The Pennsylvania State University

The Graduate School

UNDERSTANDING VISITOR PERCEPTION OF ARTIFICAL LIGHT AT NIGHT IN NATURAL AREAS: A STUDY OF VISITOR EXPERIENCE IN DETERMINING A LIGHT LEVEL THRESHOLD

A Thesis in

Recreation, Park, and Tourism Management

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of
Master of Science

May 2023

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ABSTRACT

A natural dark night sky is becoming more and more rare due to the introduction of anthropogenic light across human occupied landscapes. Even some of our most protected natural areas, U.S. national parks, are not spared from the encroachment of artificial light at night (ALAN). ALAN plays many roles in protected areas. From guiding visitors to comfort stations to lighting walkways and signage, light is a necessary component of the human experience in parks. However, how much light is necessary to serve these human needs? How do we balance human lighting needs and preferences while also being cognizant of the impact of ALAN on the natural world outside of human function? It is true that anthropogenic light sources threaten night sky visibility in National Parks, which protect some of the only remaining pristine night skies in the United States; However, light at night for humans often translates to feelings of safety, an opportunity to extend daytime recreation, and the ability to see their immediate surroundings at night. With this, there is a need to determine what level of light is needed for human use of natural spaces at night while also being cognizant of the impacts of lighting on the natural environment.

A substantial amount of the existing literature examines the effect of ALAN on the environment, but outside of health impacts, does not look at the human need for light in these same spaces. This thesis aims to explore how visitors in natural areas perceive artificial light at night while determining their preferred lighting conditions in natural spaces. The following thesis will outline visitor preference of artificial light in a natural area in relation to intensity and spectra based off an on-site visitor survey in the

Pennsylvania State University Arboretum. Participants indicated a significant preference for amber light in natural areas at night as well as for an intensity preference lower that previously noted in the existing literature. This thesis seeks to guide how low managers can go in relation to lighting in parks and protected areas.

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ACKNOWLEDGEMENTS

To Dr. Brett Seymoure, who gave an undergraduate a chance to do research. You opened my eyes and ears to sights and sounds and introduced me to a line of science that I may have not found on my own.

This product would not be possible without the endless support and encouragement of Drs. Derrick Taff and Peter Newman. It all began with a phone call with a potential graduate student who wasn't even sure she wanted to do social science. You all saw something in me that I had not even seen myself. This project became more than I could ever imagine and faced more challenges than I think any of us thought possible. So, thank you for sticking with it and for sticking with me.

Another thank you is owed to the team at the Natural Sounds and Night Skies Division. In the same vein, thank you to all the undergraduate researchers who carried the weight of this project night after night, rain, or shine. Olivia, Kyra, Emily, Nick, Garrett, Isabel, Sam, Tim, Annika, Courtney, Dante, Erin, Jessica, Lauren, and Raghad – you all kept this study running and I cannot thank you enough for all of your hard work.

Finally, thank you Mom, Dad, and Kat. Never did I expect to do the majority of my first two years of graduate school from bed with a broken leg, but I wouldn't change any of it for the world. Those months at home were some of the best and worst, but y'alls constant support made it all okay. Oh, and how could I forget to thank my four-legged friends: Otto, Kora, Harvey, and Luna. What can I say, dogs make everything better.

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. DGE1255832 and the National

Park Service CESU #148348. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

Chapter 1

Introduction

As light pollution spreads, we are slowly losing one of the oldest and most universal links to all human history.

-Astronomer, Peter Lipscomb (2013)

Throughout human history, the starry-night sky has been a muse for sonnets, songs, and more. The night sky has lasted the test of time, acting as a constant in the human experience. However, with rising levels and artificial lighting, the natural beauty of the night sky has been dulled. Artificial lighting contributes to the phenomena of artificial light at night (ALAN) which is non-natural anthropogenic light, such as streetlights, building lights, or outdoor lighting (Klinkenborg, 2008). ALAN can be further classified or labeled as light pollution. As defined by Gallaway et al. (2010), light pollution is excessive or obtrusive artificial light caused by outdated and inconsiderate design, often referring to unshielded or misdirected light that scatters into the atmosphere creating skyglow in spaces with no direct light sources (Bennie et al., 2015). It is the presence of light pollution that is tarnishing the historic beauty of natural night skies.

However, light at night often translates to feelings of safety, an opportunity to extend daytime recreation, and the ability to see immediate surroundings at night in the modern world. With an established need for light at night, there is a need to determine what level of light is necessary for human use of natural spaces at night while also being cognizant of the lightings impact on the natural environment. A substantial amount of the existing literature examines the effect of ALAN on the environment, but outside of health impacts, does not look at the human need for light in these same spaces (Rodrigo-Comino, 2021). This thesis aims to explore how visitors in natural areas perceive artificial light while determining their need of artificial light at night in natural spaces in relation to spectra and intensity.

Problem Statement

We know that there is a precedent for providing light at night in human occupied spaces, which include developed areas of national parks and protected areas, but we remain unsure about what amount of light is necessary in these spaces. There is currently no standard level of light that is required in these spaces, and therefor this thesis can act as a guide for determining a light level threshold for artificial lighting structures within parks and protected spaces. Further, no research to date has provided an understanding of visitor preference of lighting in relation to spectra and intensity within parks through an experimental study. This thesis will focus on understanding visitors needs and their ability to function under specific lighting conditions in a park-like setting while also beginning to gain an understanding of a realistic lighting threshold to be utilized in parks and protected areas.

Research Questions:

With the above-mentioned problem statement, this research seeks to answer the following research questions:

R1: What is the lowest threshold of light needed to provide for visitor needs?

R2: Do any visitor characteristics influence lighting intensity and spectra choice?

Chapter 2

Literature Review

Artificial Light at Night: An Overview

According to the First World Atlas of the Artificial Night Sky Brightness, two-thirds of the U.S. population has already lost the ability to see the Milky Way (Cinzano et al., 2001). This mark of loss of night sky viewing indicates the widespread phenomena of ALAN and its importance. The loss of night sky visibility is mostly attributed to the presence of light pollution, excessive and misdirected ALAN. Light pollution is either direct pollution (e.g., a streetlight or security light on the side of a building) or indirect, often referred to as skyglow (Bennie et al., 2015). Indirect light pollution results from direct light pollution, and people often view this as the haze of light emanating from cities or lit infrastructure at night. ALAN can quickly become light pollution if it degrades the surrounding natural environment.

Light pollution is presently growing in cities across the globe and is increasingly encroaching on our natural areas; this evolving phenomenon is impacting even our most protected lands, such as national parks and wilderness areas. Plants and animals have evolved with consistent light cycles, often using light as a cue in many critical life-history strategies. These natural light regimes are changing due to urbanization and increased levels of ALAN. This increase in anthropogenic lighting affects plant and animal species that have evolved with millions of years of natural light regimes. There is a growing body of evidence within the literature suggesting that ALAN affects the foraging, reproductive, and migration behavior of several nocturnal animals (Moore, 2006). ALAN can change prey-predator relationships and disrupts physiological processes in plants (Longcore & Rich 2004, Crump et al., 2021). Light acts as an information source for both plants and animals: providing cues for plant phenology and circadian rhythms in animals (Cronin et al., 2014; Gaston et al., 2017; Kang et al., 2010; Page, T. L. 2017). Light also dictates photoperiodism, the physiological reaction of organisms to the length of day and night, seasons, and the monthly lunar cycle (Rich and Longcore, 2004; Gaston et al., 2012). High levels of ALAN in proximity to protected areas is especially worrying (Aubrecht, 2010). With this basic understanding of ecological impacts of ALAN, we must further understand the impacts of ALAN on humans as well as their lighting needs in these same protected areas.

