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Visual Estimations of Night Sky Brightness

*We can no longer avoid the issue of light pollution, because soon we will have nowhere left to go. The global problem of light pollution has never been so artfully expressed as in Woodruff T. Sullivan's famous 'Earth at Night' satellite images.**

Kosai and Isobe 1992

Introduction

Managers of parks, preserves, refuges, and wilderness areas are becoming increasingly concerned over the loss in visibility of the night sky. Like the apocalyptic threat of Rachel Carson's *Silent Spring*, those who cherish the night skies fear a night of no stars, with only the fallow glow of streetlights for inspiration. Encroaching city lights scatter light upward, bathing the otherwise dark sky and reducing the contrast to a point where stars are lost in urban glow. The effect of urban lighting, also known as light pollution, can reach surprisingly far. For example, from Death Valley National Park the lights of Las Vegas produce an obvious and obtrusive glow even though the city is 100 miles to the southeast. Los Angeles, 160 miles to the southwest, produces a dim but broad glow across the southern horizon (Moore and Duriscoe, in prep.).

Astronomers at observatories were perhaps first to notice this problem. As early as 1970, astronomers were scouring the USA for suitable observing sites away from city lights; remaining opportunities were few (Walker 1970; Garstang 1989). Today, astronomical observatories employ multi-million-dollar equipment to measure sky brightness,

contrast, and atmospheric extinction. However, less costly tools are available to those interested in monitoring their dark sky resource. The simplest and least costly monitoring methods are visual estimations using the human eye.

Under a pristine dark sky, perhaps 14,000 stars in the celestial sphere would be discretely visible

*One of these images of the Earth at night is reproduced in color on the back outside cover. It depicts the widespread nature of the night sky issue. The degradation of the night sky by urban light sources extends far beyond what is detectable in this satellite image; large cities can scatter light well over a hundred miles in all directions.

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(Figure 1). Outdoor lighting tends to scatter light upward, brightening the background of space. This increase in sky brightness reduces the contrast between the background and fainter stars until they become invisible to the eye. Also lost with the stars are the diffuse objects in the sky—

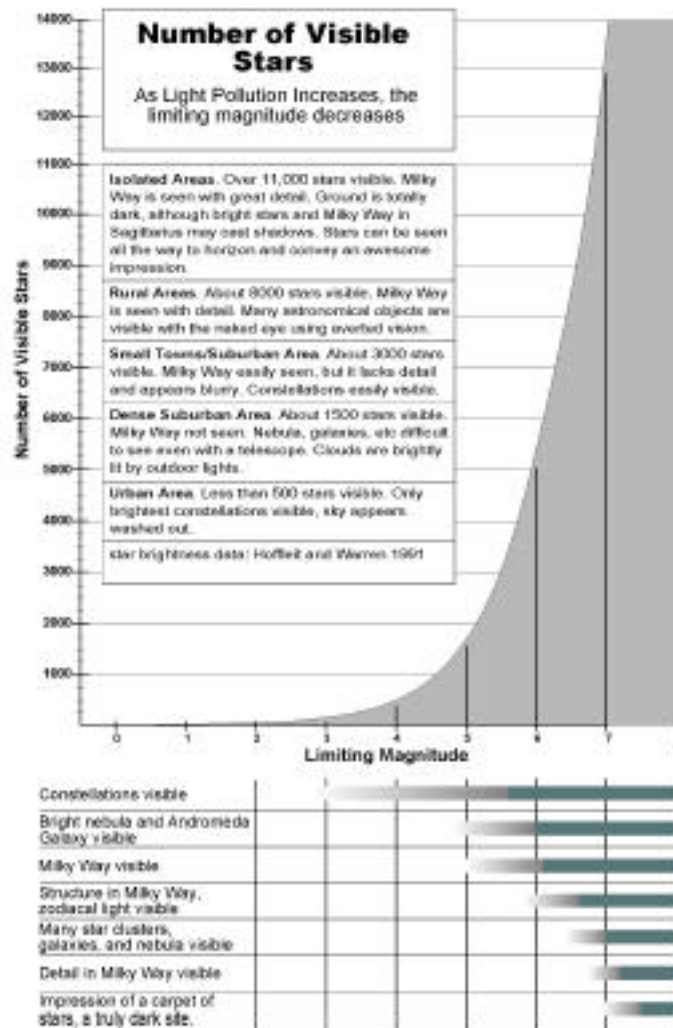


Figure 1. There is a sharp drop-off in number of visible stars as light pollution increases and the limiting magnitude decreases. Also lost is the impression of a primitive sky, and the attending astronomical objects that give it its splendor.

