Unlike Bar Harbor, the lighting in these towns is mainly used for marina lighting and safety, rather than decoration.

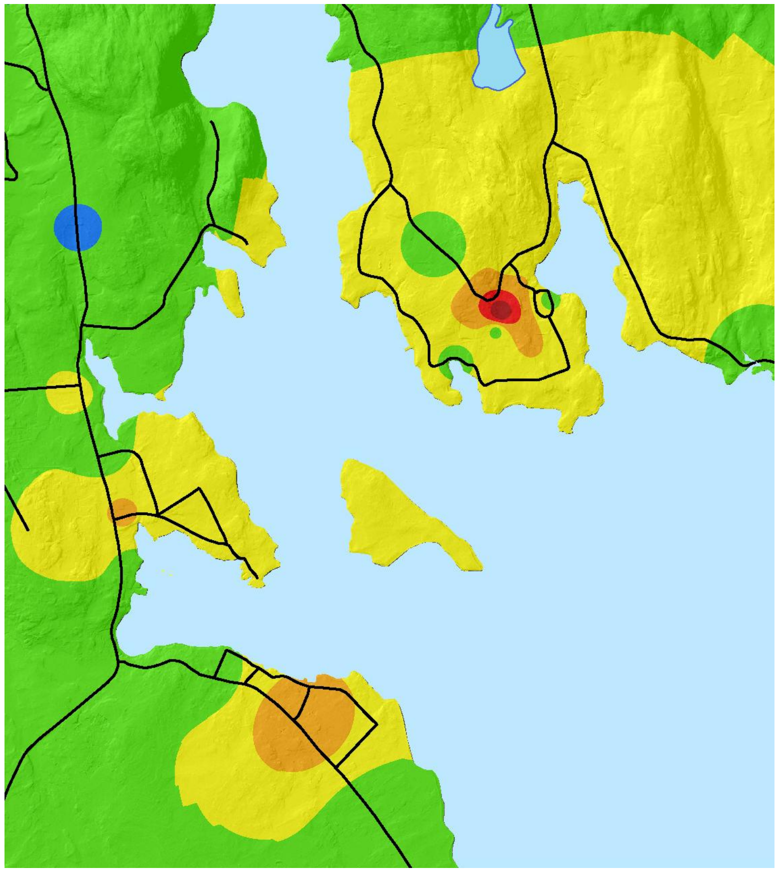


Figure 18: Northeast Harbor and Southwest Harbor

The largest amount of sky glow in the Somesville area stems from Mount Desert Island High School. There are two very prominent and bright street lights near the entryway of the school. Many of the school's lights, as well as the football field lights remain lit throughout the night. This is concerning because the lighting is seemingly unnecessary because classes were not in session at the time the WPI study was conducted.

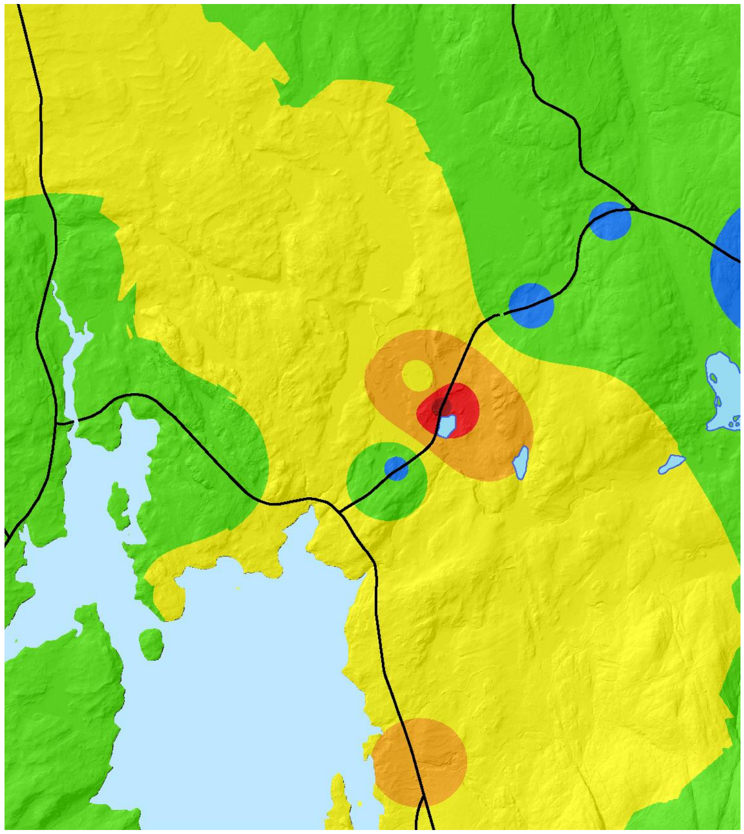


Figure 19: Somesville Area

Sand Beach is the darkest area on the map. This can be attributed to two factors: location and park lighting. Newport cove protects the beach from most of the sky glow from major population centers on the island. The beach faces out to the dark open ocean. The surrounding topography blocks the line of sight from Bar Harbor preventing residual sky glow. The park has added two main general lighting fixtures in the parking lot area of the beach. The lighting on the bathrooms and a light indicating where the staircase leading to the beach begins. Both fixtures are dim, shielded, and oriented to eliminate spill light and source intensity. These fixtures are undetectable from the beach.