Light pollution not only affects flora and fauna and night sky viewing, but it also has implications for human health (Chepesiuk, 2009). The most documented health effect of light pollution on humans is the disruption of the circadian clock (Pauley, 2004; Walker et al., 2020). The circadian clock is the twenty-four-hour day/night cycle that affects most physiologic processes, including hormone production, cell regulation, and other biological activities (Pauley, 2004). Pauley (2004) explained that the circadian clock is dependent upon nights that allow for MLT production, and the introduction of light pollution disrupts this process. By reviewing data from 78, 586 women that linked higher rates of breast cancer among night-shift workers, Pauley (2004) connected the impacts of exposure to artificial light to the disruption of circadian rhythm in humans. Disruption of circadian rhythm in humans can lead to sleep disorders, progression of certain cancers, such as breast cancer, and imbalances of hormones (Pauley, 2004; Walker et al., 2020). Walker et al. (2020) explains that extended and increased exposure to light pollution has specific impacts on endocrine function, which showed association with breast and prostate cancers. These results were concluded from epidemiological observation, case-control, and cohort studies (Walker et al., 2020). Association of artificial light at night exposure and breast cancer was drawn from the same sample size of 78,586 nurses as references by Pauley (2004) (Walker et al., 2020). With these long-term health considerations in mind, we can then look at how light pollution impacts visitor experience.

Artificial Light at Night: Visitor Experience

Some national parks are considered dark sky preserves; these parks are far away from urban areas. The National Park Service focuses on maintaining these dark sky parks and fully minimizing effects of ALAN and light pollution (Albers & Duriscoe, 2001). Night skies are a unique resource in that a true night sky is completely recoverable (Duriscoe, 2001). Effects of light pollution in national parks appear in a handful of ways. Impacts of light pollution on wildlife are the most studied in national parks.

Before examining the effects of light pollution on visitor experience in national parks, it is important to understand what nighttime recreation looks like. Nighttime recreation offers many opportunities for national park visitors. Nighttime recreation is often driven by dark sky tourism, which is visitors who are motivated to view dark, star-filled night skies that are unique to some national parks (Kulesza & Hollenhorst, 2013; Mitchell & Gallaway, 2019). Nighttime recreation experiences are also important to visitors' overall experience (Smith & Hallo, 2019). Nighttime recreation in parks provides valuable experiences for visitors, and natural night sky conditions are essential qualities of wilderness that facilitate untrammeled, natural, and undeveloped opportunities for solitude (Beeco et al., 2011; Beeco et al., 2013).

Many national parks offer night programs for visitors. Nighttime recreation is unique in that the typically low levels of visitation during night hours provide visitors with additional or better-suited opportunities to fulfill visit motivations and outcomes (i.e., leisure, adventure) (Beeco et al., 2011). Night programs can range from traditional star grazing and night sky interpretive events to camping (Beeco et al., 2011). More unique experiences include whitewater kayaking and hiking (Beeco et al., 2013). Most recreation activities can be done during the day or night, but nighttime recreation offers visitors a new way to experience national parks (Beeco et al., 2013). Nighttime recreation provides additional ways for visitors to challenge themselves, increase risks, experience different wildlife resources, and gain a different perspective of nature (Beeco et al., 2013).

However, ALAN can detract from these enhanced visitor experiences; While artificial light may prove critical in providing high-quality night recreation experiences (i.e., headlamps for hikers, bollards to light walkways, safety lighting), too much artificial light may detract from a night experience (Beeco et al., 2011). Specific light pollution disruptions to nighttime recreation include difficulty viewing the night sky, increasing frequency of encountering other groups visually, and quieting nocturnal animals (Beeco et al., 2011). Night skies and landscapes free of human-caused light are essential for opportunities for solitude, and the disruption of light pollution threatens the intentions of nighttime recreation experiences (Beeco et al., 2013).

Smith and Hallo (2019) sought to understand what lighting characteristics (brightness and correlated color temperature (CCT)) would be acceptable to park and protected area visitors in Acadia National Park. Through a paper-based questionnaire administered in three typical park settings (i.e., pathway, amphitheater, and comfort station), participants viewed the lighting fixtures at 3000K (yellow), 4200K (white), and 6000K (blue-white) before selecting the brightness level in relation to multiple scenarios resulting in 27 brightness ratings per participant. Smith and Hallo determined that participants preferred the "warmest" color choice (3000K) for the comfort station and the amphitheater, and one participant found the most undesirable and brightest setting to be "too city-like" (2019). 4200K was preferred for pathway lighting. Some participants indicated that darkness was a primary factor in their park visit, which may have driven color and intensity choice (Smith and Hallo, 2019). The color and intensity of lights tested by Smith and Hallo (2019) is well above the currently debated acceptable levels. The current guidelines were not available at the time of the study, and CCTs in the range of 1900K and 3000K are recommended for outdoor lighting and related environmental protection (Donatello, Quintero, Caldas, Wolf, Van Tichelen, Van Hoof, Geerken,2019). It is important to expand on research to determine the level of light necessary for visitors in national parks with this information. This needs to be determined concerning visitor preference and functionality and with ecological impact in mind.

Manning and others sought to determine indicators and standards of quality for viewing the night sky in national parks (2016). This research discusses how psychological research is essential for a complete understanding of the value and the influence of both visibility of night skies with a focus on applied, field-based research in national parks. This study utilized structured, quantitative questionnaires to determine visitor opinion on night skies and night skies management (Manning et al., 2016). They determined that most visitors felt that night sky viewing is important and that the National Park Service should protect opportunities for visitors to see the night sky (Manning et al. 2016). These results culminated in recommendations for national park management, suggesting that more explicit management of night skies in national parks will be required due to the increasing importance of night sky visibility to visitors (Manning et al., 2016).

Light pollution in national parks disrupts natural light regimes and negatively impacts the visitor experience (Buxton et al., 2020). Buxton and authors (2020) used two sources of information to quantify anthropogenic light: median upward radiance cloud-free composites from visible, infrared imaging radiometer suite (VIIRS) Day/night band and Zenith sky brightness, or luminance, generated by comparing a sky glow model of VIIRS data with charge-coupled device camera observations of sky glow from parks around the U.S. From this data, Buxton et al. were able to quantify the proportion of park areas experiencing light pollution above natural conditions, which correlates to levels of light that impact flora, fauna, and the human experience (2020). 62% of the 197 national park units' studied experienced ALAN greater than double the acceptable background light conditions. However, it was determined that high levels of excess light conditions occurred in small areas (less than 5% of the park's area) (Buxton et al., 2020). Light pollution is often in areas of high human activity, like those associated with the leisure industry (i.e., lodges, visitor centers, developed campgrounds, etc.). With this, understanding the necessary lighting conditions (spectra and intensity) for visitor needs could lead to lowering light levels in the developed areas of parks.