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nebulae, galaxies, comets, and the river of stars in our galaxy called the Milky Way. The visible loss of these faint and diffuse astronomical objects is what troubles amateur astronomers so much. This group has been the most vocal in opposing light pollution and promoting the conservation of dark night skies.

Amateur astronomers and meteor observers have made visual estimations of limiting magnitude for years. Limiting magnitude is a measure of the brightness of the faintest star one can see. The astronomical magnitude scale increases with faintness. Magnitude zero represents bright stars such as Vega, Antares, or Rigel, while magnitude 7 stars would be near the faint limit of most dark skies. In exceptional cases, magnitude 8 stars have been observed with the naked eye (Russell 1917; Bowen 1947). The number of visible stars, and the diversity of astronomical objects visible, decrease rapidly as the limiting magnitude falls. It is not uncommon for a remote area surrounded by rapid urbanization to lose more than half the visible stars in a decade (Moore and Duriscoe, in prep.).

The human eye is a somewhat imprecise instrument. Few people have 20/20 vision without aid of lenses, and the eye changes in light-gathering capability and acuity with age (Carr et al. 1989b). There is also potential for bias in the eye's central processing unit—the brain. How-

ever, what the eye lacks in precision, it makes up for in sensitivity and ease of use. The scopic (grayscale) vision we use at night is surprisingly sensitive, able to detect as few as 200 photons per second falling on the retina and transmitting a message to the brain (Russell 1917). The eye's rod cells are 1,000 times more sensitive than the color-detecting cone cells (Carr et al. 1989b). Scopic vision is most sensitive in the greens and blues, and least sensitive to the reds; thus the use of red-filtered flashlights to preserve night vision. The star magnitudes used in this method are measured in the "Johnson V" spectrum, which closely matches the human eye's scopic vision, and are therefore an appropriate analogue for brightness measurements.

Methodology

The visual estimation of limiting magnitude is based on star counts of 25 established sample areas (similar to methods utilized by meteor observers; Figure 2). Each area contains a field of mapped stars with known brightness values. The observer scans the field using averted vision, trying to detect sequentially fainter stars on the map. The faintest star observed becomes the sky's limiting magnitude (LM). By following the procedures for dark adaptation and counting, reasonable conformity can be attained between observers (Blackwell 1946).

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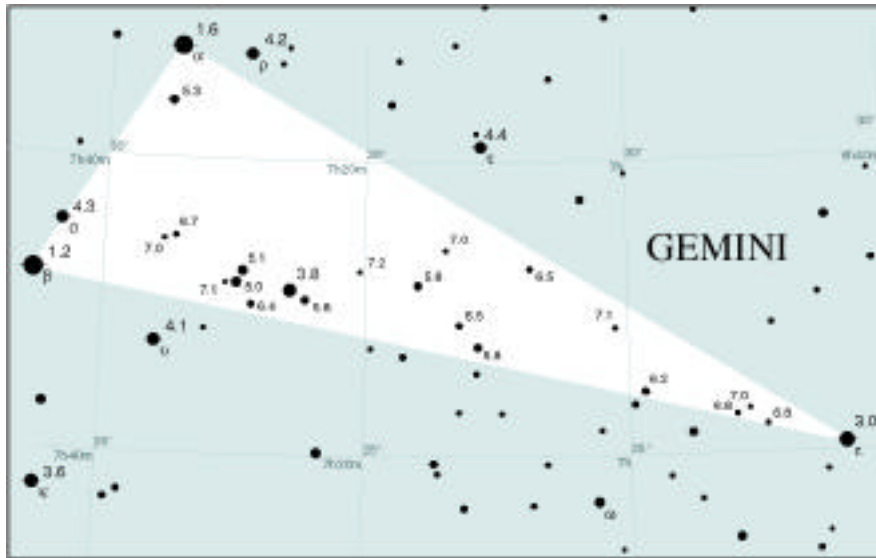


Figure 2. One of the 25 star count areas for determining limiting magnitude. This open triangle uses the familiar stars of Castor and Pollux (the Gemini Twin stars) for the short side. After proper dark adaptation, the observer takes 2-5 minutes to find the faintest visible stars, starting with the brighter ones and working fainter. The faintest visible star becomes the limiting magnitude.

