



Night Lighting Management Strategies in Dark Sky Parks: An Empirical Study on Light Pollution Prevention

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Abstract. The International Dark Sky Park provides effective mitigation strategies and best practices for the prevention and control of light pollution, guiding the development direction for light pollution management. By reducing light pollution through dark sky parks, we can protect our shared night sky heritage while ensuring social development and environmental sustainability. The article focuses on the 119 dark sky parks certified by the International Dark-Sky Association. Through the analysis and collection of materials such as certification applications, announcements, and related news from these parks, the study examines the lighting grading and light environment management measures within the dark sky parks, elucidating the strategies for their lighting management. The research reveals that the brightness standards of dark sky parks serve as a crucial foundation for the prevention and control of light pollution. Effective management strategies for light pollution prevention and control include lighting management plans, lighting configurations, lighting zoning, and the implementation of intelligent lighting management systems.

Keywords: Night Lighting Management Strategies, Dark Sky Parks, Light Pollution Prevention.

1 Introduction

Light pollution, a significant and pressing issue for human society, can impact natural ecosystems and threaten the environment essential for human survival. To safeguard the clarity of the night sky and human health, the International Dark-Sky Association (IDA) identifies and designates parks around the world with minimal light pollution and exceptional starry sky conditions as International Dark Sky Park (IDSP).

As an increasingly recognized and effective method for preventing and controlling light pollution, the concept of the Dark Sky Park is gaining global attention. Through IDA certification, these parks adhere to a sound night lighting management strategy during their development and construction. This paper examines the lighting classifi-

cation and light environment management within the International Dark Sky Parks, elucidating the pathways for lighting design and management within these parks. It aims to provide insights for international efforts in light pollution prevention and protection, thereby enhancing the quality of the light environment and improving the quality of human nocturnal experiences.

2 Research Object and Data Source

2.1 Subject

In 2001, the International Dark Sky Association initiated the International Dark Sky Places Program, which has established various categories of dark sky areas, including dark sky communities, dark sky reserves, and dark sky parks. These International Dark Sky Places are recognized for their exceptional starry quality, with their night environments receiving special protection due to their scientific, natural, educational, and cultural heritage values, as well as their role in providing public recreation. This study focuses on the International Dark Sky Parks that have been officially recognized by the International Dark Sky Association.

2.2 Data Sources

As of January 2024, the International Dark Sky Association has certified a total of 119 International Dark Sky Parks^[1]. This research involves collecting the certification applications, announcements, and related news for the certified International Dark Sky Parks. By analyzing these materials, the study aims to examine the lighting classification and light environment management strategies employed within the International Dark Sky Parks, thereby elucidating the lighting management strategies that are integral to the parks' operations.

3 Dark Sky Parks Brightness Measurement and Classification

3.1 Dark Sky Parks Brightness Measurement and Standards^[2]

Measurement of Brightness in Dark Sky Parks. The quantification of nocturnal brightness within dark sky parks has consistently been a central focus and a challenge in the thematic research of these parks. Currently, there are four primary methods for measuring the brightness of dark sky parks: the image data method^[3-4], the instrument measurement method^[5-6], the visual measurement method^[7], and the conceptual model method^[8].

Brightness Standards for Dark Sky Parks. The International Dark Sky Association has provided a clear set of measurement methods and standards for the brightness of dark sky parks. There are two main measurement methods: the SQM (Sky Quality Meter) luminance meter measurement method^[9-10] and the visual measurement meth-

od, known as the Bortle method^[6]. The detailed classification criteria for the Bortle dark night sky and the corresponding SQM measurement indices are presented in Table 1. However, the Bortle method is considered supplementary and cannot be used in isolation for applying for dark sky park status. The International Guide to Dark Sky Parks (2018) specifies that typical night conditions in dark sky parks must meet or exceed the following criteria: A. The Milky Way is visible to the naked eye; B. There are no nearby artificial light sources that produce significant glare; C. Any light domes that are present are faint, limited in scope, and close to the horizon. These conditions roughly correspond to a zenith brightness of 21.2 mag/arcsec² in the visual band^[1].

Table 1. Bortle Dark Night Sky Classification and SQM Measurement Index^[5-7].

