PROTECTING NIGHT SKIES AND NATURALLY DARK CONDITIONS IN NATIONAL PARKS

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Abstract.—The field of visual resource stewardship has historically focused on assessments of visual quality and impacts to daytime scenery. In recent years, increasing numbers of visitors have been traveling to National Parks to participate in nighttime recreation and astronomy-based park programming. In many parks, nighttime programs have become some of the most popular ranger-led activities and visitors have come to expect superlative nighttime views of starry skies and park landscapes just as they do during the day. However, development of frameworks, methods, and protocols for assessing nighttime visual resources have yet to emerge from the field. This paper discusses the importance of night skies and naturally dark environments and presents an approach developed by the National Park Service (NPS) to measure night sky quality and the photic environment in parks. The approach adopted by NPS can serve as a starting point for developing methods for effective visual resource stewardship at night.

INTRODUCTION

Throughout the development of the field of visual resource stewardship, scant attention has been paid to the protection of visual resources after the sun has set. For example, early policy and guidance on visual resource management from the Bureau of Land Management and the USDA Forest Service (Bureau of Land Management 1980, USDA Forest Service 1995) are silent on views of the night sky and the effects of light on nighttime viewsheds. However, public awareness and appreciation of dark night skies has increased dramatically as illustrated by the number of articles in the popular press and recent studies of national park visitors (Galbraithoc 2012, Kulesza et al. 2013, Manning et al. 2015). As a result, visual resource professionals are recognizing the need to assess visual quality during the night and have begun to incorporate nighttime views into their analyses.

The timing of this trend is fortunate as the technology and practices of the lighting industry and our understanding of the effects of light in naturally dark environments have expanded significantly in recent years. The confluence of increased interest in night skies and nighttime recreation, a better understanding of the effects of light on park visitors and resources, and advancements in lighting technology has created an important opportunity to develop cost-effective methods for preserving night skies and mitigating of the effects of stray light on naturally dark environments.

This paper is organized as follows. Section one briefly introduces several concepts related to light that are important for protecting national park resources and values. Section two examines the reasons for protecting naturally dark environments and night skies. It discusses the importance of minimizing stray light and protecting naturally dark environments in terms of the aesthetic experience of visitors, ecological needs, cultural resources, and wilderness. Section three describes methods used by the National Park Service (NPS) to measure and predict the presence of light in the environment, and section four introduces the six principles of sustainable outdoor lighting that NPS uses to protect night skies and the resources and values that depend on natural cycles of light.

NATIONAL PARK SERVICE POLICIES

The overarching mission and mandate of the NPS is provided in the Organic Act that established the agency (National Park Service Organic Act 1916). The Organic Act states that NPS will conserve natural and cultural resources and values under its protection while also providing for the enjoyment of those

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resources and values. In addition, the Act requires NPS to manage resources in a way that will leave them unimpaired for future generations. Subsequent legislation and NPS policy states that when there is a conflict between conserving resources and values and providing for their enjoyment, conservation is to be predominant (National Park Service 2006).

The NPS has a policy for lightscape management, which states that NPS will preserve, to the greatest extent possible, the natural lightscapes of parks and minimize light that emanates from park facilities to prevent the loss of dark conditions and natural night skies (National Park Service 2006). NPS also recognizes that light affecting the photic environment of parks often originates outside of park boundaries, and therefore directs park superintendents to seek the cooperation of park visitors, neighbors, and local government agencies to prevent or minimize the intrusion of artificial light into park environments and ecosystems.

The management policy on light restricts the use of artificial lighting in parks to those areas where security, basic human safety, and specific cultural resource requirements must be met (National Park Service 2006). Management policies also require NPS to use minimal-impact lighting techniques and to shield lighting where necessary to prevent the disruption of the night sky, physiological responses, and similar natural processes. The policy also recognizes that there are some areas and situations where light should not be introduced into the environment. It states that the NPS will not use artificial lighting in areas such as sea turtle nesting locations where the presence of the artificial lighting will disrupt park resources and values.

Safety and security are often cited as reasons for park lighting. Therefore, it is important to address NPS policy related to public safety. NPS Director's Order 50C is the primary policy document on public risk management. It states, "Within the context of the Organic Act, visitor risk management does not mean eliminating all dangers, nor can the NPS guarantee visitor safety or be responsible for acts and decisions made by visitors that may result in their injury or illness" (National Park Service 2010, p. 1). It also states that park superintendents will seek to identify risks within their jurisdiction and to mitigate these risks without compromising the integrity of the environments they are charged to protect. Specifically, it states that lighting and other safety measures might be appropriate in some settings while not in backcountry campsites, trails, and similar pristine settings, or even in some urban locations.

These and other existing policies require NPS to protect night skies and dark environments and provide direction on how superintendents and park managers can consider tradeoffs between protecting the lightscape and providing for basic human safety (National Park Service 2010). To assist park managers in making lighting decisions, NPS relies on existing guidance and best practices from the fields of lighting design and night sky preservation. Emerging science suggests that more mission-driven best practices would better serve NPS units.