Initially, this star count is conducted at the zenith (straight overhead). Counts can also be conducted in quadrants of the sky, and at various angular altitudes above the horizon. The process can take as little as 30 minutes to arrive at a zenith LM number. Observers have used this methodology to produce brightness maps of different parts of the night sky, or to take single measurements on multiple nights to capture the range of variation associated with weather, seasonal changes, or atmospheric scattering. Observations are conducted under cloudless, moonless nights. Even distant clouds or ground fog skew the results, ampli-

fying some light sources while suppressing others. The effect of local weather upon sky brightness is an interesting study in itself, but such conditions should be avoided to produce a baseline inventory to track long-term changes.

Other Factors

Affecting Limiting Magnitude

Light scattered upward is not the only factor affecting an LM measurement. Pollutants in the atmosphere can substantially increase the extinction of light as it is transmitted through the atmosphere. Airborne particulates, in the absence of light pollution, can substantially reduce

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the faintest stars visible, even though the sky background may appear very dark (Garstang 1991). In this case, the visibility of stars and astronomical objects are lost to light scattering and absorption, not due to decreased contrast. Air pollution compounds the scattering of light pollution, furthering the degradation of night sky visibility. Finally, both factors are affected by humidity in the atmosphere (Carr et al. 1989b). The growth and size of aerosol particles in the atmosphere is related to moisture. Therefore, higher humidities are expected to exacerbate both the scattering of existing light pollution as well as the absorption of starlight (Garstang 1991). Conditions of greater scattering tend to brighten nearby light sources while dimming far-off light sources (Carr et al. 1989b). The corollary to this phenomenon is that dry, high-altitude dark-sky sites are more susceptible to far-off light sources.

The lower atmosphere is turbulent, producing the common effect of twinkling stars. Turbulence scatters light and reduces the LM. Those precious few photons will be deflected away from a single retinal cell, and the eye will fail to detect a star, even though the night is dark and pollution-free (Bortle 2001). Therefore, LM estimations will integrate a measure of atmospheric stability, when perhaps we are less interested in its effects than that of scattered light or air pollution. Observers often

notice that the stars look sharpest and brightest in the late hours just before dawn. This trend is mostly due to atmospheric turbulence which settles and diminishes as the night progresses and the land cools. This trend may also be the result of reduced light pollution as people turn off their porch lights, park their cars, and outdoor athletic events come to a close.

Sources of Sky Glow

As with many natural resource measurements, much of the challenge can be separating the natural and human components. Natural sky brightness does exist; the human-made component of sky brightness is light pollution. Moonlight is the most obvious natural source, but can easily be avoided by sampling when the moon has set. Zodiacal light, the spike of illuminated dust particles circling the inner solar system, can be a significant natural light source. It is most obvious in spring and autumn, but will set a few hours after sunset and rise a few hours before dawn. Like the moon, zodiacal light is easily avoided and simply results in a shorter observing window at night (International Dark-Sky Association 2000).

Airglow is an important consideration at dark-sky locations. This results from the excitation of air molecules in the upper atmosphere that emit faint light. Airglow varies with solar activity, and tends to be

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highest during the solar maximum (which varies on an 11-year cycle; the most recent was in 2001). Lastly, galactic light and starlight can be a significant enough light source that they can affect both the eye's ability to see faint objects and the brightness of the sky itself. Star counts within the Milky Way are more difficult due to the glowing background of the galaxy (International Dark-Sky Association 2000). In extremely dark locations, the brightest portions of the Milky Way will create shadows and can spoil the eye's dark adaptation! However, for skies with LMs of 6.0 or lower, airglow, galactic light, and starlight are not a significant factor in total sky brightness.