Bortle Grades	SQM measurements (mag/arcsec ²)	Visual limit magnitudes (magnitudes)	Label	Description	Sky Colors
1	22.00-21.99	≥ 7.5	excellent dark sky	The zodiacal light and zodiacal bands are clearly visible to the naked eye.	
2	21.99-21.89	7.0-7.49	Typical dark night starry night	The zodiacal light appears noticeably yellowish, with airglow visible near the horizon and distinct galactic structures observable in the summer sky.	
3	21.89-21.69	6.5-6.99	Rural sky	The zodiacal light is evident during spring and autumn, with some light pollution visible on the horizon. Clouds near the horizon appear brighter, and the Milky Way is more discernible.	
4	21.69 - 20.49	6.0 - 6.49	Suburban transition to rural skies	The zodiacal light remains visible on clear nights in spring and autumn. There is a general presence of light pollution, with clouds at the horizon being brighter than the surrounding sky.	
5	20.49 - 19.50	5.5 - 5.99	Suburban Starry Night	The zodiacal light is visible only on exceptionally clear nights during spring and autumn, with persistent light pollution. Clouds are significantly brighter than the sky, and the Milky Way is visible only in the zenith direction.	
6	19.50 - 18.94	5.0 - 5.49	Bright suburban sky	Light pollution obscures the zodiacal light, creating a grayish-white hue up to 35° above the horizon. Clouds are quite bright, and the Milky Way is visible only in the zenith direction.	
7	18.94 - 18.38	4.5 - 4.99	suburban/urban transition	The sky is rendered a hazy reddish off-white due to light pollution, with strong light sources visible in all directions. The brightness of the clouds is such that the Milky Way becomes invisible.	
8	< 18.38	4.0 - 4.49	city sky	The sky takes on a greyish or reddish-white hue under artificial light, making stars barely visible or completely obscured. Even through a telescope, only the brightest stars can be discerned.	
9		≤ 4.0	inner city sky	The sky is brightly illuminated, rendering many stars invisible. The only celestial objects visible are the moon, planets, and some of the most luminous star clusters.	

3.2 Sky Grading for Dark Sky Parks

IDA classifies International Dark Sky Parks based on instrumental measurements of the night sky's brightness. The International Dark Sky Park Guide (2015) outlines the detailed criteria for this classification^[1]:

The Gold rating is assigned to International Dark Sky Park that possess natural, non-polluting, or near-natural night sky conditions. This rating is given when the corrected SQM magnitude (denoted by S) is equal to or darker than (i.e., greater than) $21.75 \text{ mag/arcsec}^2$ under appropriate conditions with minimal or no moonlight interference, i.e., $S \geq 21.75 \text{ mag/arcsec}^2$.

The Silver rating corresponds to night-time environments that may be slightly impacted by light pollution and other artificial light disturbances. Despite this, these parks can still exhibit a high-quality night sky and a typical nocturnal light landscape. The corrected SQM magnitude for this category is defined as $21.75 > S \geq 21.00 \text{ mag/arcsec}^2$.

The Copper rating is for areas that do not meet the Silver criteria but still offer a sanctuary for people, plants, and animals from the degraded nighttime environment. The corresponding SQM magnitude range for this level is defined as $21.00 > S \geq 20.00 \text{ mag/arcsec}^2$.

4 Dark Park Light-Scape Management

4.1 Lighting Management Plan

The International Guide to Dark Sky Parks (2018) stipulates in its "Minimum requirements for all parks" section that Dark Sky Parks must develop a high-quality, comprehensive Lighting Management Plan (LMP). This LMP is a written policy approved by the park's management and must include at least the following minimum provisions^[1]:

Outdoor lighting may only be used at night if it is necessary, where it is needed, and for a specific task, in the appropriate amount for that task. The purpose of the permitted outdoor lighting must be to ensure public safety.

All outdoor lighting installations with an initial lamp lumen output greater than 500 lumens must be fully shielded, and timers and motion sensors must be used appropriately. Lighting of 500 initial lumens or less may be used for special purposes and uses, such as historic preservation. Approved special uses must be described in the LMP, and the IDA will carefully review these lighting installations to ensure they meet high-quality public lighting standards and maximize the protection of the nighttime environment.

Lighting controlled by motion sensor activation is exempt from other requirements of this section if the lighting duration after activation is limited to 5 minutes.