From the 2013 National Park Service State of the Park Report and the Natural Sounds and Night Skies Division, the single parameter most useful for assessing the quality of a park's nighttime environment is the amount of anthropogenic light averaged over the entire sky, measured in the human visual spectral band (2013). Using this standard, dark sky conditions in national parks are determined. Gaston et al. (2015) identified minimum required levels of light as a current gap in the literature and as an area needing to be addressed. This is something that is found to still be true. Through an experiment study asking participants to identify what level of light they consider necessary for outdoor recreation in a national park setting, we can understand what level of light is necessary for national parks. Currently, outdated fixtures in national parks are producing levels of light that may be unnecessary, which makes reducing light pollution in national parks a retrofitting task. Well-designed lighting, on the other hand, sends light only where it is needed without scattering it elsewhere (Claudio, 2011). Experts in the field agree that light pollution can be easily controlled with well-designed lighting and simple measures such as turning off indoor and outdoor lights when not in use (Claudio, 2011). By gaining visitor perspective on the spectra and intensity of light needed for nighttime experiences in national parks, managers will be able to make the necessary modifications of lighting in national parks across the U.S.

Chapter 3

Methods

Study Overview

Anthropogenic light sources have expanded with growing population development in both rural and urban areas. With growing sources of artificial light at night, some light levels have now been deemed as "light pollution," which has adverse effects on wildlife, human health, and stellar visibility. The National Park Service recognizes natural dark skies as important biological, cultural, and experiential resources. With this, light pollution threatens night sky visibility in national parks. Modifications to artificial lighting in national parks are being considered to protect natural darkness and reduce impacts to wildlife while still achieving desired outcomes for visitors (e.g., safety, navigation, recreation).

Considerations of upgrades to the lighting infrastructure in national parks can help the agency to maintain quality experiences for visitors while protecting dark skies as a social and ecological resource. Currently, there is a gap in the scientific literature on how artificial light at night in natural protected areas impacts visitor experience and functional abilities, as well as an understanding of visitor lighting needs.

This research will help determine the threshold of light necessary for visitor safety and basic functionality. Advanced Lighting Guidelines are currently believed to be set at too high of a light level (Gaston et al., 2015). The National Park Service and this research team are interested in determining the level of light visitors think is necessary for a park setting. This research could help lower current light level standards and have impacts on mitigating light pollution across the national park network. This research will focus on two elements of lighting preference: (1) intensity or the brightness of light, and (2) spectra of light, or the color of light perceived by visitors. The driving question of "how low can we go?" regarding lighting at night is critical in moving forward light standards.

This research comes as a timely opportunity to provide preliminary information to the National Park Service before more in-depth light studies are launched in various U.S. national parks (Acadia National Park, Smokey Mountain National Park, and Grand Teton National Park).

Research Questions:

With the preceding literature review and the above-mentioned purpose, this research seeks to answer the following research questions:

R1: What is the lowest threshold of light needed to provide for visitor needs?

R2: Do any visitor characteristics influence lighting intensity and spectra choice?

Methods

Location

This study was designed as a pilot study, and the data and results should be treated as such. It took place in the Pennsylvania State University (PSU) Arboretum with the support of the National Park Service (NPS) in the fall of 2021, spring of 2022, and fall of 2022. The PSU Arboretum is located off Park Avenue, north of the University Park main campus in State College, Pennsylvania. While the PSU Arboretum is a more urban setting than most national parks, the quality of the night sky and the amount of light pollution visible at night from the study site is comparable to some national parks. Seven individual lighting stations were installed in both the edge habitat and in the trailed segments of the forest in the PSU Arboretum creating a course for study participants (Figure 3-1).

Figure **3-1**:Map of the study site and lighting stations (1-7).

Lighting Selection

In this study we sought to understand visitor preference and perception of white and amber lights. Amber light has been established as a wildlife friendly lighting option and has also been accepted by visitors through a past study at Colter Bay within Grand Teton National Park (Freeman et al., 2020). However, this study took place in a well-developed portion of the park. We seek to further understand how color and intensity are perceived by visitors in a trail-like setting.

Intensity, or brightness is the psychological product of electromagnetic radiation stimulating the eye (Smith & Hallo, 2019). Total darkness prevents visual sensory input, potentially decreasing the amount of information a person has about their surroundings, whereas the introduction of light increases visual cues available for processing (Schiffman, 2000; Steidle, Werth, & Hanke, 2011). However, lighting that is too bright can result in physical discomfort to the eye due to over stimulation (Tuaycharoen & Tregenza, 2005), and can also reduce visibility (IDA & IES, 2011). Within the literature, some studies have found that white light produces feelings of safety and is preferred over yellowish lighting (Knight, 2010; Rea, Bullough, & Akashi, 2009), which is most like the amber light that we are utilizing for our study. However, amber light is least disruptive to nocturnal wildlife species and produces less skyglow (Rich & Longcore, 2006). This study seeks to identify visitor preference between these two lighting colors.

Past studies (Smith & Hallo, 2019) have sought to examine color and intensity in several NPS units but did not have a choice element to their work which will be addressed in the expansion on station 7. Smith and Hallo's (2019) is the most relevant existing work in relation to this study as they asked nighttime recreationalists in several settings what their preferred lighting conditions were in regard to established lighting conditions as well as the reasoning behind the choice in lighting in developed areas of a national park.

Light selection was informed by the research aim of identifying lighting characteristics suitable for parks and protected areas while providing quality visitor experience. In considering park infrastructure, pathway lighting is a prevalent application across parks and natural areas which provide visitor access. Bollards were selected as the experiment light fixture. The small footprint of bollards also allowed for easy field deployment and breakdown during the duration for the study. To protect the natural night as a resource across protected areas, several criteria were used to select an appropriate bollard. These criteria included fixtures producing zero uplight, controlled light distribution with backlight control, dimming controls, and both broadband and narrowband color options. The Kim Pavilion ™ bollard met each of these criteria with options that produced no uplight, used controlled Type 3 light distribution with no backlight via an optional house side shield, used dimmable LED drivers, and provided 3000K CCT and 560nm direct amber LED engines.

Kim Pavilion bollards were modified by National Park Service engineers with custom dimming controls allowing for four selectable light intensities. Custom intensity selections produced 0.5 (Level 1),1.0 (Level 2), 5.0 (Level 3), and 10.0 (Level 4) average illuminance measured in lux for Stations 1 through 6. Average illuminance was calculated across a point grid within a 14’20’’ x 10’ rectangular task area, which corresponded to the light distribution of the bollard and task area of the experimental station. The different spectral power distributions of the 560nmk direct amber and broadband 3000K required that we used higher wattage direct amber lights to produce equivalent average illuminance to the broadband.

