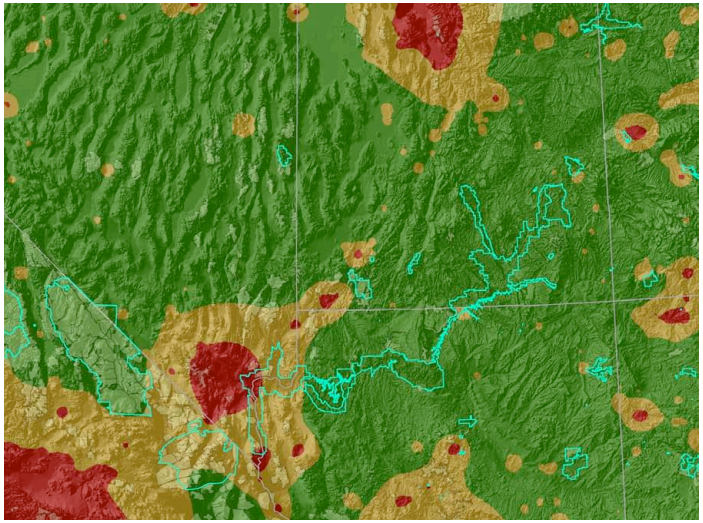
Recommended Indicators and Thresholds of Night Sky Quality for

NPS State of the Park Reports

Interim Guidance— May 7, 2013



Natural Sounds & Night Skies Division

WASO-Natural Resource Stewardship & Science

Chad Moore, Chad_Moore@nps.gov, 970-267-7212

Frank Turina, Frank_Turina@nps.gov, 970-225-3530

Jeremy White, Jeremy_M_White@nps.gov, 970-267-2174

Introduction to Lightscapes and Photic Environments

While managing the nighttime environment of the National Park Service, the Natural Sounds & Night Skies Division (NSNSD) draws a distinction between the *lightscape*— the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain, and the *photic environment*— the totality of the pattern of light at night at all wavelengths. *Lightscapes* are an aesthetic and experiential quality that are integral to natural resources and cultural resources. The *photic environment* affects a broad range of species, is integral to ecosystems, and is a natural physical process.

The quality of the nighttime environment is relevant to nearly every unit in the NPS System. The 2006 NPS Management Policies (section 4.10) speak of the importance of a natural photic environment to ecosystem function[1] and the importance of the natural lightscape for aesthetics[2]. A lightscape can be important as a natural feature, a cultural feature[3], or both. Natural lightscapes are an important component of Wilderness character and an air quality related value. Therefore, the importance of lightscapes and photic environments is related to an array of park resources and values in addition to visitor experience and scenery, and they have far broader implications for park management.

This document is intended to provide rationale, justification, and explanation of the three-tiered (red, amber, green) ratings suggested by NSNSD solely for the State of the Parks Program. Parks are encouraged to incorporate assessment of nighttime quality into their State of the Park reports and other planning documents. Parks are also encouraged to contact the NSNSD should they need clarification of, desire modification of, or have concerns about the appropriateness or validity of the ratings.

Use and Limitations of this Guidance

The recommendations herein are for characterizing the quality of the photic environment and lightscape, which are complex and multifaceted resources, using a single parameter. The parameter recommended is the average anthropogenic sky luminance presented as a ratio of natural conditions (ALR). It was selected for inclusion in park's State of the Parks reports because it is a robust and descriptive metric that can be modeled relatively easily. However the utility of a single metric to describe the quality of a complex resource such as the photic environment metric is limited. The ALR metric provides a general and relatively coarse description of overall resource conditions. Using a single metric limits the ability to fully describe and manage the variations in resource quality that often exist within a park. Decisions on whether management actions are warranted, and the best solutions to resource problems require additional metrics that capture other important characteristics of the resource. A far more comprehensive suite of indicators of the photic environment is available and should be used when developing desired conditions, conducting environmental impact assessments, and making management decisions that could affect the resource. Examples of other parameters and metrics include the maximum vertical illuminance, horizontal illuminance, spectral characteristics, impacts to wildlife species of concern, measures in certain quadrants of the sky, and qualitative indices.