Fundamentals of Light

The electromagnetic wave theory developed by James Maxwell in the late 1800s is a fundamental theory that demonstrates the relationship between electricity, magnetism, and light and shows that these effects are different manifestations of the same phenomenon. Maxwell described visible light as oscillating electric and magnetic fields, perpendicular to each other, that travel away from the source (Chaichian et al. 2014). According to the theory, light is just a small portion of a larger electromagnetic spectrum that ranges in energy level from gamma rays to radio waves. Light is the portion of that spectrum that stimulates nerve receptors in our eyes and allows us to sense our environment.

Correlated Color Temperature

Color correlated temperature (CCT) is an important characteristic that affects the color of light emitted from a fixture. This color (or spectrum) influences how light affects the environment and plays an important role in mitigating ecological impacts of stray light. CCT describes the relationship between the color of light and temperature. Stars vary in color. Some appear blue, some red, others yellow, and that difference is based on the star's surface temperature. When astronomers look at a star in the night sky, they can predict its surface temperature based on the peak wavelength of the star's spectrum. Because of this relationship, the spectra—or color—of a light bulb is typically expressed in degrees Kelvin (DiLouie 1994).

Light Propagation

Understanding how the intensity of light changes as a function of distance is critical for designing effective lighting solutions and mitigating adverse effects of light in a viewshed. The intensity of light diminishes based on the inverse square law (Schreuder 2008). When you double the distance between a light and a receptor, the light is 25 percent as bright. When you move closer by half you increase the brightness by a factor of 4. If you triple the distance, the light is 1⁄9, or 11 percent, of its original intensity. Because of the inverse square law, when you first begin moving away from a light source, the intensity diminishes rapidly. As you continue moving farther away, the intensity decreases at a slower rate.

Skyglow and Glare

There are two main types of light pollution that can affect natural and cultural resources in national parks: sky glow and glare. Sky glow is light scattered and reflected off of air molecules and atmospheric aerosols. The observer sees anthropogenic light originating on the ground as luminance in the sky. Sky glow diminishes the aesthetics of the night sky and illuminates the observer and the landscape unnaturally (Royal Commission on Environmental Pollution 2009).

Glare is stray light that strikes your eye directly from a source. Glare degrades the visual scene in two ways. First it obscures visual information and second it can degrade scotopic or dark-adapted vision. Our eyes automatically adjust to the brightest source of light in a scene, so when you see a source of glare such as an unshielded lighting fixture, the area surrounding the light becomes difficult to see. Visual information in the vicinity of the light source is lost. Glare caused by improper lighting also creates shadows that can obscure information. As a result, increasing safety and security is not solely related to how much light you have on a scene; it is also a function of how effectively the light provides information about your surroundings (Steinbach et al. 2015). Light allows us to extract information from the environment, and improper lighting often hinders its effectiveness. That is why adding more light to a scene does not always increase safety and security (Richman 2009, Sherman et al. 1997).

Glare also degrades dark-adapted vision. Human vision maintains sensitivity over an impressively large range of ambient light levels. Even though humans maintain visual sensitivity in dark areas, it can take several hours to fully adjust to low light conditions. However, dark adaptation can be lost in just a few seconds of exposure to bright light (American Optometric Association 2006).

Illuminance and Luminance

Illuminance and luminance are two additional concepts that are important for understanding how light interacts with landscapes. Illuminance is a measure of luminous flux on a surface of a given area, or luminous flux density. It is what matters most when the human eye is trying to examine objects by reflected light. Illuminance, measured in lux, is a very useful measure for quantifying anthropogenic light in the natural environment. Illuminance from the sky or a light source overhead is often measured with a detector in a horizontal plane and is known as horizontal illuminance. Horizontal illuminance is an effective measure of sky brightness near the zenith or illuminance from a pole mounted outdoor light. Illuminance from a light source at a distance on the horizon may be measured with the detector in a vertical plane. This measure is called vertical illuminance. Vertical illuminance is an excellent measure of light trespass or glare from light fixtures in a viewshed (Schreuder 2008).

Luminance is a measure of luminous intensity per unit area (candela/m^2). In contrast to illuminance, which measures the intensity of light from a source, luminance measures the intensity of light reflected from a surface. It is sometimes called "perceived brightness" or "surface brightness." Changing the characteristics of a surface such as texture, color, or reflectivity can increase or decrease its luminance (Schreuder 2008).

Both luminance and illuminance are important factors for understanding and measuring light pollution. Sky glow is light reflecting off of aerosols and particulates in the atmosphere and is typically measured using luminance values. Glare on the other hand is the direct output from a source striking the eye and is best measured using illuminance.