The Bortle Dark-Sky Scale

Although LMs have long been used by serious amateur astronomers, John Bortle recently proposed a different, qualitative-based scale (Bortle 2001). Built on the idea of categorizing night skies (Schaaf 1994), this nine-step scale has proved immediately popular, and has a few advantages over the visual estimation of LM. Like the LM methods, only a beginning knowledge of the night sky is needed. The Bortle Dark-Sky Scale uses qualitative descriptors to differentiate one class of sky to another. For example, being able to see the Andromeda Galaxy with the naked eye is indicative of class 6 skies and better. His scale is based on 50 years of night sky observing, and unfortunately his best

class 1 skies are so rare now that few have ever seen them.

The Bortle scale definitions are included and cross-referenced with LMs (Figure 3). The Bortle scale is suitable for a wide range of conditions, from the brightest urban areas (LM lower than 4) to the darkest sites (LM up to 8)—an advantage over the LM star count method. The LM star count is best suited to magnitude ranges between 5.5 and 6.5, and is unusable with LMs above 7.2 or below 4.5. The Bortle Dark-Sky Scale also integrates factors in a way similar to our own aesthetic appreciation of the night sky. However, this method tends to produce one measure for an entire sky, as opposed to the LM star count method, which can produce multiple measurements for different points in the sky, allowing sky brightness to be associated with directions or specific cities. It is also less able to capture finer variations in sky brightness. Bortle (2001) contends that the degree of human bias and error in LM star counts exceed the resolution of the method. However, basic tests using LMs found adherence to the methods produced an acceptable variation from observer to observer that is less than the 0.5-magnitude steps of the Bortle scale (Moore and Duriscoe, in prep.).

Conclusions

Dark night skies are an important resource. Dark night skies are an air quality-related value, and as such are

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Bortle Dark-Sky Scale

	Milky Way	Astronomical Objects	Zodiacal Light/ Constellations	Airglow and Clouds	Night Time Scene	LM
Class 1	MW shows great detail, and Scorpio/Sagittarius region casts obvious shadow on ground	Pinewheel galaxy is an obvious object	Zodiacal light has obvious color, and can stretch across entire sky	Bluish airglow is visible near the horizon and clouds appear as dark blobs against stars	Jupiter and Venus annoy night vision, ground objects are barely lit, trees and hills are dark	7.6-8.0
Class 2	Summer MW shows great detail, and has a veined appearance	Pinewheel galaxy is not visible with direct vision, as are many globular clusters	Zodiacal light bright enough to cast weak shadows after dusk and has apparent color	Airglow may be weakly apparent, and clouds still appear as dark voids	Ground is mostly dark, but object projecting into the sky are discernible	7.1-7.5
Class 3	MW still appears complex, dark voids and bright patches and a meandering outline are visible	Brightest globular clusters are distinct, Pinewheel galaxy visible with averted vision	Zodiacal light is striking in Spring and Autumn, extending 60° above horizon	Airglow is not visible, and clouds are faintly illuminated except at zenith	Some light pollution evident along horizon, ground objects are vaguely apparent	6.6-7.0
Class 4	Only well above horizon does MW reveal any structure. Fine details are lost	Pinewheel galaxy is a difficult object, even with averted vision, Andromeda galaxy very visible	Zodiacal light is clearly evident, but extends less than 45° after dusk	Clouds are faintly illuminated except at zenith	Light pollution domes evident in several directions, sky is noticeably brighter than terrain	6.1-6.5
Class 5	MW appears washed out overhead, and is lost near the horizon	The oval of Andromeda galaxy is detectable, as is the glow in the Orion nebula	Only hints of zodiacal light in Spring and Autumn	Clouds are noticeable brighter than sky, even at the zenith	Light pollution domes are obvious to casual observers, ground objects are partly lit	5.6-6.0
Class 6	MW only apparent overhead, and appears broken as fainter parts are lost to sky glow	Andromeda galaxy detectable only as a faint smudge, Orion nebula is seldom glimpsed	Zodiacal light is not visible, Constellations are seen, and not lost against a starry sky	Clouds anywhere in the sky appear fairly bright as they reflect back light	Sky from horizon to 35° glows with grayish color, ground is well lit	5.1-5.5
Class 7	MW is totally invisible or nearly so	Andromeda galaxy and Beehive cluster are rarely glimpsed	Zodiacal light is not visible, and constellations are most easily seen	Clouds are brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color	4.6-5.0
Class 8	not visible	Pleiades are easily seen, but precious few other objects are visible	Zodiacal light not visible, and some dimmer constellations lack key stars	Clouds are brilliantly lit	Entire sky background has an orangish glow, and it is bright enough to read at night	4.0-4.5
Class 9	not visible	Only the Pleiades are visible to all but the most experienced observers	Only the brightest constellations are discernible	Clouds are brilliantly lit	Entire sky background has a bright glow, even at the zenith	<4.0