The Kim Pavilion bollards for Station 7 were modified in a different manner. One white and one amber bollard was constructed with a turn knob to adjust the intensity of the light. This allowed for the installation of a voltage reader to note visitor preference of intensity during the survey. In measuring intensity, we recorded voltage in the field which can then be converted to lux to be compared to lux conditions shown at Stations 1-6.

Survey Methods

To properly understand visitor perception of light and visitor experience this study employed the use of convenience sampling in an experimental field study. Convenience or opportunity sampling can be defined as the selecting of participants because they are often readily and easily available (Taherdoost, 2016). Convenience sampling tends to be a favored sampling technique among students as it is inexpensive, and an easy option compared to other sampling techniques (Ackoff, 1953). In the case of the lighting study at the Penn State Arboretum, convenience sampling was selected due to the location of the study and the timing of the study. This study was conducted far enough away from well-developed areas to avoid ambient lights and it took place at night when people are often not generally walking in this area. Ideally, a simple random sampling technique would have been utilized to give an equal probability to every case of the population of being included in the sample, but the physical and temporal element of the study limited us in such ways where this was not possible (Taherdoost, 2016). Undergraduate students were recruited from a variety of courses, primarily within the Recreation Park and Tourism Management department at Penn State's University Park campus.

A Qualtrics survey was developed for quantitative data collection. It focused on visitor perception of light in natural areas and their ability to navigate and complete tasks throughout the study (Appendix). The survey was delivered to participants at the Penn State Arboretum at night as they walked the experimental lighting course (n=167). Participants were guided through the course in groups of five in 15-minute intervals starting 30 minutes after sunset Using Samsung Galaxy A7 Tablets with screen light control through the app Twilight. Twilight allowed the screen to be viewed in red light to conserve participants' night vision. Participants completed survey questions at each of the seven stations. The survey took around 40 minutes on average.

Field Design

The trail includes seven light stations (Figure 3-1). Stations 1 through 6 were randomly set as white or amber light and at an intensity of 1-4 in relation to lux, as determined by a randomized predetermined schedule (i.e., Station 1 is Amber at intensity 4 one night and the next night it could be White 1). Participants answered repeated questions at stations 1 through 6 about their perception of the lighting condition and their ability to complete the tasks provided. Tasks included participants identifying the color of a sticker on a sign 10' away, reading a word on a sign 10' away, and identifying a shape (circle, star, square) 13' away. Task requirements at each station remained constant throughout the entirety of the study. Station 7 differs in that participants were asked to identify what spectra (amber or white) of light they prefer and what level of intensity they think they need in natural areas during the night. Participants were able to select which spectra as well as intensity on a continuous turn knob (i.e., not restricted to the 4 levels presented at stations 1-6) that they prefer. Participants went to Station 7 one at a time to decrease bias from seeing other participants selections.

Data Analysis

All statistical analyses were performed in R version 4.2.2 (R Development Core Team, 1999). Data was cleaned and voltage values recorded at Station 7 were converted to illuminance values (lux) using **Equation 1** for the participants who selected amber as their color preference and **Equation 2** for those who selected white as their color preference. Equations were provided by the National Park Service- Natural Sounds and Night Skies Division. They were crafted using the standardized lux readings from Stations 1-6 in relation to the lighting area at Station 7 in relation to the two different CCT. We first confirmed that our data were normally distributed to enable the use of parametric tests. This also included viewing the demographic information of study participants (Table 4-1, Figure 4-1). The basis of this study is exploratory analysis due to the lack of literature that would conventionally guide hypothesis testing with a similar data set. With this, all statistical tests were performed to inform the guiding research questions of what spectra and intensity of lighting to park visitors prefer (R1) as well as if any visitor characters influenced their lighting preference (R2).

$$Illuminance = -(0.1078voltage^2) + (2.5085voltage) - 2.2725 \quad \textbf{(1)}$$

$$Illuminance = 2.9483voltage - 2.5418 \quad \textbf{(2)}$$

Research Question 1

To explore our first research question, we ran a $\chi 2$ goodness of fit test for the choice in spectra (amber or white) (Figure 4-2). We also explored the relationship of spectra and intensity by performing a one-sample t-test testing for significance in intensity in relation to the spectra (Figure 4-3).

Research Question 2

To explore our second research question, we first looked at select demographics of survey participants (Table 4-1). We then modeled spectra choice and visitor characteristics (nighttime recreation experience, youth upbringing environment, gender) using one way-ANOVA. We also conducted two-way ANOVA testing between spectra choice and visitor characteristics as explanatory variables with and intensity after running the initial ANOVA test (Figure 4-4).

Chapter 4

Results

Survey participants (n=167) were evenly distributed in relation to gender; however, most participants were college aged (Table 4-1, Figure 4-1).

Table **4-1**:Descriptive results of the sample

Group	n	Percent of Sample
Gender		
Female	82	49.10%
Male	82	49.10%
Youth Environment		
Rural (population <5000)	38	22.75%
Suburban (population between 5000 and 50 000)	92	55.08%
Urban (population<50 000)	33	19.76%
Country of residence		
US Resident	148	88.62%
Non-US Resident	15	8.98%
Prior Nighttime Recreation Experience		
Yes	131	78.44%
No	33	19.76%

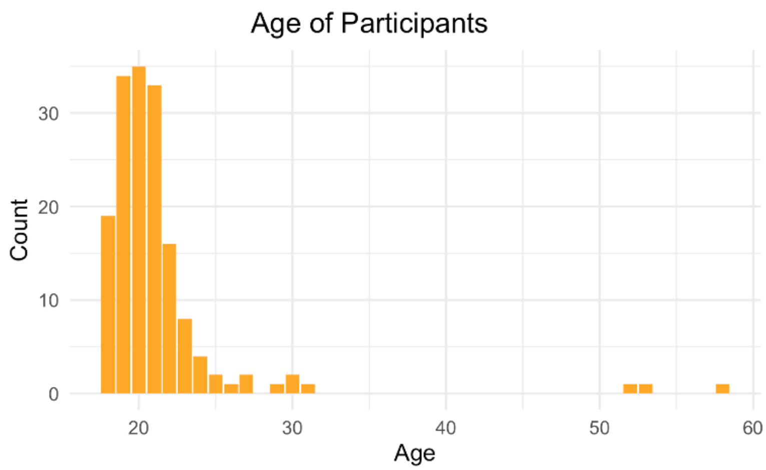

Figure **4-1**: Distribution of age of participants

Research Question 1

The Chi-square goodness-of-fit test showed that the distribution of the number of participants who chose amber or white in our study was not consistent with the expected distribution of a 50:50 distribution ($\chi 2 = 17.361$; df = 1; p = <0.001). This means that the color choice of amber (n=97) is significantly different than the color choice of white (n=47) at Station 7 (Figure 4-2). In looking at the choice of intensity in relation to spectra, there is a significant difference in mean intensity between amber (mean = 2.87) and white (mean = 5.18) (t (-2.5318); df = 56.246; p=0.01417) (Figure 4-3). These results suggest that amber light is the preferred color of light with 2.87 lux being the average level of intensity preferred. For comparison, 0.2 lux is the average illuminance of a natural full moon. It is important to note that while the majority of participants selected amber light, those who selected white light preferred it at a higher intensity (mean = 5.18) than those who selected amber light (mean = 2.87). This will need to be taken into consideration when making managerial decisions on lighting intensity.