Therefore, the metric (ALR) and condition thresholds provided in this document should not be used in isolation to manage the photic environment in parks. Other relevant park-specific information such as park enabling legislation, park significance, management objectives, desired conditions, presence of sensitive resources and sensitive species, wilderness status, and other factors should be considered when making decisions or taking management action related to the resource. Parks are encouraged to discuss their rationale for modifying this framework with the NPS Natural Sounds & Night Skies Division.

Classification of Parks

In order to assess the state of park conditions for lightscapes and photic environments, two levels of sensitivity are delineated. While there is a wide variety of parks with a range of purposes, resources, and mandates within the National Park System, these recommendations are designed to provide a rapid and simplified approach that can be applied broadly. For this purpose parks are divided into two levels based on the NRSS Inventory & Monitoring (I&M) Program natural resource designations. Level 1 parks include those which have been designated by the I&M Program as having significant natural resources. As such, these areas include parks in which the nighttime photic environment has a greater potential influence on natural resources and ecological systems. These areas often have higher quality night sky conditions and less anthropogenic light levels. As a result, these parks tend to be more sensitive to the effects of light pollution. Level 2 parks include those units that are not recognized by NRSS I&M Program as having significant natural resources. In Level 2 parks, there are fewer natural resources and light pollution has less of an influence on wildlife and ecological systems. In these areas, night skies are often degraded due to high levels of anthropogenic light. These parks are often located in urban or suburban areas. However, Level 2 parks often include relatively dark areas surrounded by highly urbanized lands. The resources in these areas can often serve as an important access to nature for nearby residents, and although degraded, these sites often provide the best available night sky conditions for large numbers of people, visitors often travel to theses parks to see starry skies, or astronomy and night sky interpretive programs may be very popular. In some cases, the photic environment may be more sensitive to further degradation and parks should consider changing their designation from Level 2 to Level 1. In addition, some parks initially categorized as Level 2 may be changed to Level 1 if the park contains important cultural resources associated with night skies or the photic environment. For example, a cultural park created to preserve seagoing vessels and sailing heritage may want to preserve the view of the night sky historically used by mariners for navigation.

Condition Thresholds

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[4], measured in the green (human visual) spectral band[5]. As long as the horizon is fairly unobstructed while the measurement is taken, the measure does not vary significantly based on the microenvironment from which it is taken. Trends in average anthropogenic sky luminance are more likely to be real changes in the resource condition rather than false or short-term occurrences during measurement conditions. For example, air pollution can substantially impact the gradient of intensity of a light dome over a distant city, yet the aggregate flux from that city is less affected by

atmospheric conditions when averaged over the entire sky. Another advantage of average all–sky luminance is that a suite of other measurements track parallel to it, and thus greater inference can be made from this one single measure.

Average anthropogenic light is calculated by taking the total observed sky brightness and then removing the natural night sky component from the observed conditions, yielding the anthropogenic quanta[6]. A natural night sky has an average brightness across the entire sky of 78 nL (nanolamberts, a measure of luminance), and includes components such as the Milky Way, Zodiacal light, airglow, and other starlight. This parameter is expressed as a ratio of anthropogenic to natural light, known as the Anthropogenic Light Ratio (ALR). For example, a ratio of 0.0 would indicate pristine natural conditions where the anthropogenic component was 0 nL and natural component was 78 nL. A ratio of 1.0 would indicate that anthropogenic light was 100% brighter than the natural light from the night sky, equating to an anthropogenic component of 78 nL and natural component of 78 nL (See figure 1a and 1b).

The average anthropogenic sky luminance is derived from ground–based measurements when available, or from a GIS model (calibrated to other ground-based measures) when in-park ground-based measures are not available. The GIS model is derived from data from the 2001 World Atlas of Night Sky Brightness[7], which depicts *zenith* sky brightness (the brightness of the sky directly above the observer). A neighborhood analysis is then applied to the World Atlas to determine the anthropogenic sky brightness over the *entire* sky. Finally, the modeled anthropogenic light over the entire sky is presented as a ratio (ALR) over the natural sky brightness[8]. There is a moderate level of uncertainty with the modeled data.