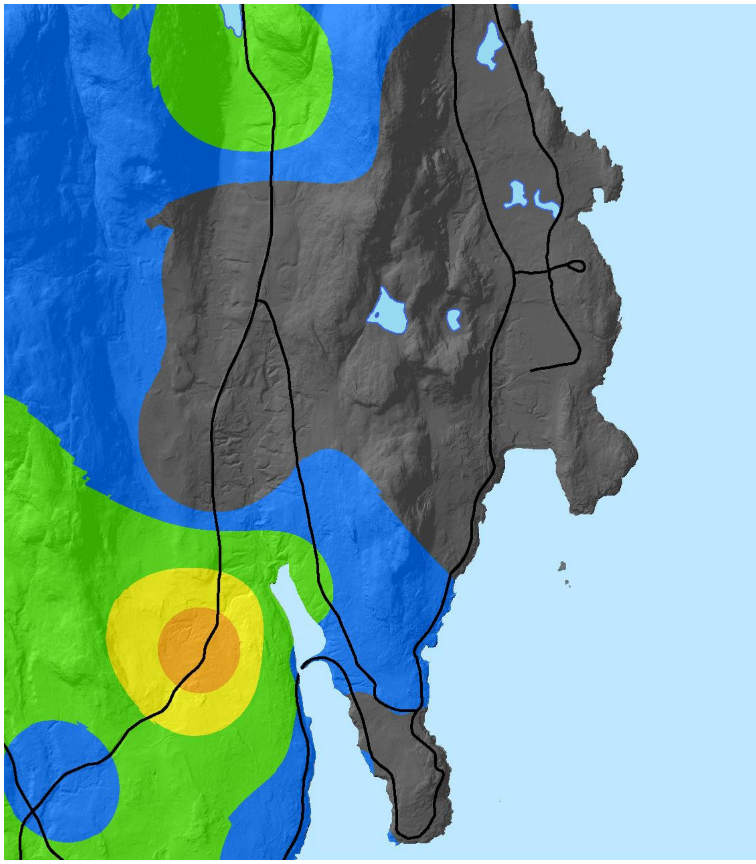


Figure 20: Sand Beach

Seawall campground and picnic area is another dark area located within park boundaries. Its dark sky can be attributed to park testing of efficient lighting that cuts down excess lighting and sky glow in the campground.

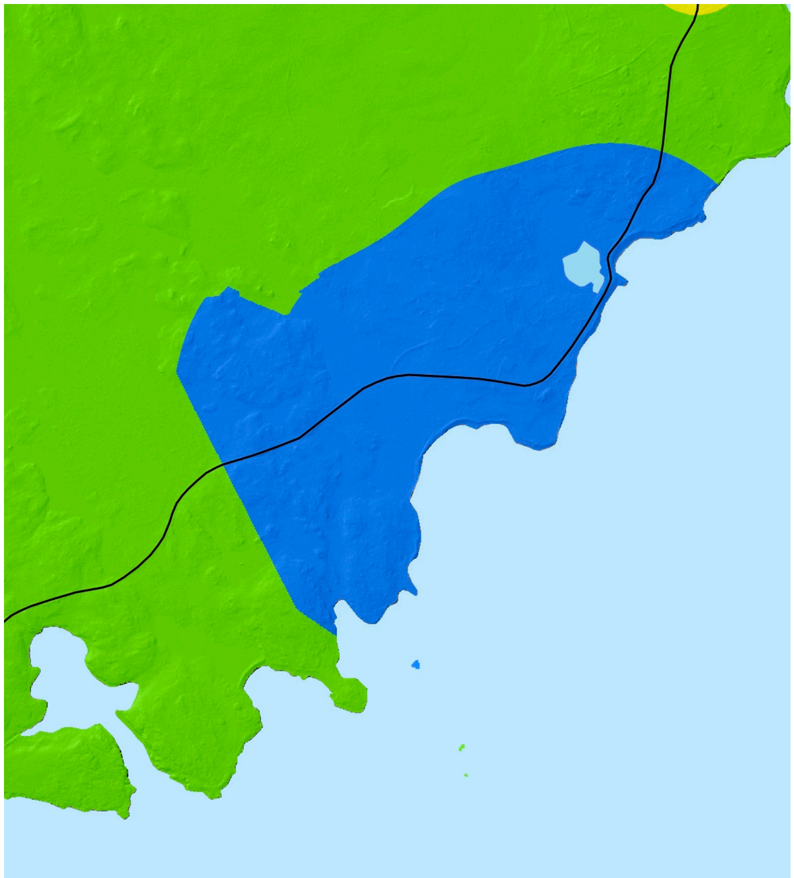


Figure 21: Seawall Campground and Picnic Area

Chapter 5: Recommendations

Future studies should be conducted to further understand how synthetic light affects Mount Desert Island.

5.1 Study Continuation and Expansion

The Dark Sky team recommends that the mapping of Mount Desert Island's sky quality be continued as a longitudinal study, and that it be expanded to gain more knowledge before lighting solutions are suggested or implemented.

5.1.1 Summer Study

The team recommends that annual studies be conducted during the summer months. Readings collected year after year can be compared to show trends. These trends can show increases or decreases in light pollution severity or verify previous results as constant.

The resolution of the Sky Quality map may still be improved upon by reaching the carriage roads by foot or bike. Hiking trails may be used to reach areas inaccessible by main roads and cars. This improvement in resolution will aid future projects with identifying the darkest and lightest areas of the island. Expanding the Mount Desert Island study to include the surrounding islands, where possible, will improve the data interpolation of the maps from future studies. These islands include, but are not limited to: Bar Island, Bartlett Island, and Great Cranberry Island.