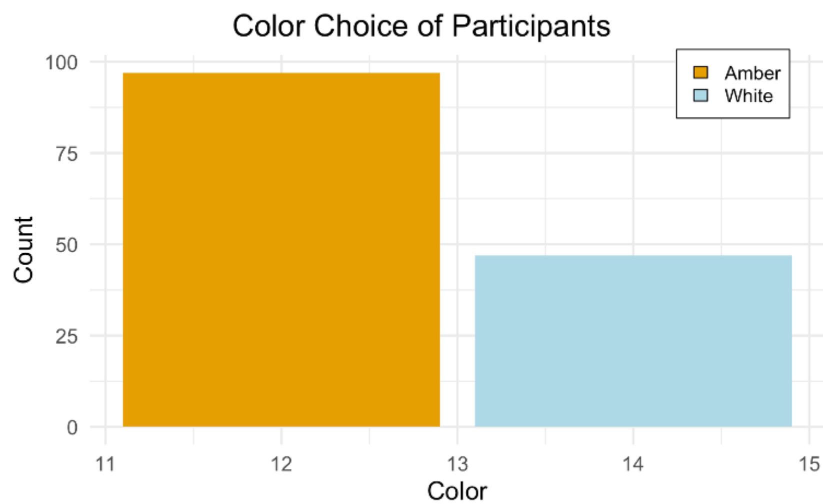

Figure **4-2**: Participant choice of amber or white light at Station 7.

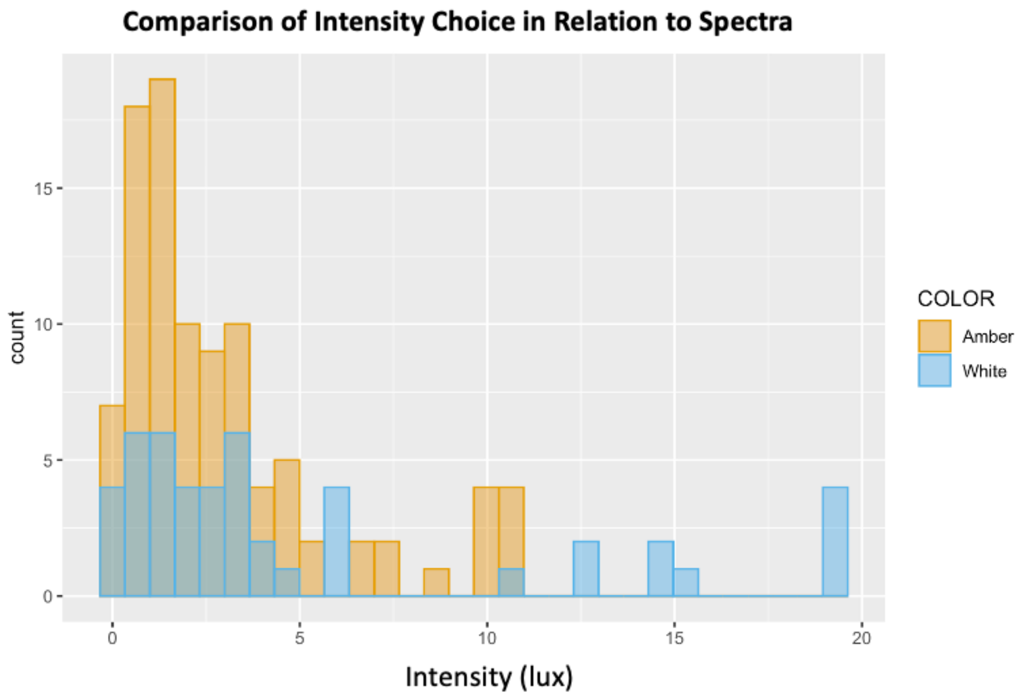

Figure **4-3**: Participant choice of light color and intensity (lux).

Research Question 2

Regarding color selection in relation to participant demographics, those who had previous experience with nighttime outdoor recreation were more likely to select the amber color light than the white (Table 4-2). Looking at intensity selection, those who had prior outdoor nighttime recreation experience and selected amber light had the lowest mean intensity selection of 2.48 lux (Table 4-2). Both males and females were more likely to select amber light than white light (Table 4-2). Those who were raised in rural or suburban environments were more likely to select amber light, however in looking at those raised in urban areas, there was no clear preference of white or amber light (Table 4-2). Those who were raised in urban environments and selected white light selected the highest mean intensity at 5.93 lux (Table 4-2).

Research Question 2 also required us to look at the relationship of intensity selection, color selection, and participant demographic characteristics (Figure 4-5, Figure 4-6, Figure 4-7). Two-way ANOVA testing confirmed that there is a significant relationship between color selection and intensity (Table 4-3, Table 4-4, Table 4-5). In looking at intensity in relation to color and gender or youth environment, there was no statistical significance in relationship to the gender or youth environment (Table 4-4, Table 4–5). However, when conducting an ANOVA test for intensity selection, color selection, and prior nighttime recreation experience we found a significant relationship (Table 4-3) (Amber-Experience n=80, Amber-No Experience n=17, White- Experience n=35, White-No Experience n=12).

Table **4-2**: Descriptive statistics for ANOVA testing.

Color	**Prior Nighttime Outdoor Recreation Experience**	**n**	**Mean**	**Std. Deviation**
Amber	Yes	80	2.48	2.37
	No	17	4.72	3.86
White	Yes	35	4.96	5.55
	No	12	5.78	7.09
	Gender			
Amber	Male	49	2.97	2.76
	Female	48	2.78	2.86
White	Male	23	5.60	6.32
	Female	24	4.77	5.59
	Youth Environment			
Amber	Rural	22	2.95	3.05
	Suburban	57	2.48	2.49
	Urban	17	4.08	3.35
White	Rural	7	4.38	4.17
	Suburban	26	4.98	5.68
	Urban	14	5.93	7.25

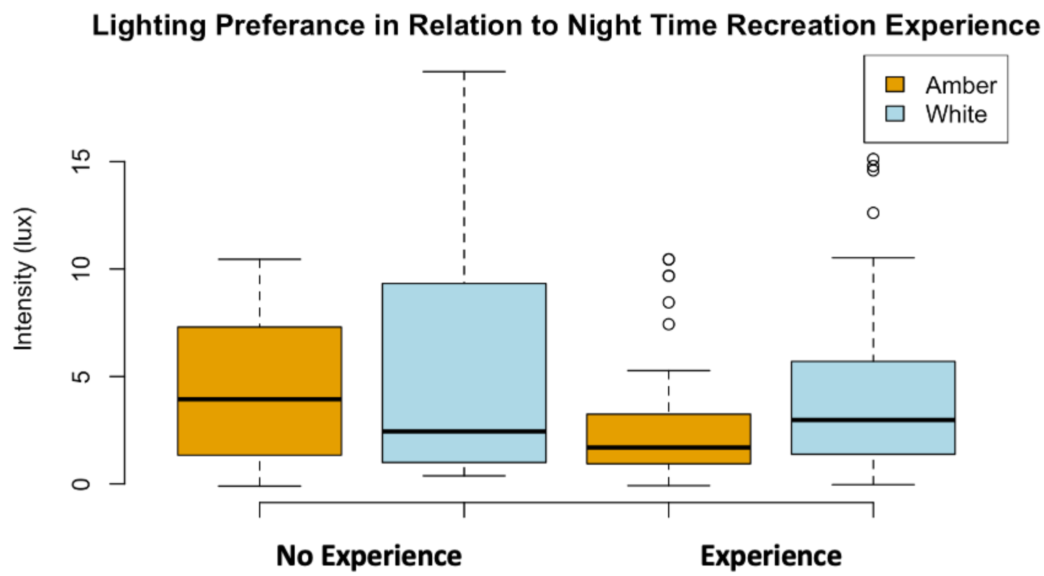

Figure **4-4**: Intensity (lux) in relationship to color choice and nighttime recreation experience