IMPORTANCE OF NIGHT SKIES AND NATURALLY DARK ENVIRONMENTS

Aesthetics

As indicated by satellite data, outdoor light levels are rising dramatically, and the visual quality of the night sky is diminishing rapidly in many areas. As the public loses the view of stars and the Milky Way in their backyards, they are increasingly seeking it out in parks and protected lands. In many national parks, nighttime programs such as astronomy and moonlight hikes are among the most popular ranger-led activities. A visitor survey at two Utah parks revealed that 99 percent of visitors prefer to stargaze in a national park over other locations. Ninety percent believed that there should be places that protect dark skies, 80 percent thought that the surrounding communities should help support such protection, and over 80 percent indicated that the quality of night skies was an important or very important part of their visit (Mace and McDaniel 2013). Manning et al. (2015) found that 90 percent of visitors feel that night sky viewing is important and the National Park Service should protect opportunities for visitors to see the night sky. Likewise, Kulesza et al. (2013) found that dark night skies were important to 81 percent of visitors and that the ratings increased over the 24-year period of the study (1988 to 2011).

Astrotourism and Economic Value

Protecting night skies and increasing opportunities for astronomy-based recreation can have a positive impact on local economies surrounding national parks. Attending a nighttime program often turns a drive-thru park visit into additional dinner, breakfast, and lodging revenue for the local economy. The growing public appreciation for these activities has spawned a new component of tourism industry called astrotourism. According to Fayos-Solá et al. (2014, p. 663), "Astrotourism is an activity of travelers wishing to use well-kept nightscapes for astronomy-related leisure and knowledge. This practice has increased in popularity during the past few years, adding value to offbeat tourism destinations offering high-quality night skies and astronomical or archaeoastronomical heritage."

However, measuring the economic value of naturally dark environments poses some significant challenges. Some scholars have suggested that conventional economic approaches used in natural resource valuation are inadequate to capture the scope and complexity of such an expansive resource (Gallaway 2014). According to Willis (2014, p. 250), "The main challenge in the economic appraisal of improved night sky visibility is estimating this public good value of the night sky, and also the other economic externalities (fear about personal safety, accidents, injuries and crime) due to any reduction in street lighting."

In an unpublished manuscript, Mitchell and Gallaway (n.d.) presented an analysis of the potential economic value of night skies above the Colorado Plateau. The authors conclude that over the next 10 years, visitors trying to see a dark sky at night will spend nearly $2.5 billion visiting NPS parks in the area. This additional spending generates $1.68 billion in revenues for local and State economies and creates an additional 52,257 jobs that increase wages in the states by over $1 billion.

Human Health

Since the beginning of life on this planet, there has always been a 28- or 29-day lunar cycle and a 24-hour daily cycle. This natural pattern is ingrained in the DNA of most creatures on Earth. Throughout this time the environment has changed in countless ways. Continents have formed and eroded, sea level has risen and fallen, even the chemistry of our atmosphere has changed. But we have always had the same light-dark cycle—until the last hundred years.

Exposure to light can have direct and indirect physiological effects. In addition to rods and cones, our retinas contain a type of cell called intrinsically photosensitive retinal ganglion cells. These cells play a major role in synchronizing circadian rhythms to the 24-hour light/dark cycle. Stimulation of these cells influences our circadian rhythm primarily by suppressing the production of melatonin, which in turn influences sleep, cognitive performance, mood, memory, and other physiological functions (Cao and Barrionuevo 2015, Pickard and Sollars 2012).

While light of any kind can suppress the secretion of melatonin, recent studies have suggested that blue light has a greater effect on physiological processes than other portions of the spectrum. One study found that blue light suppressed melatonin for about twice as long as green light and shifted circadian rhythms by twice as much (3 hours vs. 1.5 hours) (Harvard University 2017).

Cultural

For thousands of years, views of the night sky have influenced the course of human activity and development. Most people can recall in their own lives an inspirational moment under the stars when the visual perspective of looking outward beyond our planet provided an emotional perspective for our lives. Such perspective has been a wellspring of inspiration for writers, scientists and philosophers (Moore et al. 2009). Musicians from Gustav Holst (*The Planets*) to Joseph Haydn (*The Creation*) have been influenced by the night, and starry skies have inspired artists throughout millennia from the creators of pre-Columbian rock art to Vincent Van Gogh, Edvard Munch, and Georgia O'Keeffe (International Dark-sky Association 2016). Even today, the public seeks views of starry skies in national parks for their scenic and inspirational value. The recent explosion in popularity of astrophotography is evidence of that enthusiasm.

Sites such as the pyramids in Egypt, Angkor Wat, Chichen Itza, and the pueblos of Chaco Canyon are standing testament to our ancestors' relationship with the stars. Humans have looked to the night sky to navigate great distances and measure time, studied the motions of the stars, recorded astronomical events in rock art, aligned our buildings to celestial objects, developed calendars, and made decisions on when to plant crops based on the position of the stars and moon (Ceci 1978, Penprase 2017, Ruggles 2015, Spence 2000).

Big Horn Medicine Wheel located in northern Wyoming provides an example of the cultural importance of the night sky to Native Americans. The "wheel" is a pattern on the surface of the ground, made up of an imperfect circle of stones, about 25 meters in diameter. It includes a central cairn about 4 meters in diameter. Twenty-eight spokes radiate from this inner cairn and connect to the rim. The medicine wheel marks both the rising and setting sun on the summer solstice as well as the rising of the bright stars Aldebaran, Rigel, and Sirius (Eddy 1974). In these and myriad other ways, the night sky connects us with our ancestral past.