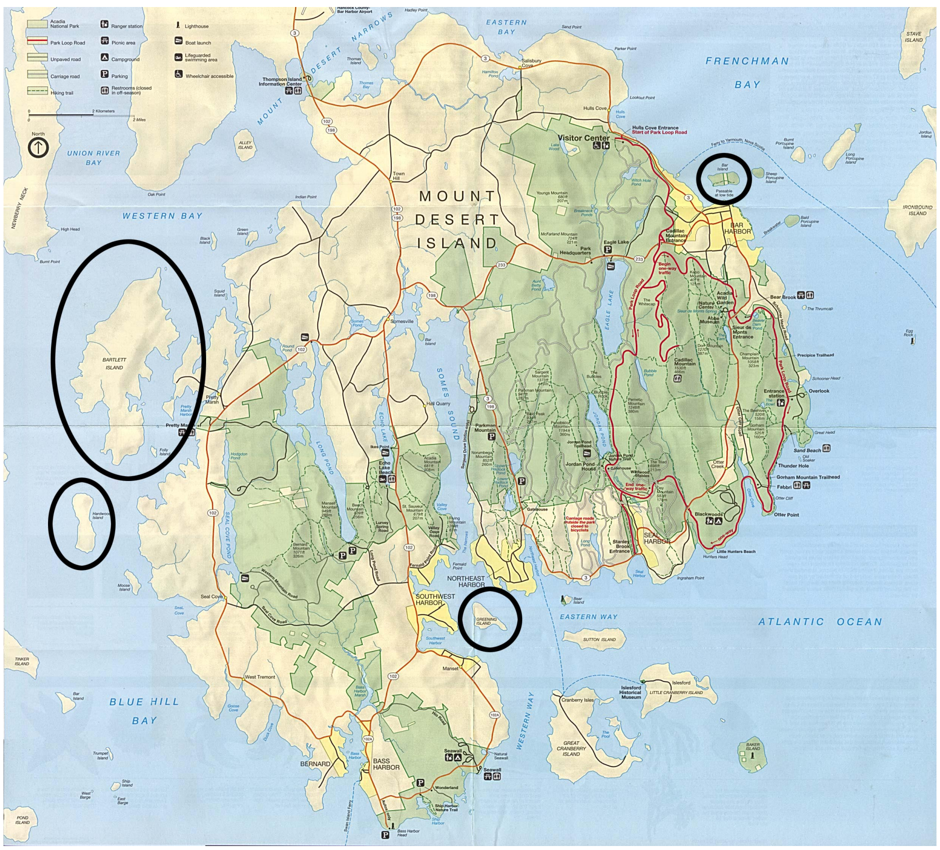


Figure 22: Island expansion sites

The summer study can be expanded to include more detailed maps of the island's major towns. Bar Harbor, Northeast Harbor, and Bass Harbor can be mapped extensively to gain better understanding of where most sky glow is concentrated.

5.1.2 Winter Study

The team recommends that the study is repeated during the winter months, as the July map is not directly comparable to the CoA map created in December. Used together, the summer and winter studies can direct future projects towards what light sources cause the most significant damage to the night sky on Mount Desert Island, as they will give a more complete picture of which light sources are a constant problem.

5.1.3 Schoodic Peninsula

The team recommends more extensive readings and maps of Schoodic Peninsula. The resolution can be improved by adding readings from hiking trails, picnic areas, and, depending on tides, even Little Moose Island. If Schoodic Peninsula is included in the winter study previously recommended, Schoodic Island, and Rolling Island can be included. Another recommendation is to create more extensive maps of Winter Harbor and Birch Harbor.

5.2 Time Lapse Graphs

The Dark Sky Project can be expanded by recording for a full night to show the evolution of light over time. The team experimented with this idea during the project. The SQM-LU-DL was used to collect data. Below is the proof of concept conducted on Cadillac Mountain from sunrise to sunset.

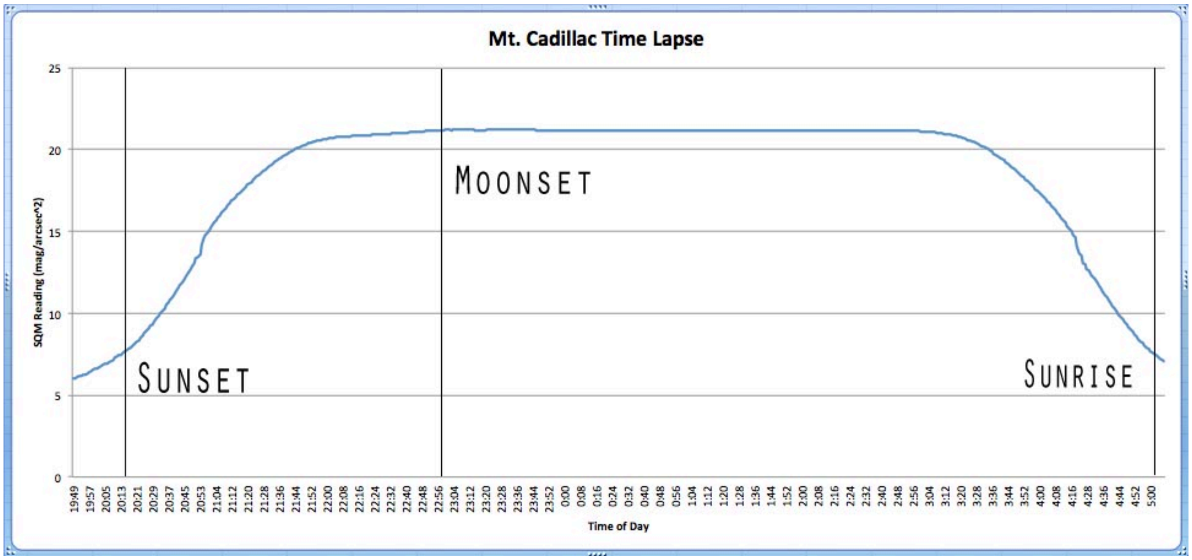


Figure 23: Sky Quality Over Time

The data output from the SQM-LU-DL is not in a Microsoft Excel readable format. To make the data manipulation easier for this portion of the project, a python program was written to output the data into a format that is Microsoft Excel compatible. This can be found in Appendix A.

