Artificial Light at Night: State of the Science 2022

International Dark-Sky Association

This briefing summarizes the current state of knowledge about how the widespread and growing use of artificial light at night interacts with six key topics: the night sky (Section 1); wildlife and ecology (Section 2); human health (Section 3); public safety (Section 4); energy security and climate change (Section 5); and social justice (Section 6). It also includes a discussion of the emerging threat from light pollution caused by objects orbiting the Earth (Section 7). Finally, it concludes with a discussion of the knowledge gaps that exist within these topics and the research questions whose answers can fill the gaps (Section 8). It is intended be useful to those seeking to broaden their understanding of research on the causes and consequences of artificial light at night.

Introduction

Light pollution is surging in both its presence and reach across our planet (1, 2). It is the source of both known and suspected harm to the nighttime environment (3). Scientific studies suggest the over-use of artificial light at night (henceforth, 'ALAN') is the main source of light pollution (4, 5). The main challenge they identify is how to maximize the human benefits of ALAN while limiting its potentially negative social and environmental impacts (6–8).

1 The Night Sky

Light emitted into the night sky makes it difficult to see the stars. On the ground, ALAN makes the nighttime environment brighter. Weather changes like clouds and snow on the ground can make this impact worse. New and inexpensive light sources like white light-emitting diodes (LEDs) have a growing impact on both the night sky and outdoor spaces at night.

The most immediate symptom of light pollution is the phenomenon of "skyglow". It brightens the night sky in and near cities where large installations of outdoor lighting exist. The lower layers of the Earth's atmosphere scatter light emitted near the ground. Some of that light escapes the atmosphere where Earth-orbiting satellites detect it, but many light rays encounter molecules and small particles in the atmosphere. These interactions redirect the paths of some of the light rays back down to the ground. Observers there see light appearing to come from the night sky itself; see Figure 1. Skyglow competes with the faint light of astronomical objects in the night sky. It lowers the contrast between those objects and the background sky, making it difficult to observe them.

A slow but steady rise in skyglow in much of the world leads to gradually degraded visibility of the natural night sky and a transformation of lighted outdoor spaces. Such a situation, changing slowly over decades, may go unnoticed due to a psychological effect know as a "shifting baseline" (9). This applies to various aspects of artificial light on a 'normal' night: the number of visible stars, the amount of artificial light associated with perceptions of safety, and the experience of using non-visual senses such as hearing and balance at night. Along with other effects, the loss of the night sky is barely noticed.

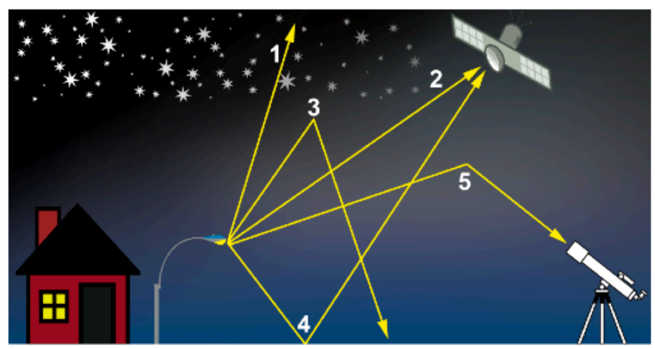

Figure 1. The streetlight at left emits light in many different directions. Some of the light rays (1) travel upward into the sky and pass completely through Earth's atmosphere. Satellites detect some of these rays (2) as they pass over the nighttime side of our planet. In other cases (3), the atmosphere scatters rays back to the ground. This light becomes the familiar "skyglow" seen over cities. Some of the rays traveling downward (4) reflect off the ground into the sky where they are seen by satellites. Lastly, some rays scatter into astronomers' telescopes (5), blocking their view of the universe. Credit: IDA.

Remote sensing of light pollution

"Remote sensing" is a method of measuring the properties of something at a distance without directly sampling it. It is often applied to observations of our planet made by orbiting satellites. When those satellites look at light on the night side of Earth they provide a view of the global scale of the problem of light pollution (1, 10, 11).

Figure 2 shows a global map of night lights made with remote sensing observations (12). This is a composite image composed of observations of Earth made over many nights in one year. It gives the appearance of our planet as if it were simultaneously night everywhere at once. It also ensures that the result does not include clouds or light from the aurora near the Earth's poles.