Ecological

The ecological consequences of stray light in parks are primarily a function of changes to the natural regimes of light and dark in which all species have evolved. The disruption of natural patterns of light and dark produces a range of adverse effects for wildlife (Longcore and Rich 2006). Recent studies have suggested that in addition to food, shelter, water, space, and other key environmental resources, many species also require darkness. Longcore and Rich's (2017) review of the literature illustrates effects from light on numerous ecological processes including orientation, reproduction, communication, competition, and predation.

Examples of research demonstrating adverse ecological effects are commonplace in the literature and the number of articles is increasing at a rapid pace. The relationship between light and wildlife behavior was a topic of concern as far back as 1918 when Squires and Hansen (1918) documented the destruction of birds near lighthouses. The effects of artificial light on birds continue to be relatively well studied in comparison to other taxa. Birds are susceptible to light pollution as many species are known to migrate using celestial navigation (Mouritsen and Larsen 2001). It is hypothesized that on nights with fog or low cloud ceilings when other visual cues are obscured, migrating birds attempt to use artificial light sources to assist in navigation (Gauthreaux and Belser 2006). Attracted to these light sources, they often have difficulty escaping from the illuminated areas and may die from collision or exhaustion. Becoming trapped by a light source may also lead to additional consequences such as reduced energy stores or delayed arrival at wintering or breeding areas (Seress and Liker 2015). In addition, males of several bird species often start their dawn choruses earlier in the day in places with more pronounced light pollution compared to birds in darker territories (Kempenaers et al. 2010, Miller 2006).

One of the best-known examples of ecological disruption caused by artificial light is the fate of hatchling sea turtles as they emerge from nests on sandy beaches. Under normal circumstances, hatchlings move away from dark inland areas and move quickly toward the relatively bright surf. In many developed areas, light sources from roads and towns disrupt this natural condition and turtle hatchlings move inland toward bright areas instead of out to sea. This disorientation often results in increased predation and higher overall mortality for the hatchlings (Longcore and Rich 2006, Salmon et al. 1995).

Although our understanding of the effects of light on wildlife have increased in recent decades, there are still many unknowns. For example, we know that insects are attracted to light sources. Lights, especially those near natural areas, can attract insects within a large radius (Souza de Medeiros et al. 2017, Wakefield et al. 2018). Unfortunately, the ecological effects of these light traps on insect populations and distributions are still largely unknown.

Wilderness

Wilderness is a unique, vital, and irreplaceable source for a wide range of ecological, cultural, social, economic, ethical, and other values (Cordell et al. 2005). The Wilderness Act of 1964 directs agencies administering any area designated as wilderness to preserve the wilderness character of the area (Pub. L. 88–577). Based on the interagency publication "Keeping It Wild" (Landres 2008), NPS has adopted five qualities of wilderness character: natural; untrammeled; solitude or a primitive and unconfined type of recreation; undeveloped; and other features of value (National Park Service 2014). Protection of night skies and naturally dark conditions is related to all of the wilderness qualities.

Natural

This component of wilderness character holds that ecological systems should be substantially free from the effects of modern civilization. Views of the night sky and natural cycles of light and dark are critical components of the "natural" quality of wilderness character. Stray light negatively impacts natural cycles of light and dark, affects wildlife physiology and behavior, and disrupts important ecological processes. Sky glow and glare within a wilderness viewscape diminish naturalness by creating scenic elements that are caused by modern development.

Untrammeled

Wilderness is untrammeled when it is essentially unhindered and free from intentional human actions or manipulation. This quality is influenced by any activity or action that intentionally controls or manipulates the components or processes of ecological systems inside wilderness. Adding light to the environment is often a way to manipulate the physical characteristics of an area and can reduce the untrammeled quality of wilderness character. Natural night skies are an effective indicator of an untrammeled landscape.

Undeveloped

Undeveloped wilderness retains its primeval character and influence and is essentially without permanent improvement or modern human occupation. This quality is preserved by the absence of structures and installations, and by refraining from other uses prohibited by Section 4(c) of the Wilderness Act, which include the presence of habitations and the use of motor vehicles, motorized equipment, or mechanical transport. Undeveloped wilderness should be without the lighting often associated with these uses.

Solitude or a Primitive and Unconfined Type of Recreation

Wilderness provides outstanding opportunities for solitude or primitive and unconfined recreation. This quality is related to opportunities for visitors to experience wilderness character and is preserved or improved by actions that reduce signs of modern civilization inside wilderness. The night sky contributes significantly to opportunities for visitors to experience solitude or a primitive and unconfined type of recreation. Skyglow, glare, and other forms of light trespass are constant reminders of modern civilization and diminish the sense of solitude that many wilderness users seek.