Chapter 6: Conclusion

The Dark Sky Project was a success. The team expanded the CoA study. A more detailed set of maps was created. In addition to recreating the CoA study, the team adjusted the color scale to a standardized version: the Bortle scale.

The team went further than just the creation of Mount Desert Island maps. A Schoodic Peninsula map was produced. Future studies could further improve the resolution of this map. The team completed a proof of concept for a time-lapse study on Cadillac Mountain.

Overall, the fundamental project goals were achieved. The Dark Sky Project set a baseline for a longitudinal study. By standardizing their results, future studies can be compared to discover changes and trends of light levels on Mount Desert Island and Acadia National Park.

Appendix

Appendix A: Python Program

```
openedfile = open('sqm.dat', 'r') #Open the output from the SQM (Name it workfile.dat)
origdata = openedfile.read() #reads the data
openedfile.close() #close the file

splitdata = origdata.split('\n') #splits the data by newlines
usefuldata = splitdata[35:] #remove the 35 line long header
writtenfile = open('sqmdata.txt', 'w') #Open the new output file (It will either overwrite or create it)

for data in usefuldata:
    singledata =  data.split(';')  #split by the ; character
    #at this point a single line of data is split into a list as follows
    #singledata[0] = UTC time
    #singledata[1] = local time
    #singledata[2] = internal temp
    #singledata[3] = voltage
    #singledata[4] = mpsas
    #what we really want is the local time and the mpsas (if you want others you can alter this script easily)
    time = singledata[1][11:16] # Truncate the time to just include HH:MM
```

writtenfile.write(time + '\t' + singledata[4] + '\n') #write the time, tab, mpsas, then newline

writtenfile.close() #end program

This file can be found on the team website located at

https://sites.google.com/site/mdiprojectdarksky/files

Appendix B: Light Readings and GPS Coordinates

Latitude	Longitude	Reading	Date
44.40935	68.24822	21.49	July 6th
44.40764	68.24163	20.77	July 6th
44.40542	68.23728	21.36	July 6th
44.39883	68.23099	20.72	July 6th
44.39167	68.22948	20.2	July 6th
44.38436	68.22982	21.35	July 6th
44.37801	68.23318	21.1	July 6th
44.37237	68.22175	20.99	July 6th
44.37271	68.21409	21.26	July 6th
44.36946	68.20624	21.59	July 6th
44.36092	68.19812	21.53	July 6th
44.36019	68.1883	21.52	July 6th
44.34953	68.18789	21.68	July 6th
44.33005	68.18398	21.78	July 6th
44.32918	68.18336	21.75	July 6th
44.32072	68.18861	21.5	July 6th
44.31044	68.1896	21.67	July 6th
44.31414	68.1964	21.56	July 6th
44.31736	68.19962	21.38	July 6th
44.30725	68.20094	21.45	July 6th
44.29793	68.21285	21.38	July 6th
44.31686	68.22704	21.31	July 6th
44.31482	68.24877	21.32	July 6th
44.32011	68.25345	21.35	July 6th
44.32816	68.24983	21.42	July 6th
44.3383	68.25048	21.31	July 6th
44.35139	68.24498	21.47	July 6th
44.35408	68.24105	21.41	July 6th
44.36436	68.24153	21.43	July 6th
44.3685	68.22984	21.3	July 6th
44.35298	68.2246	21.39	July 6th
44.35023	68.23001	21.38	July 6th
44.36087	68.23005	21.41	July 6th
44.36882	68.23831	21.25	July 6th
44.39291	68.22015	20.31	July 7th
44.3858	68.21339	18.85	July 7th
44.38739	68.20512	17.94	July 7th
44.38089	68.2025	18.8	July 7th
44.36824	68.19761	20.43	July 7th
44.36089	68.20409	21.22	July 7th
44.34974	68.20301	21.04	July 7th
44.34104	68.20273	21.72	July 7th

Latitude	Longitude	Reading	Date
44.32865	68.20718	21.76	July 7th
44.31788	68.208	19.4	July 7th
44.31107	68.21902	21.49	July 7th
44.29969	68.23061	21.3	July 7th
44.29841	68.24066	19.46	July 7th
44.29329	68.25391	20.65	July 7th
44.28976	68.26514	21.06	July 7th
44.30086	68.28079	20.77	July 7th
44.31826	68.28781	21.05	July 7th
44.32717	68.29213	21.24	July 7th
44.33856	68.29758	21.12	July 7th
44.34814	68.30105	19.72	July 7th
44.36008	68.30436	20.79	July 7th
44.36682	68.3177	21	July 7th
44.36905	68.32976	20.93	July 7th
44.37863	68.3306	20.96	July 7th
44.3871	68.33157	20.62	July 7th
44.39625	68.33403	19.78	July 7th
44.39914	68.33447	19.59	July 7th
44.40636	68.34669	20.38	July 7th
44.41434	68.35679	20.79	July 7th
44.41974	68.35813	20.44	July 7th
44.41872	68.34111	20.54	July 7th
44.42327	68.3295	20.53	July 7th
44.43622	68.31492	20.54	July 7th
44.43226	68.29954	20.58	July 7th
44.42888	68.28214	20.54	July 7th
44.42985	68.26719	19.5	July 7th
44.42645	68.25061	20.36	July 7th
44.41741	68.25095	20.25	July 7th
44.40941	68.24438	19.84	July 7th
44.39911	68.22884	18.81	July 7th
44.39436	68.22197	18.8	July 7th
44.42858	68.28448	20.93	July 8th
44.42096	68.28855	21.06	July 8th
44.41395	68.29608	20.98	July 8th
44.40533	68.29996	21.06	July 8th
44.39358	68.29273	20.8	July 8th
44.38289	68.2856	20.86	July 8th
44.35592	68.34345	21.04	July 8th
44.34825	68.34772	21.25	July 8th
44.33778	68.35278	21.35	July 8th
44.33057	68.34913	21.37	July 8th