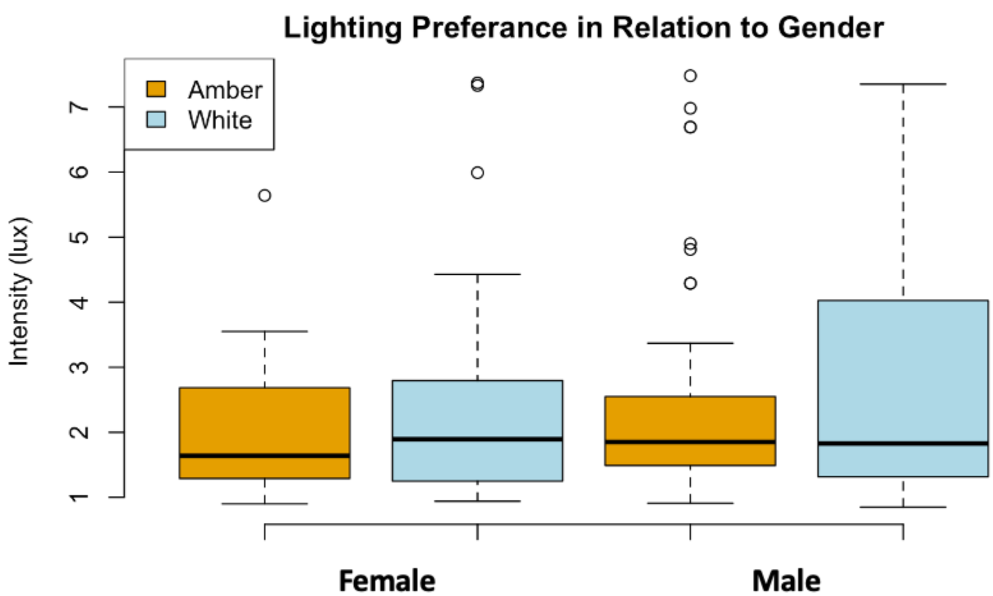

Figure **4-5**: Intensity (lux) in relation to color choice and gender.

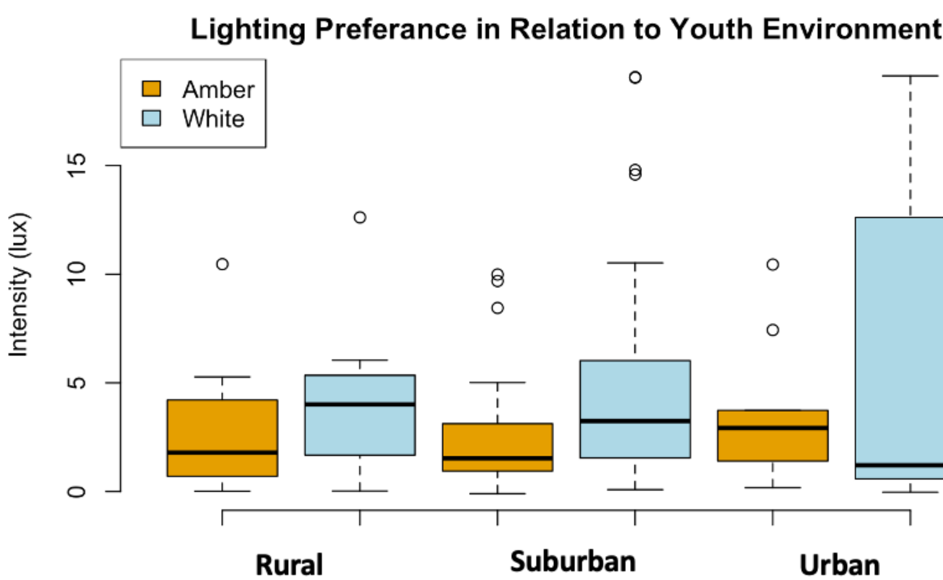

Figure **4-6**: Intensity (lux) in relation to color choice and youth environment.

Table **4-3**: ANOVA table comparing intensity (lux) across color choice and prior nighttime recreation experience.

	df	Sum of squares	Mean square	F	p
Color	1	68.904	68.90	4.22	0.042*
Nighttime Recreation	1	50.79	50.76	3.11	0.040*
Color*Recreation	1	10.819	10.82	0.66	0.417
Error	141	2298.0	16.30		

*Indicates a significant response

Table **4-4**: ANOVA table comparing intensity (lux) across color choice and gender.

	df	Sum of squares	Mean square	F	p
Color	1	168.80	168.80	10.04	0.02*
Gender	1	8.37	8.37	0.98	0.48
Color*Gender	1	3.25	3.24	0.19	0.66
Error	140	2353.71	16.81		

*Indicates a significant response

Table **4-5**: ANOVA table comparing intensity (lux) across color choice and youth environment.

	df	Sum of squares	Mean square	F	p
Color	1	391.90	89.35	5.29	0.023*
Youth Environment	3	38.35	12.83	5.29	0.519
Color*Youth Env.	2	5.76	2.88	0.76	0.84
Error	137	2325.36	16.90		

*Indicates a significant response

Chapter 5

Discussion

This study explores visitor preference of lighting for nighttime outdoor recreation regarding participant selection of intensity and spectra. It is important to note the mean age of participants in this study was 20 years old and the results of color and intensity preference may change when sampling a more diverse range. There have been reports of fewer young people and more older people visiting national parks over the past few years (Keen & Dorell, 2012). In Smith and Hallo's (2019) study, the average participant age was 41.4 years old with a range of 18 to 63 years of age whereas our study had a range of 18 to 58 years of age. Smith and Hallo (2019) did test different light colors, but younger visitors may be more accepting of different lighting colors than the norm. Mudd (2021) notes that there is movement in younger populations to combat light pollution such as the STEM civic action program Youth Organization for Lights Out (YOLO). Direct education and advocacy for combating light pollution in younger populations may influence lighting color and intensity preferences in spaces such as national parks and natural areas.