Other Features of Value

Section 2(c) of the Wilderness Act states that wilderness also preserves other tangible features that are of scientific, educational, scenic, or historical value. According to the NPS Wilderness Stewardship Plan Handbook, this quality captures important elements of wilderness that may not be covered in the other four qualities, such as cultural or paleontological resources (National Park Service 2014).

Dark environments are very fragile, and even small amounts of stray light in wilderness have the potential to overwhelm the natural features of the night sky and interrupt natural cycles of light and dark. Light is one of the most common human intrusions that a wilderness user is likely to encounter and can easily decrease their sense of solitude, naturalness, and other components of wilderness character.

MEASURING LIGHT IN PARK ENVIRONMENTS

Natural resource monitoring is a major component of park stewardship. The overall purpose for measuring and monitoring natural resource conditions such as night sky quality and light trespass is to determine the status and trends in the condition of these important resources and values. Monitoring results can be used to determine the effectiveness of management decisions, provide early warning of impending threats, and provide a basis for understanding and identifying meaningful changes in natural resource conditions (National Park Service 2018). Scientists and engineers at the Natural Sounds and Night Skies Division have worked with universities, nongovernmental organizations, and other public and private partners to push the boundaries in developing technology, methodologies, and protocols for measuring the photic environment in National Parks.

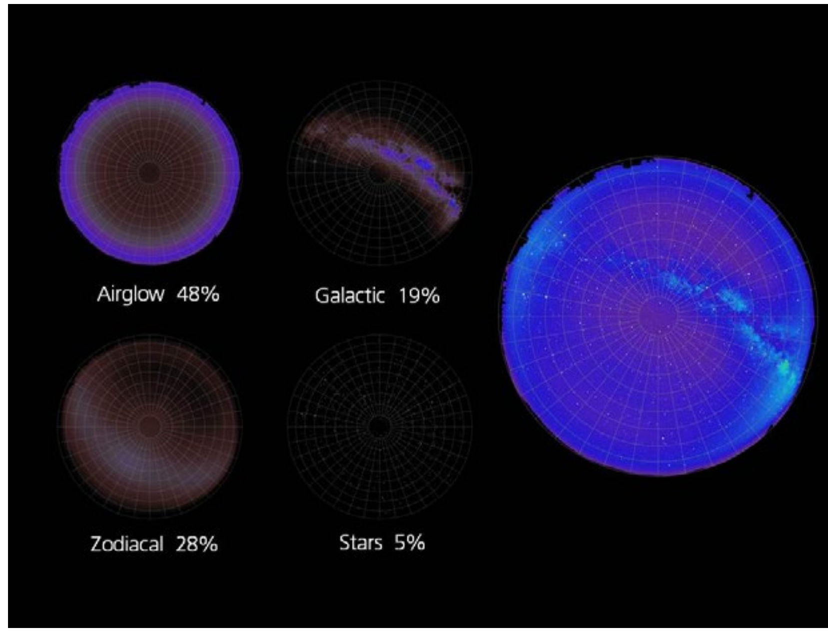

Figure 1.—The main components of the night sky and the average percentage of light that each contributes to natural conditions (Duriscoe 2013). These components are combined into a model of the natural night sky that can be used as a benchmark for comparing existing light conditions. Images from National Park Service.

Natural Sources of Light

In order to assess the levels and effects of anthropogenic light, park managers need to be able to compare existing light levels to a natural reference condition. This natural condition is obtained by modeling the natural light in the moonless night sky devoid of any anthropogenic sources. Natural sources of light in the night sky include starlight, galactic light, zodiacal light, and airglow.

The total amount of light originating from stars represents a small portion of the natural light in the night sky. Venus, the brightest natural object other than the moon, has an illumination level of 0.14 lux. By comparison, the illumination level of the full moon is 250 mlux (Roach and Gordon 1973). Most stars are significantly dimmer than Venus and, when aggregated across the night sky, the light level from stars is relatively low. Compared to other sources of natural light, starlight contributes only about 5 percent of the total natural light in the night sky. Galactic light is the accumulated light from the dense band of stars that make up the Milky Way. Because the stars in this region are so dense, they are measured as a single source. Galactic light represents about 19 percent of the natural light in a cloudless, moonless night sky.

Zodiacal light, sometimes called “false dawn,” is sunlight reflected off of dust particles in the planetary plane of our solar system between Mars and Mercury. Near twilight zodiacal light forms a wedge-shaped band of light at the horizon in the direction of the sun and can be surprisingly bright under dark clear skies. Zodiacal light represents 28 percent of the natural light in the night sky. Airglow is light that emanates from the ionization of gases in the upper atmosphere. It can be seen as a subtle “shell” of light around the Earth. Air glow is the source of approximately 48 percent of the natural light in the night sky. Duriscoe (2013) combines these sources into a model of the natural night sky. Figure 1 illustrates each of the sources of light in the natural night sky and the composite model used by NPS. This model of the natural night sky is used as a benchmark by which the condition of any night sky can be assessed.