44.31515	68.3438	21.38	July 8th	44.34984	68.33637	21.3	July 12th
44.32336	68.34345	19.99	July 8th	44.28874	68.32989	20.69	July 12th
44.34429	68.3549	21.31	July 8th	44.28778	68.34054	21.24	July 12th
44.35106	68.35892	21.26	July 8th	44.28455	68.34857	21	July 12th
44.35489	68.36225	21.27	July 8th	44.27777	68.36045	21.11	July 12th
44.36192	68.3618	21.18	July 8th	44.27773	68.36828	21.17	July 12th
44.36939	68.35871	20.75	July 8th	44.27803	68.37994	21.22	July 12th
44.3647	68.34562	20.89	July 8th	44.28173	68.38543	21.25	July 12th
44.35662	68.34604	20.9	July 8th	44.28679	68.40108	21.45	July 12th
44.35362	68.36736	21.2	July 8th	44.28322	68.40876	21.29	July 12th
44.34632	68.37979	21.28	July 8th	44.2861	68.41563	21.36	July 12th
44.33969	68.39251	21.17	July 8th	44.29492	68.42042	21.24	July 12th
44.34039	68.39967	20.52	July 8th	44.30197	68.42443	21.19	July 12th
44.34754	68.39434	21.3	July 8th	44.30833	68.4155	21.22	July 12th
44.37632	68.38234	21.14	July 8th	44.31539	68.40865	21.27	July 12th
44.37967	68.37236	21.35	July 8th	44.3165	68.40369	21.04	July 12th
44.38565	68.35857	21.39	July 8th	44.31435	68.39262	21.22	July 12th
44.39799	68.34273	21.17	July 8th	44.32035	68.37948	20.53	July 12th
44.39819	68.33265	21.19	July 8th	44.32994	68.37449	20.98	July 12th
44.40058	68.32226	21.18	July 8th	44.33253	68.38495	21.05	July 12th
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44.41517	68.26262	20.97	July 8th	44.2973	68.4029	21.29	July 12th
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44.23696	68.30211	21.49	July 12th	44.28083	68.3995	21.25	July 12th
44.24383	68.29872	21.44	July 12th	44.27042	68.39926	21.37	July 12th
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44.29093	68.32886	21.08	July 12th	44.26229	68.33555	21.13	July 13th
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44.32869	68.33095	21.13	July 12th	44.37781	68.2362	21.42	July 14th
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44.38098	68.28509	21.44	July 14th	44.39	68.20481	15.32	July 15th
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44.36612	68.3026	21.42	July 14th	44.38814	68.20451	15.54	July 15th
44.34153	68.30115	21.25	July 14th	44.38725	68.20384	19.51	July 15th
44.33097	68.30519	21.41	July 14th	44.3865	68.20406	15.4	July 15th
44.32351	68.30504	21.47	July 14th	44.38705	68.20425	18	July 15th
44.2975	68.29473	21.29	July 14th	44.38759	68.20441	17.21	July 15th
44.29023	68.29334	21.03	July 14th	44.38859	68.20456	16.85	July 15th
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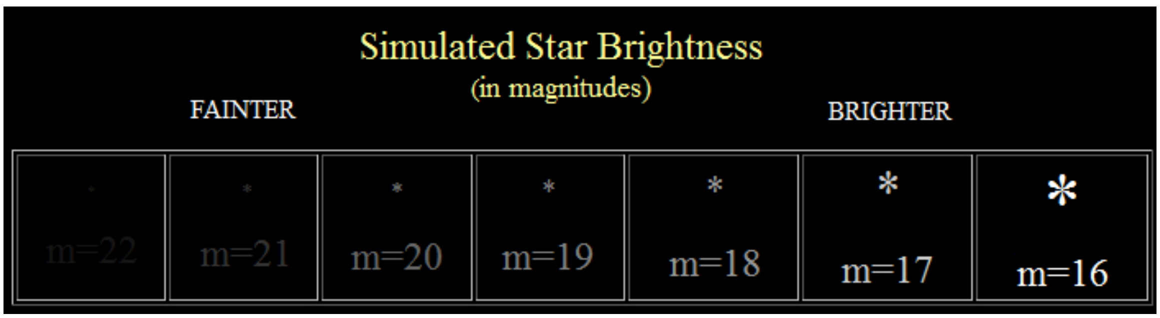
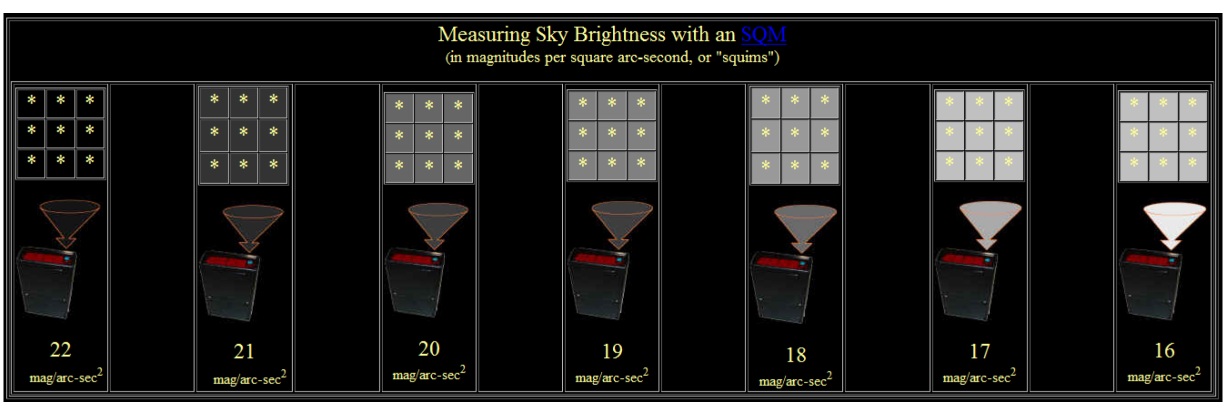
44.29337	68.28935	16.95	July 14th	44.38975	68.20588	15.99	July 15th
44.29208	68.28979	21.08	July 14th	44.38945	68.2066	15.99	July 15th
44.39217	68.20405	19.85	July 15th	44.38927	68.20719	16.51	July 15th
44.39081	68.2038	16.75	July 15th	44.38885	68.21069	15.97	July 15th
44.3908	68.20453	20.1	July 15th				