Research Question 1

This thesis set out to determine a lighting threshold for outdoor nighttime recreation in national parks and natural areas. Gaston et al. (2015) identified minimum required levels of lighting as light as a current gap in the literature and as an area needing to be addressed. This in conjunction with a lack of industry or park standards for lighting requirements leaves park managers on their own to determine lighting levels and design. Through an experimental study asking participants to identify what intensity and spectra of light they consider necessary for outdoor recreation in a national park setting, we can understand what level of light is necessary for national parks. Our results show significance in the selection of spectra at Station 7 by participants. More participants selected amber (n=97) than white (n=47). Our result were inconsistent Hallo and Smith's (2019) where park visitors preferred white light for pathway lighting. Possible cause in difference in results could be in relation to age of participants as well as difference in spectra used in the study. Hallo and Smith (2019) used 4200K as their white whereas we used 3000K for our white light which is equivalent to their softer lighting (3000K) which was preferred at comfort stations and amphitheaters. Our results show that participants prefer amber lighting. This could be related to education and outreach on light pollution and a better understanding of how the color of lights impact both wildlife and stargazing. There is growing literature, signage, and promotion of wildlife and stargazing friendly lighting colors, such as turning off lights during bird migration or encouragement of using the red-light function of headlamps to preserve night vision, in recent years (Elgert, 2020; Peña-García, 2020; Schulte-Römer, N, 2019).

Our results show a significant difference of intensity preference between those who chose amber light and white light. Participants who chose amber light selected a much lower average intensity of 2.87 lux whereas those who chose selected white light selected an average intensity at 5.17 lux. While 2.87 lux is still much higher than any naturally occurring light (i.e., a full moon), this lighting level is considerably less than the dimmest streetlight that averages at 10 lux (Gaston, 2012). Smith and Hallo (2019) found the preferred lighting intensity of visitors to be 1.4 lux, but this value is only comparable to those who selected white as their preferred hue. Taking into consideration the intensity and color choice of participants, managers could both lower the brightness of park light while also implementing a more wildlife friendly color of lighting into a park's light design. In addressing the research question of "how low can we go," our results suggest that with amber light, the average park visitor will find a lighting intensity of 2.87 lux to be acceptable for outdoor nighttime recreation. As with any recommendation, there will be outliers. Within this study, participants who chose amber did so in the intensity range of 0.10 to 10.46. This all must be taken into consideration for managerial action.

Research Question 2

In determining a lighting threshold for national parks and protected areas, you must consider the consumer, the visitor. This thesis also sought to determine if any visitor characteristics or demographics influenced their lighting intensity and spectra choice. Across the visitor characteristics of gender, youth environment, and previous nighttime recreation experience, there was no statistically significant relationship between spectra choice and any of the characteristics. However, there was a statistically significant relationship between intensity with the explanatory variables of previous nighttime recreation experience and spectra choice. Interestingly, those without previous nighttime recreation who selected amber as their spectra had a higher mean intensity (lux) than those who selected amber with previous recreation or those who selected white for their spectra. While a higher intensity of light is not preferred, selection of amber by those without nighttime recreation is an encouraging result. Those without nighttime recreation experience may have selected a higher intensity in the association of more light meaning more safety (Peña-García, 2015). Individuals often associate brighter lights with feelings of safety, however, too bright of light can be counterproductive in increasing the visibility of their surroundings due to glare (Stone, 2017). The lack of results from testing participant characteristics in relation to spectra and intensity are encouraging for management in that the population was fairly uniform in their preferences with the majority selecting a wildlife friendly alternative lighting color as well as a lower level of intensity than present in existing park infrastructure.

Chapter 6

Conclusion

This study sought to understand national park and protected area visitors' preference of lighting spectra and intensity. The objectives of this study were twofold; The first objective was to develop a baseline lighting threshold that can be consulted when retrofitting and updating park lighting infrastructure. The second objective was to better understand how visitor demographics influence lighting preference for nighttime outdoor recreation. The night sky is an important cultural and ecological asset with important benefits to humans and wildlife (Mace, Bell, & Loomis, 2004; Gallaway, 2010) and is protected by law by the National Park Service. The literature of the study of artificial light at night and light pollution is heavily saturated with studies on the impacts of lights on wildlife, but rarely take into consideration visitor needs or preferences of lighting when making suggestions for change. Natural dark skies are increasingly recognized as an important cultural and experiential resource in national parks (Manning, 2016; Hallo, & Smith, 2016).

Light pollution threatens night sky visibility in national parks, which protect some of the only remaining pristine night skies in the United States (Albers & Duriscoe, 2001; Duriscoe, 2001). Increasingly, artificial lighting is leading to the degradation of natural darkness and the quality of experiences for nighttime visitors to parks (Smith & Hallo, 2019a). With this in mind, it is critical to keep the visitor at the forefront of managerial decisions alongside considerations of wildlife and the environment. This study suggests that there can be a balance in lightscape management within national parks that prioritizes wildlife friendly lighting regarding spectra while considering lighting needs of visitors in relation to intensity.

From this research, amber light at a minimum intensity of 2.87 lux is the recommended lighting infrastructure for nighttime visitors needs in national parks and natural areas. This recommendation comes from the results of Station 7 in our experiment. Amber light was preferred by the majority of visitors at the mean level of 2.87 lux. 2.87 lux is the minimum light level recommendation due to participants who preferred white light preferred it at almost double the intensity (mean = 5.18).

Limitations and Future Research

While this study incorporated visitor choice in lighting in a way that had not been seen before in the literature, we only sampled a college-aged population which is not representative of the demographics of national park visitors. The results from this study are not generalizable across age groups, and this should be taken into consideration for future research. Implementing this study in a national park should increase the range and mean age of our sample size. While conducting this study, it was noted that older participants and those who wear glasses had difficultly performing tasks at Stations 1 through 6 which could have influenced their choice of spectra and intensity at Station 7. With the sample mean age so low, we are not considering the eyesight and ability of older visitors to see in a dark natural area.

While our sample size was not small (n=167), the study ran for an additional two semesters beyond the expectation. A larger sample size would have painted a clear picture of visitor preference in relation to color and spectra of lighting for nighttime outdoor recreation. The time and location of sampling limited our sampling population. An easily accessible field site that has nighttime occupants would greatly increase the power of sampling at night.

When considering future research, I believe that it is critical to keep visitor needs at the forefront of lighting studies. No level of artificial light at night will ever be acceptable for wildlife. Wildlife and plants have evolved with natural light cycles, and any deviation from this norm will cause some form of an impact on physiology (Rich & Longcore 2006). Future research should focus on confirming the lowest level of light acceptable for humans in all contexts possible. I believe that an interesting approach to this would be presenting humans with natural light level (i.e., full moon, halfmoon, etc...) and measuring acceptability. The current state of the world requires humans to cohabitate with the natural environment; With this, all constituents must be taken into consideration when addressing the best way forward for managing night skies.

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Appendix

OMB Control Number 1024-0224
Expiration Date:12/31/2022

Effects of Outdoor Lighting on Visitor Enjoyment in National Parks

PAPERWORK REDUCTION and PRIVACY ACT STATEMENT: The Paperwork Reduction Act requires us to tell you why we are collecting this information, how we will use it, and whether or not you have to respond. We are authorized by the National Park Service Protection Interpretation and Research in System (54 USC §100702) to collect this information. The routine uses of this information will be for the benefit of NPS Managers and Planning staff at the Natural Sounds and Night Skies Division. Your responses to this collection are completely voluntary and will remain anonymous. You can end the process at any time and will not be penalized in any way for choosing to do so. Your participation poses only minimal risks. Data collected will only be reported in aggregates and no individually identifiable responses will be reported. A Federal agency may not conduct or sponsor, and you are not required to respond to, a collection of information unless it displays a currently valid OMB Control Number (1024-0224).