For *Level 1* parks, the threshold separating green and amber conditions is set at an Anthropogenic Light Ratio (ALR) of 0.33 or 1/3rd brighter than natural conditions (see Table 1). This value for average anthropogenic sky luminance corresponds with the point at which portions of the sky typically become bright enough that humans are unable to fully adapt to the dark (i.e. scotopic vision) when looking toward them. Above this threshold, humans lose visual sensitivity and require time under dark conditions to re-adapt their eyes. This attribute of human "night" vision is likely similar in other mammals, although certain mammals may be more or less sensitive. This threshold also corresponds to the transition between Bortle Class 3 (rural and dark) and Class 4 (suburban) skies; Bortle Class is a nine-step qualitative index of the night sky[9]. The threshold separating amber and red conditions is set at an ALR of 2.0. This value corresponds with a point at which portions of the sky typically cast shadows, at which the Milky Way can no longer be seen in its entirety, at which the Zodiacal lights is very seldom seen, and full dark adaptation is not possible no matter which direction an observer looks (see Table 2).
For parks that contain lands managed as wilderness (designated and proposed Wilderness, or other lands managed as wilderness at the discretion of park management), the thresholds for Level 2 standards must be met in more than 90% of the area.

For *Level 2* parks, the threshold separating green and amber conditions is set at an ALR of 2.0, possessing the same visual characteristics as described above. The threshold separating amber and red conditions is set at an ALR of 18.0. This corresponds to the point at which extended features of the night sky (e.g. Milky Way, Andromeda Galaxy) are invisible in nearly all situations, constellations become difficult to identify, and the sky is colorized by the light from numerous lights.

At this level of anthropogenic light, contrast of illuminated monuments is reduced, photographs at night easily capture the altered appearance of the night sky, and it becomes difficult to retain a historical cultural landscape at night (see Figure 2 for map).

The ALR thresholds are applied spatially to the park. For both high and low sensitivity parks, the designated condition (green, amber, red) corresponds to the ALR level that exists in *at least half of* (median condition) the parks' landscape. Thus it is probable that a visitor will be able to experience the specified night sky quality. It is also probable that the majority of wildlife and habitats found within the park will exist under the specified night sky quality. For parks with lands managed as wilderness, the designated condition is based on the ALR level that exists in more than 90% of the wilderness area. Some professional judgment may be applied to both the measured and modeled values to compensate for the influence of terrain and to attain a proper estimate of spatial coverage. Modeled data is currently only available for the lower 48 states.

Table 1— Thresholds for Level 1 and 2 Parks

Indicator	**Threshold for Level 1 Parks**	**Additional Threshold for Areas Managed as Wilderness**	**Threshold for Level 2 Parks**
Anthropogenic Light Ratio (ALR)— Average Anthropogenic All-Sky Luminance : Average Natural All-Sky Luminance Light flux is totaled above the horizon (the terrain is omitted) and the anthropogenic and natural components are expressed as a unitless ratio The average natural sky luminance is 78 nL	ALR < 0.33 (<26 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*	ALR < 0.33 (<26 nL average anthropogenic light in sky) *At least 90% of wilderness area should meet this criteria*	ALR < 2.00 (<156 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*
	ALR 0.33–2.00 (26–156 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*	ALR 0.33–2.00 (26–156 nL average anthropogenic light in sky) *At least 90% of wilderness area should meet this criteria*	ALR 2.00–18.00 (156–1404 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*
	ALR > 2.00 (>156 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*	ALR > 2.00 (>156 nL average anthropogenic light in sky) *At least 90% of wilderness area should meet this criteria*	ALR > 18.00 (>1404 nL average anthropogenic light in sky) *At least half of park area should meet this criteria*