Appendix C: Magnitudes per Square Arcsecond (mag/arcsec^2)

The magnitude of an object is the measure of its brightness. Magnitudes work on a logarithmic scale. A magnitude 10 star is 2.5 times brighter than a magnitude 11 star. A magnitude 5 star is 100 times brighter than a magnitude 10 star. This means that the higher the number, the darker it is.

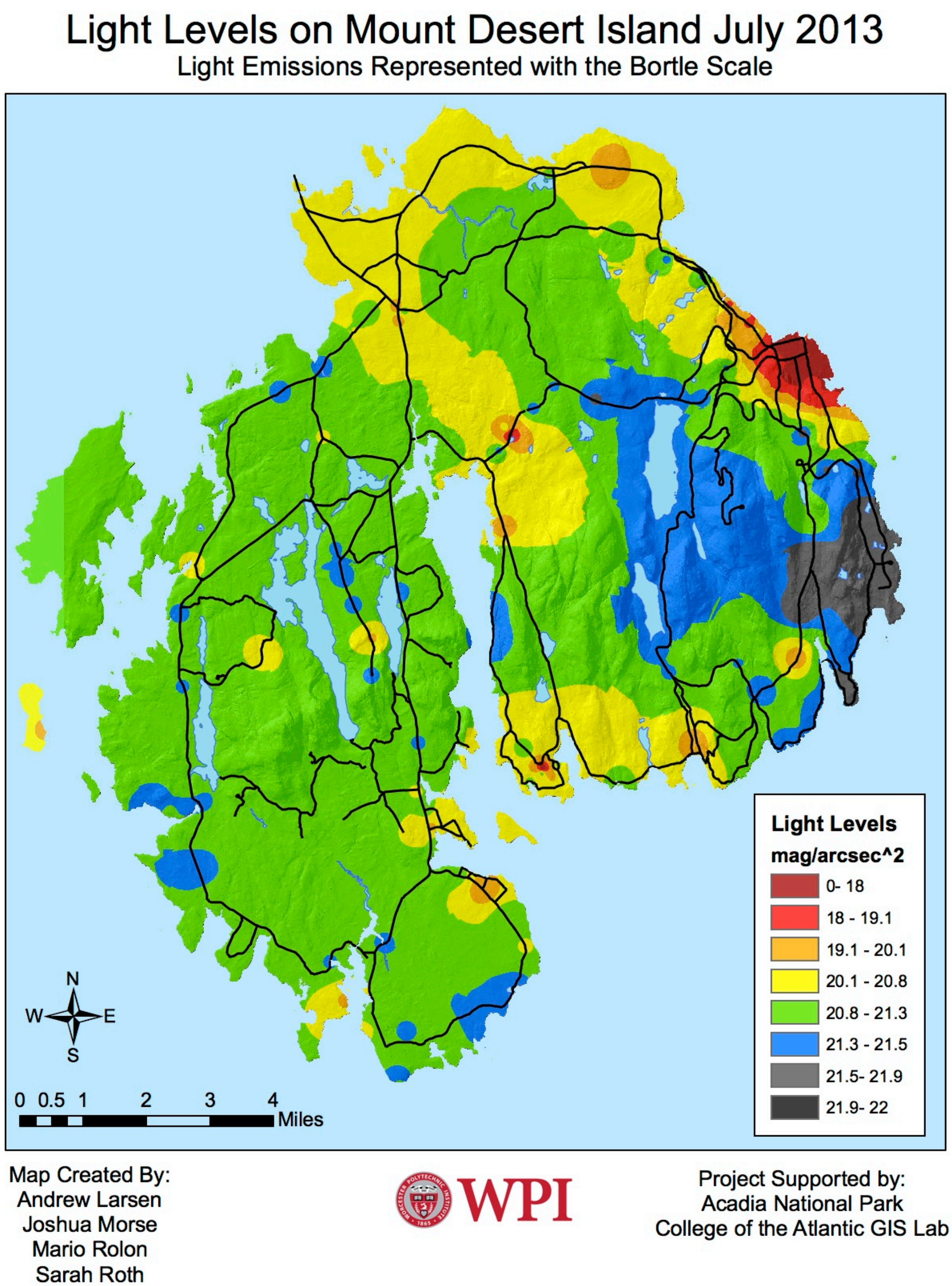


An arcsecond is a degree measurement from an arc, like a circle. A second is 1/3600 of a degree. A square arcsecond is an angular area 1 arcsecond x 1 arcsecond. Therefore, magnitudes per square arcsecond (mpsas) is the measure of the brightness in magnitudes averaged over a square arcsecond of sky. Therefore a 16 mags/arcsec^2 sky would be equivalent on average to a 16 magnitude star stretched across the sky.