BURDEN STATEMENT We estimate that it will take about 30 minutes to complete and return this short survey. You may send comments concerning the burden estimates or any aspect of this information collection to: Peter Newman, Department Head of Recreation, Park, and Tourism Management, Penn State University at pbn3@psu.edu; or Phadrea Ponds NPS Information Collection Clearance Officer at pponds@nps.gov.

NOTE TO REVIEWERS: This has two sections.

- *Section 1 is completed at each station.*
- *Section 2 is completed at the end of the respondent's rotation through all stations.*

Section 1. Completed at each station.

1. Please indicate the degree to which you agree or disagree with the following statements. (*Select one number for each statement.)*

The lighting condition at this station as compared to an unlit setting…	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
… makes nighttime recreation activities more pleasurable.	-2	-1	0	1	2
…makes it easy for my eyes to transition from light to dark places.	-2	-1	0	1	2
… makes it more difficult for me to do nighttime activities.	-2	-1	0	1	2
…makes me feel safter to be in a park, forest, or other outdoor recreation area at night.	-2	-1	0	1	2
…makes it more difficult to navigate while doing nighttime activities.	-2	-1	0	1	2
… provides benefits for wildlife.	-2	-1	0	1	2
… negatively impacts wildlife.	-2	-1	0	1	2
…makes it seem too bright for a park, forest, or other outdoor recreation area.	-2	-1	0	1	2
…makes it seem too dark for a park, forest, or other outdoor recreation area.	-2	-1	0	1	2
… makes it easier to find areas and points of interest (e.g., restrooms, campground)	-2	-1	0	1	2
…helps me to be able to see in unlit areas (e.g., in the shadows)	-2	-1	0	1	2

Section 2: Post Conditions

This experiment was about different nighttime outdoor lighting conditions in parks, forests, or other outdoor recreation areas. Please answer the following questions about your experiences in park, forest, or other outdoor recreation areas.

1. Have you spent time in parks, forests, or other outdoor recreation areas at night?

☐ YES

- What things do you like most about the nighttime environment in parks, forests, or other outdoor recreation areas?
- What things do you like least about the nighttime environment in parks, forests, or other outdoor recreation areas?
- Please check all of the following things you've done in parks, forests, or other outdoor recreation areas during the night. (*Check all that apply)*

☐ Attended a ranger program
☐ Walked/hiked somewhere in a park, forest, or other outdoor recreation area
☐ Stargazed/viewed the night sky
☐ Kayaked or boated
☐ Hunted or fished
☐ Camped
☐ Observatory
☐ Other: ______________________________

☐ NO

- Why haven't you spent time in parks, forests, or other outdoor recreation areas at night?

2. Are you interested in participating in any of the following nighttime activities? (*Check "Yes" or "No" for each item.*)

	Yes	No
a. Attending educational programs at night or about night in a park, forest, or other outdoor recreation area?	☐	☐
b. Night photography	☐	☐
c. Stargazing with telescopes or binoculars	☐	☐
d. Stargazing without telescopes or binoculars	☐	☐
e. Attending a star party/night sky festival	☐	☐

f. Visiting a planetarium	☐	☐
g. Visiting an observatory	☐	☐
i. Walking at night in a park, forest, or other outdoor recreation area	☐	☐
j. Walking at night in an urban park, forest, or other outdoor recreation area	☐	☐

3. Please indicate the degree to which you agree or disagree with the following statements about park, forest, or other outdoor recreation areas *(Select one number for each statement.)*

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
a. Viewing the night sky ("stargazing") is important to me.	-2	-1	0	1	2
b. I would feel uncomfortable hiking at night with no supplemental light.	-2	-1	0	1	2
c. While in a park, forest, or other outdoor recreation area, natural darkness increases my sense and opportunities for solitude.	-2	-1	0	1	2
d. Protection of natural nighttime conditions (e.g., darkness) is not an important conservation effort.	-2	-1	0	1	2
e. Observing the night sky is an important part of my experience in parks, forests, or other outdoor recreation areas.	-2	-1	0	1	2
f. It is important to promote public appreciation for the value of a natural night sky.	-2	-1	0	1	2
h. Natural lightscapes are an important component of a wilderness type experience for me.	-2	-1	0	1	2
i. In many parks, forests, or other outdoor recreation areas, there is excessive lighting, causing light pollution.	-2	-1	0	1	2

NOTE TO REVIEWERS: The next question will be randomly presented so that half of all respondents in the study will answer Version 1 and half will answer Version 2. The respondents will be given a scenario/no scenario option in

NSKIES16 (MODIFIED)

4. *Treatment message will be given prior to question 4.*

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
For lighting in parks, forests, or other outdoor recreation areas, managers should focus on wildlife needs, even if it makes some people feel less safe	-2	-1	0	1	2
For lighting in parks, forests, or other outdoor recreation areas, managers should focus on human enjoyment, even if it means worse lighting conditions for natural nighttime environment	-2	-1	0	1	2
Managers should ensure lighting conditions do not disturb wildlife, even if human preferences are not met.	-2	-1	0	1	2
Managers should make lighting conditions safer for humans, even if it means impacts to wildlife	-2	-1	0	1	2
Managers should promote the color of lighting in parks, forests, or other outdoor recreation areas that is best suited for wildlife, even if it means the color is not preferred by visitors	-2	-1	0	1	2
Managers should promote the color of lighting in parks, forests, or other outdoor recreation areas that promote easy eye adaptation for humans, even if it means impacts to wildlife	-2	-1	0	1	2
Cities and towns near parks should adopt ordinances to reduce light levels over parks, forests, or other outdoor recreation areas	-2	-1	0	1	2
I would support reducing lighting in parks, forests, or other outdoor recreation areas to improve the natural environment, even if I had to pay a special fee to help improve outdoor lighting.	-2	-1	0	1	2
In parks, forests, or other outdoor recreation areas, the primary lighting concern of managers should be the safety and security of visitors.	-2	-1	0	1	2
In parks, forests, or other outdoor recreation areas, the primary lighting concern of managers should be the impacts to natural nighttime environment.	-2	-1	0	1	2

5. Imagine that you are tasked with selecting lighting that strikes the balance of conditions that are good for both humans and wildlife. What would be the most ideal nighttime lighting condition? (*The respondent selects the lighting condition intensity. An open-ended question follows asking them to explain their choice.*)

What is your gender? Please select only one.

☐ Male
☐ Female

What is your major? ____

Which of the following best describes the area you <u>grew up</u> in?

☐ Rural
☐ Suburban
☐ Urban

Are you a permanent resident or citizen of the United States?

☐ NO - What is your country of origin? ____________________

☐ YES - What is your primary zip code? ____________________

What is your age? ____________________