Ground Based Data 90% confidence interval= ±8 nL (±0.1 ALR)
Modeled Data 90% confidence interval= ±40%
nL= nanolambert (0.0031831 mcd/m^2)
For other conversions see table in appendix

Table 2— Functional Impacts of Condition Determinations

Qualitative Description	Sensitivity	Good Condition (Green)	Moderate Condition (Amber)	Poor Condition (Red)
Bortle Class [9]	More Sensitive	Bortle Class 1-3	Bortle Class 4	Bortle Class 5-9
	Less Sensitive	Bortle Class 1-4	Bortle Class 5-6	Bortle Class 7-9
Typical Limiting Magnitude [10]	More Sensitive	6.8–7.6	6.3–6.7	<6.2
	Less Sensitive	6.3–7.6	5.6–6.2	<5.6
Sky Quality Meter[11]	More Sensitive	≥21.60	21.20-21.59	<21.20
	Less Sensitive	≥21.20	19.70-21.19	<19.70
Celestial Feature Appearance	More Sensitive	Zodiacal light can be seen under favorable conditions, Milky Way shows detail and stretches from horizon to horizon	Milky Way has lost most of its detail and is not visible near horizon, Zodiacal light is rarely seen	Milky Way may be visible when it is directly overhead, otherwise not apparent, Andromeda Galaxy may be barely visible
	Less Sensitive	Milky Way frequently visible	Milky Way is only visible when it is directly overhead and is not generally apparent	No extended celestial features are visible, only brightest constellations are visible
Lightscape Appearance	More Sensitive	Most observers feel they are in a natural environment, with natural features of the night sky readily visible	Anthropogenic light dominates natural celestial features, some shadows from distant lights may be seen	Little sense of naturalness remains in the night sky, landscape is clearly shadowed or illuminated, horizon aglow
	Less Sensitive	From within a built environment sky appears largely intact	Discoloration of the sky is likely apparent, shadows are seldom noticed from within a built environment	The sky has lost all aspects of naturalness except for a few hundred visible stars (or less)
Human Vision	More Sensitive	Negligible impact to dark adaptation looking in any direction	Dark adaption possible in at least some directions, though visible shadows are likely present	Full dark adaptation not possible, substantial glare may be present, circadian rhythms may be disrupted
	Less Sensitive	Full dark adaption possible in at least some directions, though visible shadows may be present	Full dark adaptation not possible, shadows obvious at night from light sources in sky or along horizon, circadian rhythms may be disrupted	Full dark adaptation not possible, significant glare from sky or sources near horizon, higher concern over impact to circadian rhythms
Sky Quality Index [12]	More Sensitive	>75	50–74	<50
	Less Sensitive	>50	25–49	<25