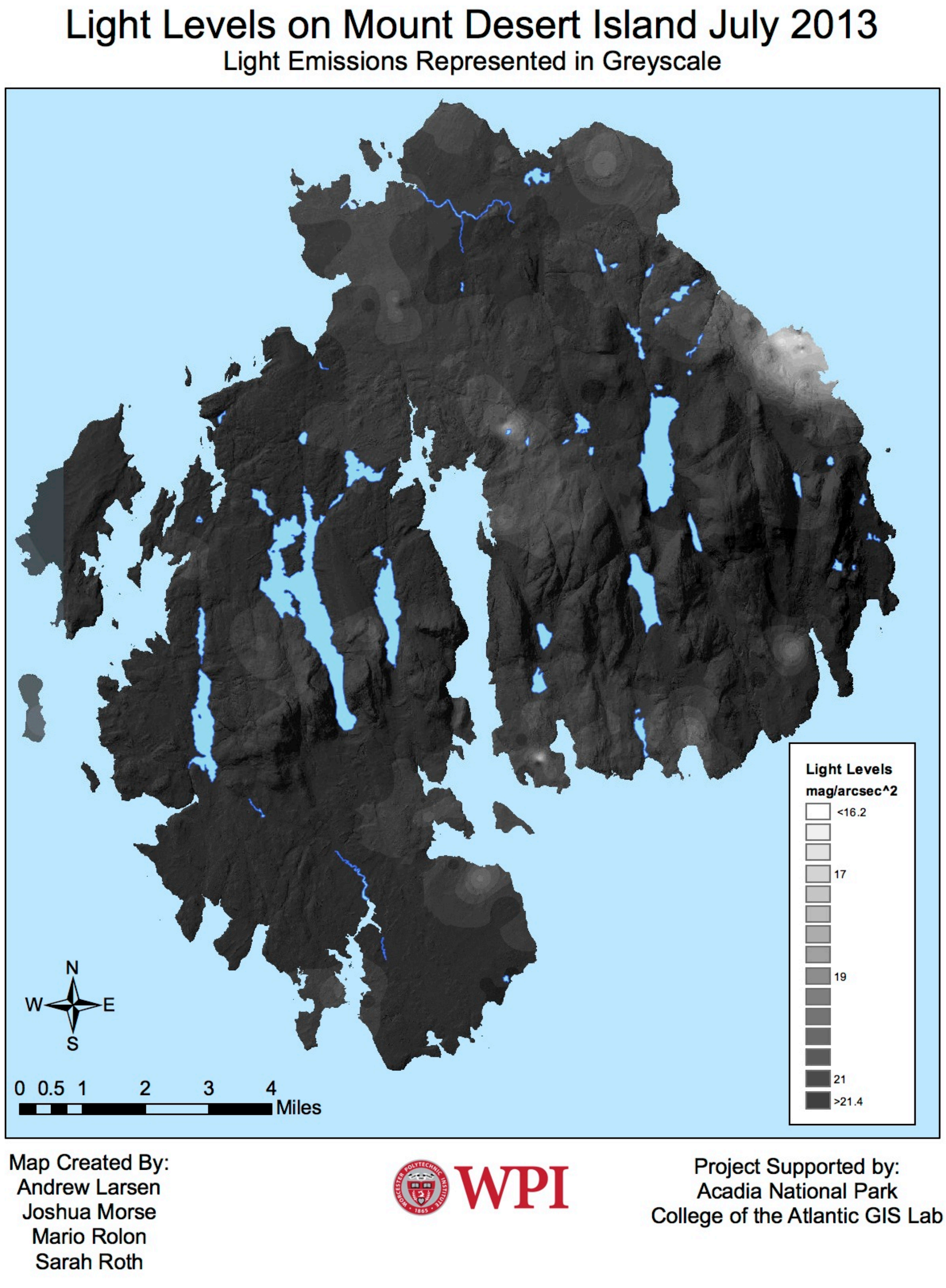


Appendix D: Extra Maps

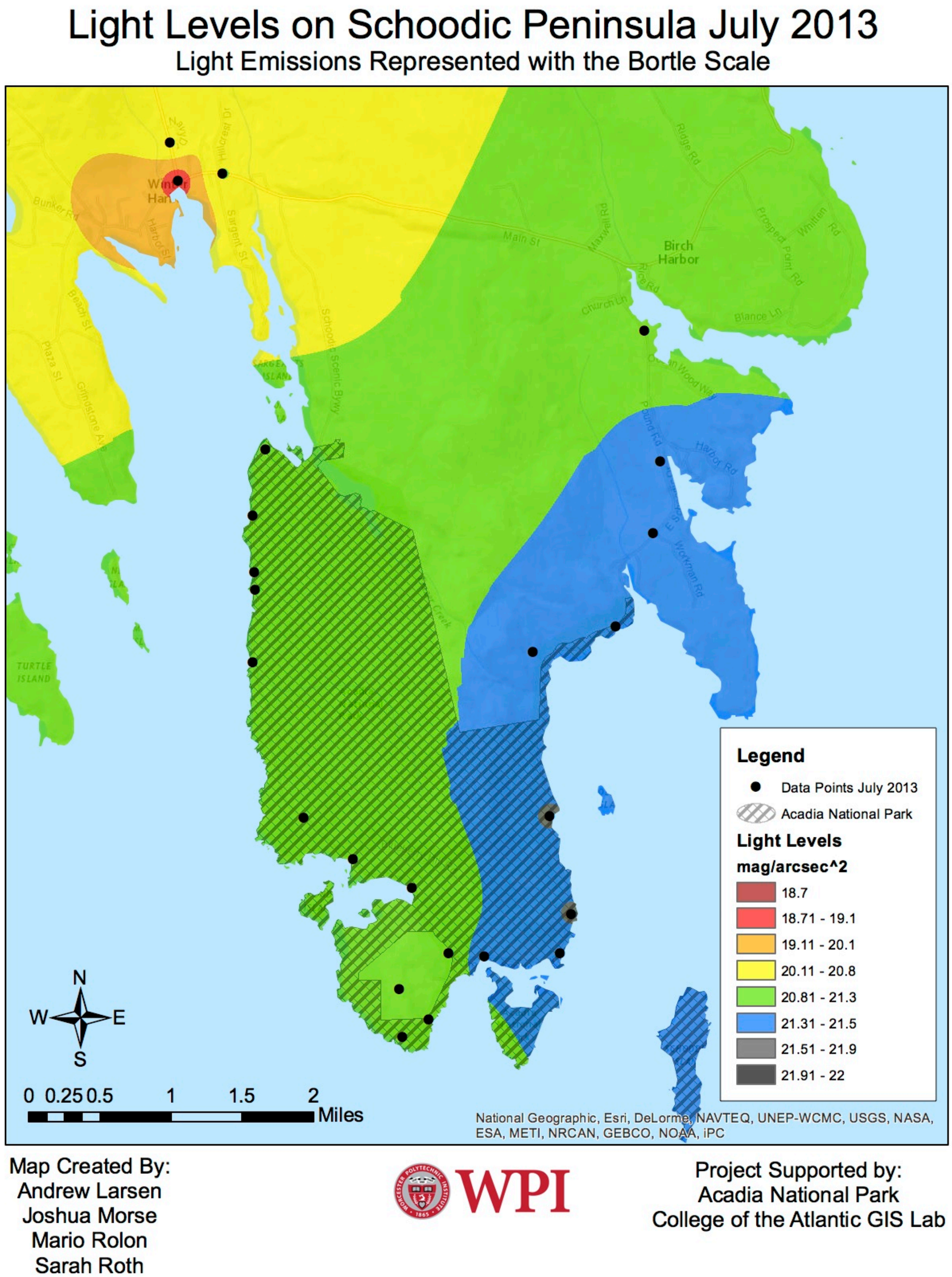
Final map with major roads shown.