Figure 3. The Bortle Scale uses nine steps to rate the quality of the night sky. Using fairly common astronomical objects, and qualitative descriptors of the Milky Way, zodiacal light, and nighttime scene, a class can be established; some minor additions have been made by the author. Bortle's scale includes exceptionally dark skies that are increasingly rare today. His class 1 and 2 skies not only require the absence of light pollution, but also require atmospheric conditions low in air pollution, aerosols, and moisture. Because of this, the darkest skies are strongly weather-dependent. In the more humid eastern USA, such skies would be exceedingly rare today.

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provided ancillary protection under the 1977 Clean Air Act Amendments. They are an important component of wilderness areas in “retaining primeval character and influence,” as defined in the 1964 Wilderness Act. They are necessary to a growing list of wildlife species, and are increasingly sought after by park visitors as they lose the experience of a starry night at their homes in the city. Night skies also serve as a “vital sign”: an indication of the degree of encroachment of development, and of the level of cooperation between a protected area and surrounding communities.

The Bortle scale gives glimpses of the potential quality of night sky that is currently lost at most locations in the USA. Land managers whose responsibilities include significant night skies, but who have no measure of their quality, are at least 30 years behind. The value of a baseline condition, even if substantial resources have already been lost, cannot be overestimated. Visual estimations of night sky brightness are simple and repeatable. Because of their simplicity, they can “readily become the most extensive body of data” available on night skies (Kosai and Isobe 1992). They also allow a direct comparison from one area to another, whether that area is a few miles away or atop a distant mountain.

Visual estimations of night sky brightness are an easy and rapid tool for land managers to inventory the

quality of their dark sky resource. They are an effective first step in monitoring and ultimately protecting this threatened resource.

Epilogue

In early 2000, the National Park Service (NPS) funded a Night Sky Team. Using Natural Resource Preservation Program and Fee Demonstration funds, the team set out to standardize methods for measuring and monitoring night skies, and to employ these methods at several parks. Complete methods for visual estimations of LM are available from the Night Sky Team, and now include cross-references to the Bortle Dark-Sky Scale. Additional quantitative methods and computer models are being refined or developed, and will become the mainstay of the program’s efforts. In addition to standardizing methods, the Night Sky Team provides technical assistance for community outreach and visitor interpretation. The Night Sky Team is based out of Pinnacles National Monument and Sequoia and Kings Canyon National Parks, with support from the NPS Air Quality Division.

Several studies provide examples of good science and leadership in night sky management. In a program between amateur astronomers, the National Astronomical Observatory, and the Japan Environmental Agency, a map of sky brightness was developed for the entire country of Japan (Kosai and Isobe 1992). Com-

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binning star counts, photographs, and photometric observations, the study documented the location of the darkest areas as well as the change in sky brightness over time.

Bryce Canyon National Park examined the potential impact from a planned coal mine, as well as the human perception of light pollution (Carr et al. 1989a, 1989b). These two studies were pioneering in their use of computer modeling of light pollution. Additionally, they cross-referenced particular brightness values in the sky to what is commonly perceived by park visitors. The human perception of sky glow is an important component of night sky protection, since aesthetics and the wilderness experience are often cited as core values.

In another study by NPS, Organ Pipe Cactus National Monument conducted complete sky surveys with a stellar photometer (NPS 1995). Light pollution contributions from

near and distant cities were mapped and their exact brightness values determined. In 2001, these measurements were repeated, giving the park long-term monitoring data and the ability to detect small changes in night sky brightness over time (Casper 2001).

After only 18 months in operation, the Night Sky Team (composed of resource scientists with other full-time duties) is nearing standardization of methodologies and completion of a pilot study at four national parks. The task remaining is tremendous. At the time NPS was created, the night skies above our national treasures were unimpacted by light pollution. Today, only about 1% of parks are free from this problem. Many flagship parks in the National Park System have substantial degradation, but fewer than a dozen parks have any data whatsoever on the quality of their night skies.

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