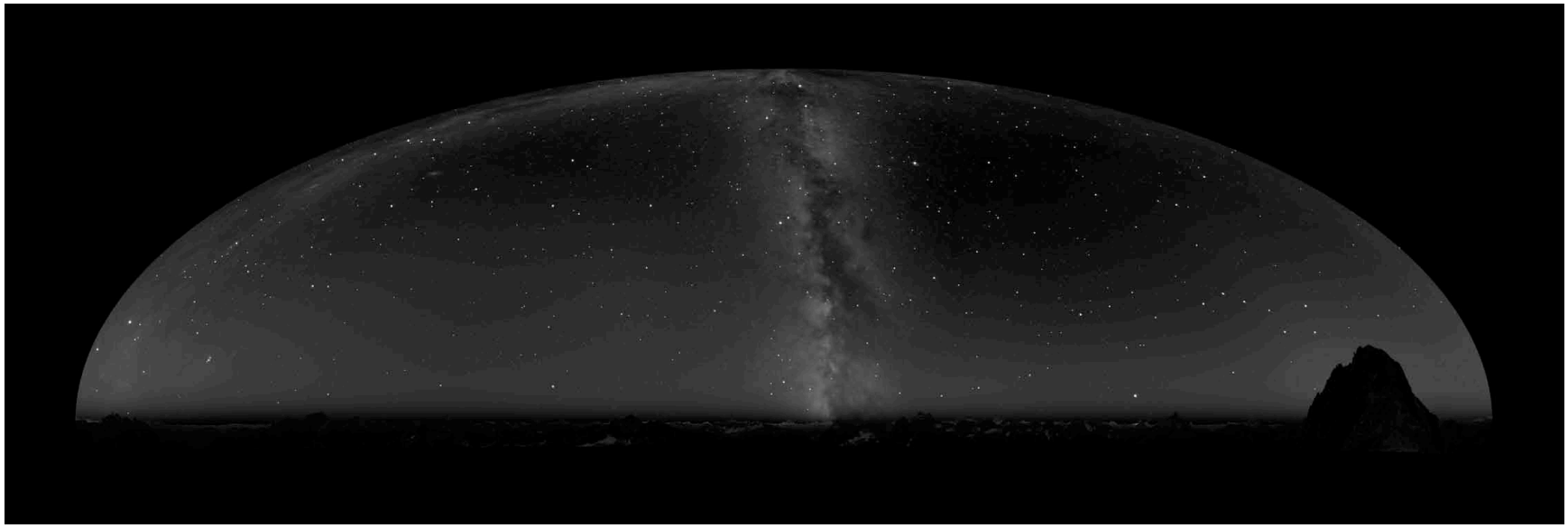


Figure 1a— Modeled simulation of a natural night sky (ALR=0) at North Cascades National Park.

Figure 1b— Actual data of a night sky with modest artificial light, depicting an ALR of approximately 0.33 at North Cascades National Park.