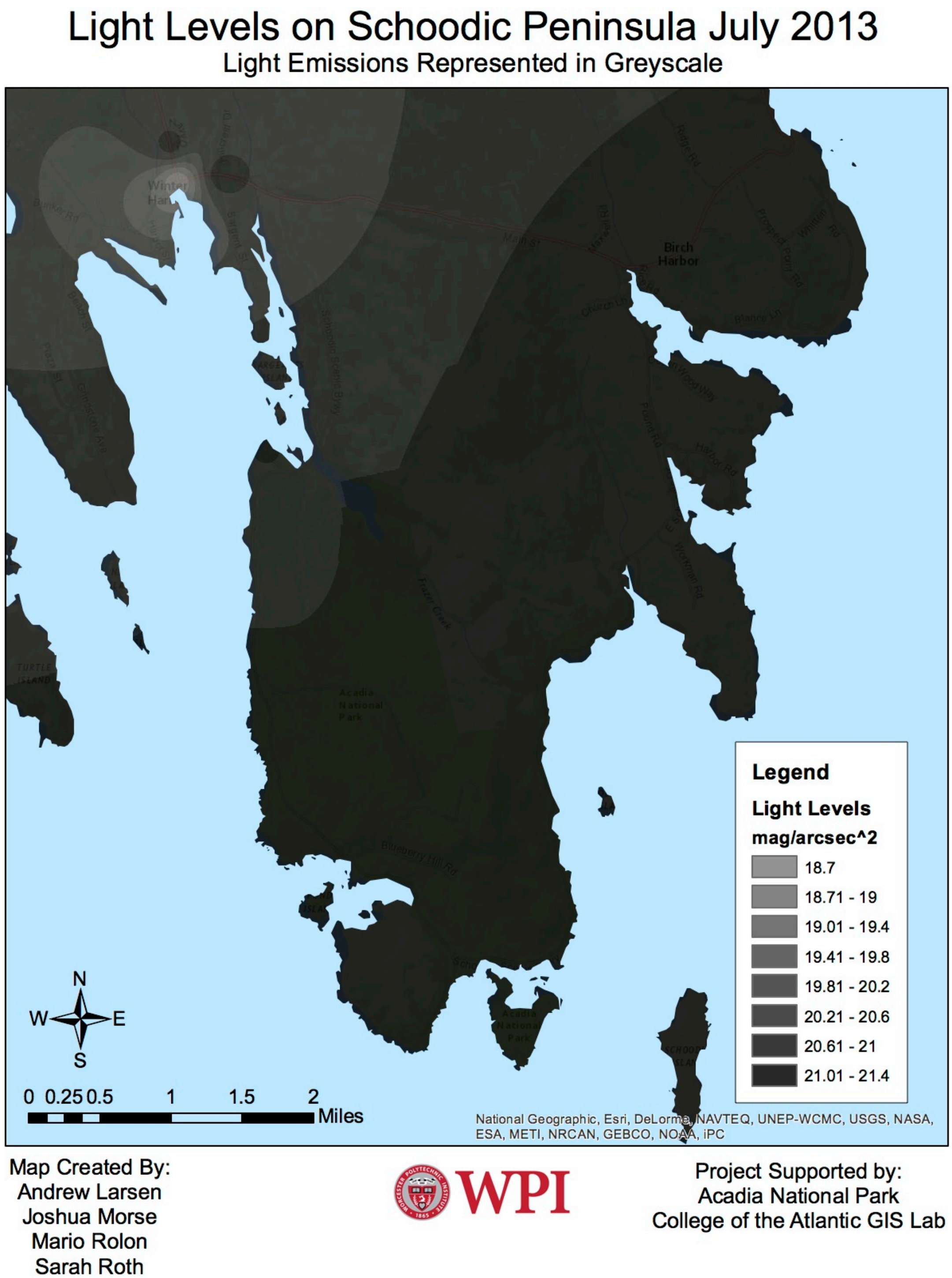
Final Map in greyscale



Schoodic Peninsula with Acadia National Park borders



Schoodic Peninsula in greyscale



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