Anthropogenic Sources of Light

As mentioned above, the two main sources of light trespass are glare and sky glow. Glare can easily be measured using a standard illuminance meter. In addition to lux levels, some models also provide information related to the light’s spectrum. To measure sky glow, a sky quality meter can be used. Originally designed as an affordable meter for measuring sky brightness for astronomers, sky quality meters measure the brightness of the night sky in magnitudes per square arcsecond. These instruments can be used in the field by visual resource professionals to quickly assess and quantify night sky quality and sources of glare within a viewshed. NPS is also developing technology, methodologies, and protocols for using digital single lens reflex (DSLR) cameras to measure light levels in the field. DSLRs are portable, convenient, and readily available and after effective calibration can be used to precisely measure light levels. DSLRs also provide an excellent qualitative record of the night sky and nighttime visual resource conditions.

Currently, NPS uses a charged coupled device (CCD) camera to assess night sky quality in National Parks. CCDs allow NPS to create a mosaic of 45 images that can capture the entire night sky with an astonishing level of detail (Duriscoe et al. 2007). As illustrated in Figure 2, the data can be presented in natural and false color graphics to better demonstrate variations in light levels. To illustrate the portion of light levels from anthropogenic sources, natural sources from the natural night sky model are subtracted from the all sky images. The resulting images demonstrate the portion of the light originating solely from anthropogenic sources. The anthropogenic data are then compared to our natural sky benchmark to calculate the anthropogenic light ratio (ALR).

Figure 3 illustrates contours depicting various ALR levels of the night sky measured in Death Valley National Park. In this view, the zenith of the sky directly overhead is at the center of the circle. The brightest areas within the brown contours are 200 percent brighter than natural conditions. The yellow contours represent areas that are 60 percent greater than natural, and areas within the blue contours are 15 percent brighter than natural conditions. The median level for the entire sky is 17 percent above natural.

Figure 4 shows ALR levels from Keye's view in Joshua Tree National Park, a popular lookout with sweeping views that include the Coachella Valley and Palm Springs. As a result, the all sky median ALR is 96 percent above natural and the brightest area is almost 7,000 percent above natural conditions.

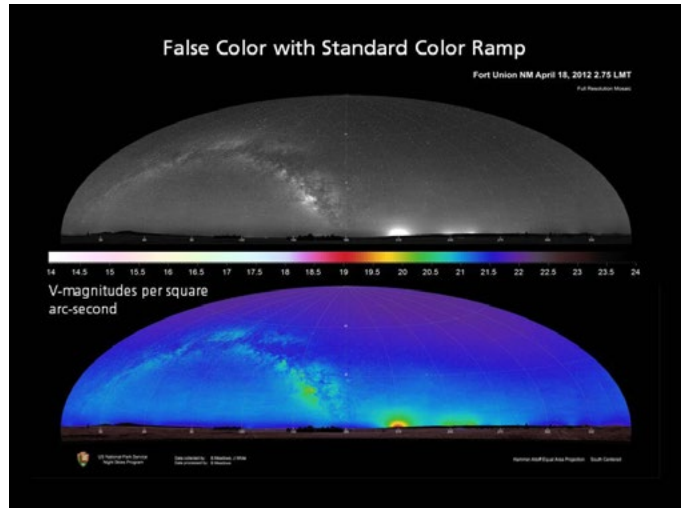

Figure 2.—All-sky brightness levels in natural and false color. Image from National Park Service.

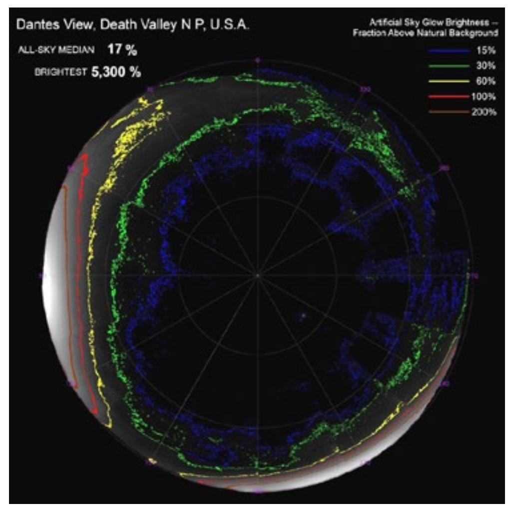

Figure 3.—Anthropogenic light ratio of the night sky measured in Death Valley National Park. Image from National Park Service.

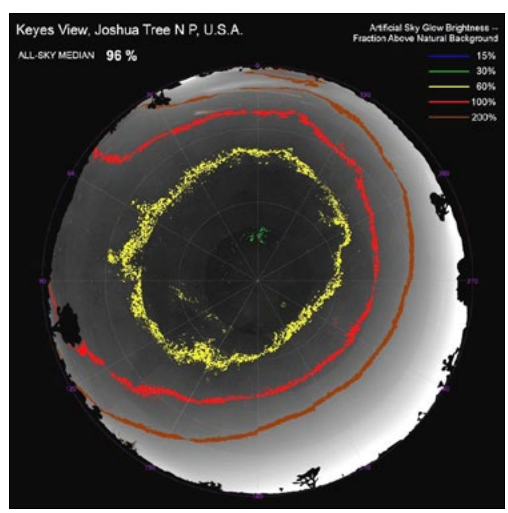

Figure 4.—Anthropogenic light ratio of the night sky measured in Joshua Tree National Park. Image from National Park Service.