The camera used to make this map uses a sensitive detector that records faint light in the visible spectrum. It can resolve features on Earth smaller than one kilometer in size. This is smaller than the size of most cities, so the images give detailed information about the number and characteristics of various light sources on the ground. Images like these dating from as early as the 1970s are available to the public and for scientific study.

In recent years, researchers have learned much about the spread of light pollution across the globe by studying remote sensing data. They found that skyglow fouls the night sky for more than 80% of all people and more than 99% of the U.S. and European populations (10).

Both the amount of artificial light seen on Earth at night and the land area that light covers grow by about two percent each year on average.(Figure 3) (1). Yet, both numbers vary across our planet (13). There are only a few countries in which they seem to be either stable or decreasing (1, 14).

Satellite remote sensing used to make studies like these is not perfect. For example, the best available satellite cameras are not sensitive to some colors of light. In particular, they do not see the blue light emitted by white LED lighting. This means that key light pollution indicators are probably underestimated. Combining satellite data with ground-based observations can improve the reliability of results (15), but the need for new, dedicated orbital facilities to address important research questions is urgent (16, 17). This is especially true given that some Earth-observing satellite missions, such as NASA's Terra, are slated to end in coming years.

Environmental conditions change night sky quality

Cloudy conditions tend to make skyglow more intense in urban and suburban areas because overcast nights can increase the intensity of light reflected back down to ground level by up to ten times (18, 19). However in rural areas with few light sources, cloud cover tends to *darken* the night sky (20). This is because clouds efficiently absorb and scatter light from both natural and artificial sources, decreasing the amount reaching the ground. Skyglow is also sensitive to very small particles in the air (21), and it can be increased by air pollution (22).

Ice and snow make skyglow worse because they reflect much more light than darker ground covers. This enhances the apparent nighttime artificial light emissions from cities (23). Snow cover on the ground under clear-sky conditions can increase night sky brightness by up to three times (24). When clouds cover the sky in the winter months, light reflected from both snow and clouds amplifies skyglow. The result can raise the night sky brightness by over 3,500 times compared to overcast conditions with no artificial light (25). Even in clear weather, the tendency of ground covers like asphalt and concrete to reflect light can raise night sky brightness (26, 27).

The rise of solid-state lighting may threaten dark skies

Global light pollution has increased in recent years in part because of the introduction of solid-state lighting (SSL). This kind of lighting uses semiconductor materials to generate light. It differs from earlier technologies that used electric currents in tubes of gases like sodium vapor. Those earlier methods of making light once dominated the global outdoor lighting market.

The most familiar kind of SSL technology is the white LED. This technology now accounts for almost 50% of global lighting sales (28). The lighting market's explosive growth in recent years is due in part to the exceptional energy efficiency of SSL, which is up to ten times higher than earlier technologies like incandescent filament lamps. While one-for-one SSL replacements save energy compared to earlier technologies (with beneficial impacts; see Section 5), the energy efficiency and low cost of SSL can encourage overlighting (with negative impacts; see Sections 2, 3, and 5). In order achieve the full promise of SSL, factors such as the spectrum and distribution of the light source should be carefully designed.

The rapid rush to adopt and install SSL has changed the color of artificial light emitted into the nighttime environment (29, 30). White LED lighting generally emits much more short-wavelength (i.e., blue) light than other technologies. This causes a shift in the color of cities as they transition to SSL (31). It may also make skyglow over cities worse even when the number of lumens – that is, the *amount* of light to which the human eye is sensitive – used is the same (32–34). This may extend the impact of city lights much farther into adjacent, ecologically sensitive areas (35, 36). It also specifically threatens the productivity of ground-based astronomical observatories (37), which rely on sites with dark night skies in order to produce new knowledge about our universe. However, the characteristics of LED lighting can enable its more efficient use, often requiring less light for the same applications than previous technologies (38). When cities plan LED retrofits carefully, they can hold light pollution steady or even reduce it (39–41).

Dark-sky conservation and astrotourism

Meanwhile, the ongoing conversion of world outdoor lighting to SSL, and its potential to increase skyglow, may work against dark-sky landscape conservation goals. Public interest in visiting naturally dark places is increasing (42). This has created a new kind of "astrotourism" (43, 44) with significant revenue-generating potential (45). This may in turn encourage lighting practices and public policies that protect night skies, yet it calls into question what defines a "dark sky" (46) and how it should be quantified (47, 48). It also requires understanding how to measure or describe nighttime darkness to best preserve it (49, 50). Limited evidence suggests that efforts that recognize the value of dark skies and support their conservation may have positive benefits in re-