Lighting fixtures must be selected to minimize the emission of short-wavelength light into the nighttime environment. The park's LMP must limit lighting based on one of the following measures: A. The relative color temperature (CCT) of the fixture must not exceed 3,000 Kelvin; B. At wavelengths less than 550 nanometers, permitted

lighting cannot exceed 25% of its total spectral power; C. The dark light ratio (S/P) of permitted illumination shall not exceed 1.3.

Visitor activities that introduce unnecessary artificial light into the park's nocturnal environment must be regulated and restricted. This includes reasonable restrictions on the lighting of camping equipment and recreational vehicles, and a general prohibition of inappropriate "light painting," the use of searchlights, and similar activities.

Illuminated signs must meet all of the following requirements: A. Sign lighting is permitted only for relevant activities. B. The display must be monochrome with a black background; C. The overall brightness of the sign must not exceed 100 nits (100 candelas per square meter, cd/m^2) after sunset; D. The luminous or illuminated surface area of the individual sign shall not exceed 18.6 square meters (200 square feet).

The policy governing temporary lighting installations requires that any such installation comply with the LMP to the greatest extent possible and that the duration of lighting installations be limited to the shortest possible time.

4.2 Lightscape Management and Practice

Lighting Configuration. On this basis, this section further summarizes and clarifies the lighting configuration of dark sky parks from the three macro levels of "suitable," "appropriate," and "timely." The "suitable" aspect refers not only to the compatibility of lighting facilities with the places and lighting configurations as limited by the Lighting Management Plan (LMP) but also to meeting the minimum requirements necessary for human use of lighting. "Appropriate amount" refers to the requirements and restrictions on both the number of lighting facilities and the intensity of lighting, measured in candelas, candelas per square meter (cd/m^2), lumens, and illuminance (lux). The boundary for these quantities is the "minimum requirement for human needs" mentioned earlier. "Timely" encompasses not only the daily scheduling configuration requirements mentioned by the LMP but also attention to the seasonal changes and the "timely" requirements for the park's lighting configuration at night, which vary according to different regions, seasonal variations, sun heights, and sun-earth distances that affect daylight hours^[1].

Lighting Zoning. Most international Dark Sky Parkss, in their lighting management plan, zone their park lighting according to the actual conditions of the park. For example, Galloway Forest Park (Scotland)^[11] divides its area into a core zone and a buffer zone. The park's LMP designates this area as the core of the dark sky park. These areas provide temporary accommodation without power for management teams or climbers during inclement weather, thus eliminating permanent lighting installations. The core area of Galloway Forest Park is home to a vast array of mammals, birds, and reptiles, from the red deer, the largest mammal in Britain, to the smallest insects. However, it is particularly known for its number and variety of bats and owls, both nocturnal species that rely on darkness to find food. Consequently, the park's core areas and buffer zones are monitored for light intrusion to assist in conserving the breeding cycles of local wildlife: within the core area boundaries, a policy of no

permanent lighting is maintained; it is ensured that no light enters the core area from adjacent permitted lighting areas, and any overflow lighting in the buffer zone does not exceed 0.10 lux in light intensity compared to overnight lighting.

4.3 Intelligent Lighting Management System

In addition to meeting the configuration standards of the LMP, the lighting in International Dark Sky Parks should also consider the energy efficiency and cost of lighting. On one hand, energy-saving lighting facilities inevitably come with a higher cost; the capital cost should be weighed against energy efficiency. On the other hand, the maintainability of lighting facilities is closely related to cost; the capital cost should be compared with the maintenance interval, and the lighting design should evaluate the maintenance-related workload. Choosing energy-saving bulbs that last longer may have a higher upfront cost, but over time, the investment in longer-lasting and more efficient bulbs pays off. Intelligent lighting management systems—ranging from basic timers to motion sensors, dimmers, and complex computer-controlled lighting—further improve lighting efficiency and save energy while reducing the maintenance and operating costs of lighting systems.

5 Conclusion

This study finds that the night brightness standard is the "core point" for the prevention and control of light pollution in Dark Sky Parks, providing an important basis for night-time light pollution management. The Dark Sky Parks lighting management plan (LMP) and Light scape management measures are effective means of preventing and controlling light pollution. The paper points out that the lighting configuration, lighting partitioning, and intelligent lighting management modes of dark sky parks are effective measures and methods for preventing and controlling light pollution in these parks, also offering a good reference for international night light environment and light pollution management.

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