PRINCIPLES OF SUSTAINABLE OUTDOOR LIGHTING

Mitigation of potential effects is a cornerstone of the visual impact assessment process (Bureau of Land Management, n.d.; Landscape Institute and the Institute of Environmental Management and Assessment 2013). In an effort to reduce the effects of lighting on national park resources and values, NPS has built upon existing recommendations and best practices (Dick 2016, Illuminating Engineering Society 2014, International Dark-sky Association 2018) to develop the following six principles of sustainable outdoor lighting. In designing, selecting, and operating outdoor lighting, the combination of these six principles will lead to lighting systems that simultaneously and effectively address social, economic, and environmental concerns of lighting. When designing, installing, maintaining, and replacing lighting fixtures and systems in national park units, park managers are encouraged to implement these principles to protect, preserve, and restore the photic environment and other park resources and values.

Light Only If You Need It

The first principle involves an assessment of whether a light is necessary and warranted. While outdoor lights are often installed with the express purpose of increasing illumination, the real need is often improving visibility. There is a number of ways to improve visibility that do not require illumination such as painting curbs, steps, and crosswalks with light colored or retro-reflective paint, using lighter colored pavement, trimming vegetation that obscures lights or sight-lines, and installing glow-in-the-dark markers.

If there is a particular risk that needs mitigating, such as tripping on a pathway or potential vandalism of valuable resources, there may be solutions available other than installing lighting. Smoothing paved surfaces, reworking stairways, or installing alarm systems can be more effective and cost less than outdoor lighting. Whenever possible, the underlying risk or hazard should be directly addressed as opposed to adding light in order to mitigate risk.

Light Only When You Need It

The central precept of this principle is to turn off or dim lighting when it is not needed. Outdoor lighting should have controls that limit the use of lights when sufficient daylight is available. Timers should be used in appropriate areas to turn off or dim lights when the area is not in use (International Dark-Sky Association and Illuminating Engineering Society 2011). This can be accomplished through the use of motion sensors, timers, dimmers, and other control technologies that reduce the overall time and intensity of illumination. New LED technologies also allow precise control of the direction and spectral composition of light (Pandharipande and Newsham 2018; U.S. Department of Energy, n.d.). In addition to reducing stray light, effectively managing the time that lights are lit, as well as the intensity and spectra emitted, results in the added benefits of prolonged lamp life, lower maintenance costs, reduced energy consumption, and decreased carbon emissions (California Lighting Technology Center 2014, Pandharipande and Newsham 2018, Pust et al. 2015).

Use the Appropriate Spectrum for the Task

All lights emit a characteristic color, also known as correlated color temperature (CCT), that is expressed in degrees Kelvin. Warm tones appear yellow, amber, and red while cool tones appear white and often have a bluish tint. Paradoxically, warmer tones have a lower CCT and cooler color tones have higher CCTs (see Fig. 5). Light with higher CCTs contain a greater proportion of energy in the blue portion of

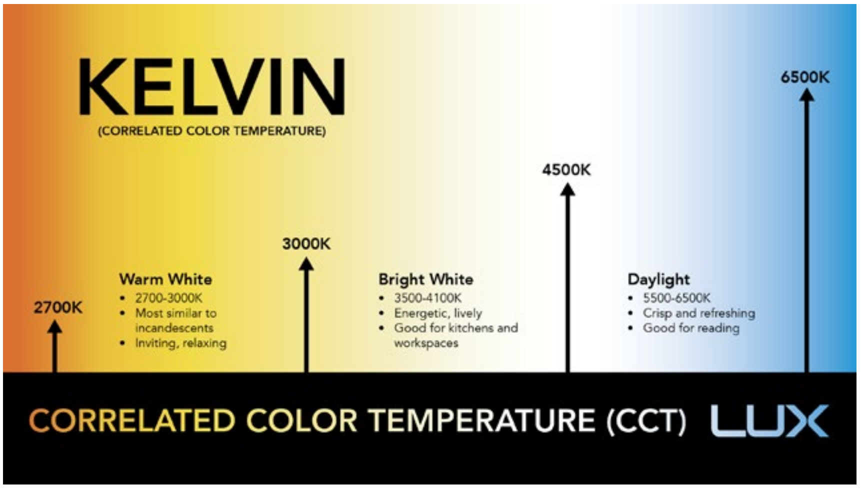

Figure 5.—Correlated color temperature. Image from Sedat ONAT, via Flickr Creative Commons.

their spectrum, which has a disproportionately high impact on dark adaptation, circadian rhythm, and other physiological processes in humans and wildlife (Holzman 2010, Tosini et al. 2016). Also, due to increased atmospheric scattering of short wavelengths, blue-rich light sources produce more skyglow in the vicinity of light sources than an equivalent intensity of yellow-rich lighting (Falchi et al. 2011, Gaston et al. 2012). Considering this greater impact, blue-rich white light with high CCTs should be used only when and where necessary. Otherwise, lamps with a warmer tone (e.g., those that are yellowish, amber, or red) should be used to minimize human and environmental effects.