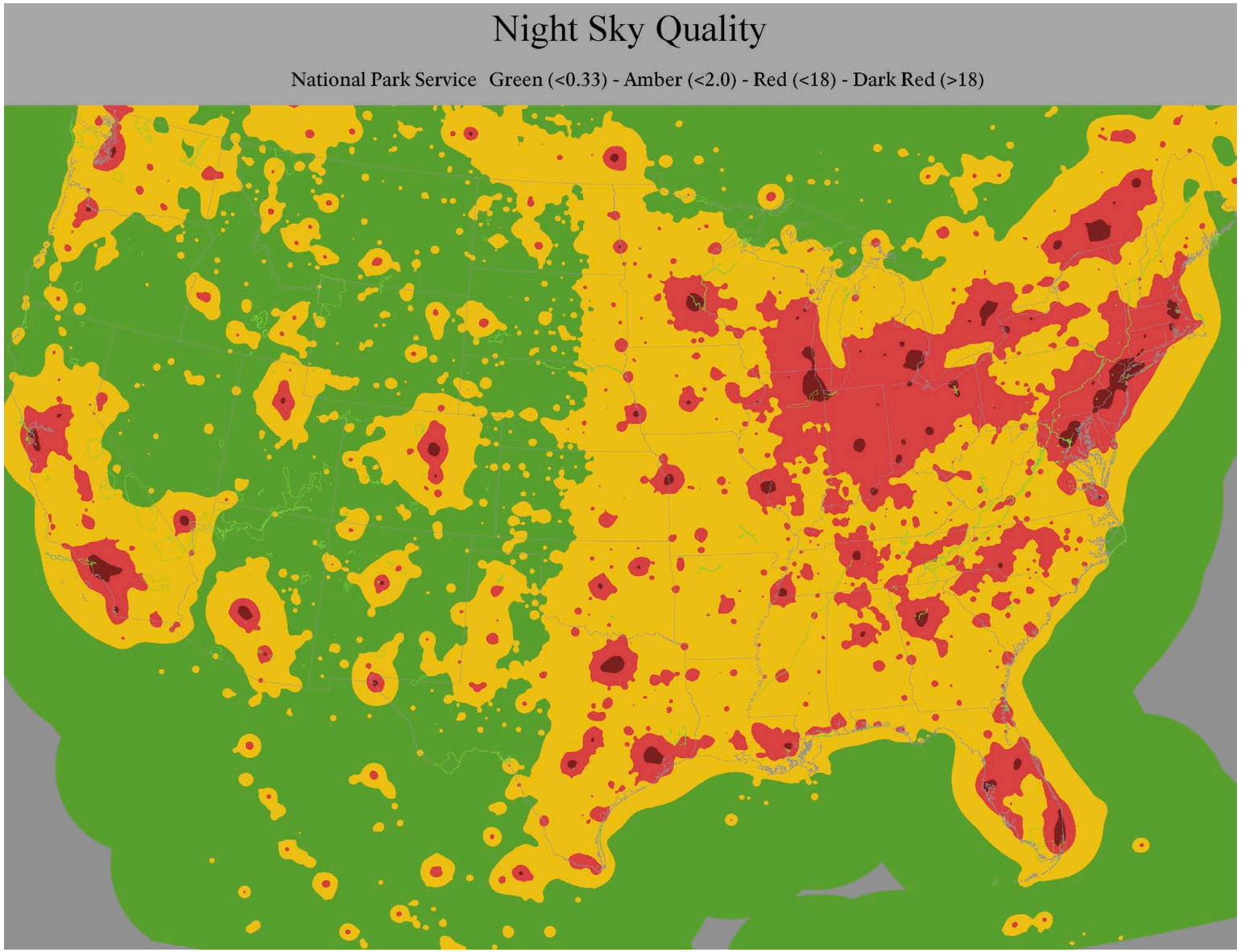


*Figure 2— Map depicting modeled data for the 48 states. For Level 1 parks the thresholds of 0.33 and 2.0 separate the green, amber and red colors. For Level 2 parks the thresholds of 2.0 and 18.0 separate the green **and** amber, the red, and the **dark** red.*

End Notes

[1] Longcore, T. and C. Rich. 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2(4): 191-198.

[2] Duriscoe, D. 2001. Preserving Pristine Night Skies in National Parks and the Wilderness Ethic. The George Wright Forum 18(4): 30-36

[3] Rodgers, J. and Sovick, J. 2001. The Ultimate Cultural Resource. The George Wright Forum 18(4): 25-29

[4] Duriscoe et al. in preparation. Indicators of Sky Quality Based Upon High Resolution All-Sky Measures.

[5] Duriscoe, Luginbuhl, and Moore 2007. Measuring Night-sky Brightness with a Wide-field CCD Camera. Publications of the Astronomical Society of the Pacific 119:192-213.

[6] Duriscoe et al. in preparation. Measuring Anthropogenic Sky Glow using a Model of the Brightness of the Natural Sky.

[7] Cinzano, P. Falchi, F. and Elvidge C. The First World Atlas of the Artificial Night Sky Brightness. Monthly Notices of the Royal Astronomical Society. 328: 689-707.

[8] Duriscoe et al. in preparation. All Sky Measures Applied to the First World Atlas of Artificial Sky Brightness.

[9] The Bortle Dark Sky Scale is a qualitative index that groups the visibility of various celestial and lightscape features into 9 classes. See http://www.skyandtelescope.com/resources/darksky/3304011.html

[10]Limiting magnitude is semi-quantitative visual estimate of sky brightness determined by the dimmest star one can see. It works on the principle that brighter skies mask out faint stars, but varies with the training and visual acuity of the observer and with air quality. Moore, C. 2001. Visual Estimation of Night Sky Brightness. The George Wright Forum 18(4): 46-55.

[11]The Bortle Dark Sky Scale is a qualitative index that groups the visibility of various celestial and lightscape features into nine classes. See http://www.skyandtelescope.com/resources/darksky/3304011.html

[12] The Sky Quality Index is an experimental 1-100 index being developed by the National Park Service that features units of equal aesthetic value.

Appendix Table— Conversion between ALR and other photometric units of average all-sky anthropogenic brightness

ALR	Nanolamberts (nL)	milliNits (mcd/m^2)	V Magnitudes	S10 units
0.00	0	0	—	0
0.33	26	.083	22.79	99
2.00	156	.500	20.84	596
18.0	1404	4.50	18.46	5361