LEDs generally produce light with high levels of radiant energy in the blue wavelengths. As a result, phosphors are added to the diodes to shift the blue light emitted by most LEDs into a broad spectrum of white light (McKenna 2015). In the past, phosphors had the unfortunate effect of decreasing the overall energy efficiency of the lights. That is why early LED lighting was often perceived as harsh and blue; the lights included less phosphor resulting in higher CCTs in order to maximize energy efficiency. Newer technologies have reduced that effect and the reduction in energy efficiency due to phosphors is negligible (Liu et al. 2015). Recently, the American Medical Association (AMA) released lighting guidance that encourages the use of 3,000K or lower lighting for outdoor installations (American Medical Association 2016). In response to the AMA report, many cities and towns that initially installed 4,000K to 5,000K LEDs are replacing them with 3,000K bulbs (Fundira 2017, Middlebrook 2016).

Light Only Where Needed

The objective of this principle is to limit the footprint of illumination to the area where it is needed. Lighting fixtures should be shielded such that no light is cast upward or horizontally. With proper shielding and advances in controlling the directionality of LEDs, light can be precisely aimed at the area intended to be illuminated, reducing offsite impacts, and preventing light trespass. A fully shielded or full cutoff fixture produces substantially less sky glow and glare compared to an unshielded fixture. As a result, numerous organizations including the U.S. Green Building Council (2018), Royal Astronomical Society of Canada (Dick 2016), and International Dark-sky Association and Illuminating Engineering Society (2011) recommend full cutoff or 0 percent uplight fixtures for outdoor lighting. Similarly, NPS policy also states that parks should shield lighting where necessary to prevent the disruption of the night sky and other park resources (National Park Service 2006).

Minimize the Amount of Light Used

Parks should use the minimum amount of light necessary to meet a task. Most visual tasks in parks such as way-finding, orientation, or detecting whether a person is present, require fairly low illumination levels (International Dark-sky Association and Illuminating Engineering Society 2011, U.S. Green Building Council 2018). Similarly, research shows that simply increasing or maintaining high lighting levels does not promote or enhance safety or security (Richman 2009, Sherman et al. 1997, Steinbach et al. 2015). In order to minimize lighting needs, additional measures should be considered to improve visibility that do not require illumination such as painting curbs, steps, and other features to increase contrast, and using lighter colored pavement. To ensure that minimum lighting levels are used, parks should perform task-based assessments of lighting needs.

Choose Energy Efficient Lamps and Fixtures

When assessing lighting requirements, the most energy efficient lamp and fixture that meets the lighting need should be selected. Energy efficiency is mandated by Executive Orders 13423 and 13693 and is critical in reducing carbon emissions and energy consumption. Lighting constitutes a significant portion of total energy use in national parks and careful selection of lamps and fixtures can help make considerable gains in energy efficiency and cost savings (U.S. Department of Energy 2014). In addition to choosing efficient lamps and fixtures, following the other principles of sustainable outdoor lighting such as implementing controls and minimizing lighting levels will also reduce energy consumption and costs.

CONCLUSIONS

For decades, land managers have understood the importance of protecting daytime viewsheds and the field of visual resource stewardship has created an extensive toolbox of theory, methods, and protocols to support that effort. In recent years, managers have begun to recognize that appreciation of scenic beauty does not end when the sun sets. The aesthetic of the night sky and landscape lit by the stars and moon is as varied, inspirational, and compelling as that of the day. Research suggests that interest and enthusiasm for astronomy, stargazing, and nighttime recreation is increasing as visitors flock to national parks to take part in these activities. As a result of these trends, visual resource professionals need to recognize naturally dark environments and night skies as important elements of visual resource management and incorporate views of the night sky and the nocturnal landscape in visual resource assessment process.

At night, viewsheds expand to include the moon, stars, and landscapes illuminated by these celestial features, and these visual elements are important components of the scenic experience of national park visitors. Stray light in the form of skyglow and glare affects the visual quality of these resources as well as other park resources and values. It impacts wildlife behavior and disrupts visual acuity, circadian rhythms, and other important ecological processes. Methods for precisely measuring photic conditions are available and the NPS has been measuring light levels in national parks for years. Measurement protocols and procedures for assessing potential effects from light on natural and cultural resources continue to improve and lighting technologies that can minimize the impacts of light on visitors and the environment are advancing rapidly. This confluence of increasing public awareness of the resource, improvements in measurement protocols and mitigation strategies, and continuing development of lighting practices and technologies have created an important moment in the field of visual resource stewardship. It is time to extend the realm of visual resources from the light of day into the relative darkness of night.

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