The world at night

Preserving natural darkness for heritage conservation and night sky appreciation

David Welch, Robert Dick, Karen Treviño, Travis Longcore, Catherine Rich, John Hearnshaw, Clive Ruggles, Adam Dalton, John Barentine and István Gyarmathy

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IUCN PROTECTED AREA DEFINITION, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES

IUCN defines a protected area as:
A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The definition is expanded by six management categories (one with a sub-division), summarized below.

Ia Strict nature reserve: Strictly protected for biodiversity and also possibly geological /geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
Ib Wilderness area: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
II National park: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III Natural monument or feature: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/species management area: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
V Protected landscape or seascape: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected areas with sustainable use of natural resources: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75 per cent rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types.
Type A. Governance by government: Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).
Type B. Shared governance: Trans-boundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).
Type C. Private governance: Conserved areas established and run by individual landowners; non-profit organizations (e.g. NGOs, universities) and for-profit organizations (e.g. corporate landowners).
Type D. Governance by Indigenous peoples and local communities: Indigenous peoples' conserved areas and territories – established and run by Indigenous peoples; community conserved areas – established and run by local communities.

For more information on the IUCN definition, categories and governance types see Dudley (2008). Guidelines for applying protected area management categories, which can be downloaded at: www.iucn.org/pa_categories

For more on governance types, see Borrini-Feyerabend, et al., (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/node/29138

The world at night

International Union for Conservation of Nature

IUCN helps the world find pragmatic solutions to our most pressing environment and development challenges. IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, non-governmental organizations, the United Nations and companies together to develop policy, laws and best practice. IUCN is the world's oldest and largest global environmental organization, with more than 1,400 Members from government and non-governmental organizations and more than 15,000 volunteer experts volunteer experts. IUCN's work is supported by around 950 staff in more than 50 countries and hundreds of partners in public, non-governmental organizations and private sectors around the world.

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IUCN's World Commission on Protected Areas (WCPA) is the world's premier network of protected and conserved areas expertise. The Commission has over 2,500 members spanning 140 countries who provide strategic advice to policymakers and work to strengthen capacity and investment for protected areas establishment and management. The Technical Reports series is one of the Commission's flagship products, providing timely guidance on aspects of protected area planning, management and assessment.

iucn.org/wcpa

IUCN WCPA Urban Conservation Strategies Specialist Group

The Specialist Group works to strengthen the ability of the protected areas community to serve urban people, urban places and urban institutions. Protected and conserved natural areas are a central theme. Since most political support for conservation comes from urban places, this has to do with protecting remote wilderness as well as nature in and around cities. The group has also gone in unexpected directions, including protecting nature from artificial light; promoting long-distance trails as conservation tools connecting urban, rural and wild; encouraging cooperation between protected areas and museums (Natural Neighbors); and looking for places in and around protected areas whose stories will inspire people to act for greater justice and sustainability (Points of Inspiration).

theurbanimperative.org

Dark Skies Advisory Group

Established in 2009, the Group provides advice and guidance to IUCN, other bodies and individuals in regard to light pollution and dark sky values, in particular as they relate to ecological and commemorative integrity, visitor appreciation and public understanding of protected areas, and to the long term maintenance of dark sky values for future generations. In connection with IUCN's role as an Advisory Body to the World Heritage Convention, the Group also provides advice in regard to World Heritage studies that address or touch upon dark skies and light pollution. The group consists of members of the Urban Conservation Strategies Specialist Group which in turn reports to the WCPA. All authors of this report are members of the Dark Skies Advisory Group.

darkskyparks.org/dsag

InterEnvironment Institute

Based in California, the Institute is an independent public policy centre affiliated with Claremont Graduate University. Since its founding in 1969, it has specialised in making connections that otherwise would be unlikely to happen. Internationally, it has done this by: convening and promoting high-level policy dialogues; producing resource guides that 'map' organizations; and defining the concept of sustainability, which cuts across political, social, cultural, economic and ecological concerns. Thus, the 'Inter' in InterEnvironment stands for interconnections, as well as international. Much of the Institute's work is done with or through IUCN, of which it has been a member since 1980. It provides the secretariat for the IUCN WCPA Urban Conservation Strategies Specialist Group, which in turn includes the Dark Skies Advisory Group.

InterEnvironment.org

United States National Park Service, Natural Sounds and Night Skies Division

The Division works to protect, maintain and restore acoustical and dark night sky environments throughout the National Park System. It uses science, engineering and technology to understand and better manage these spectacular resources. It pioneers innovative techniques to measure the impact of noise and light pollution, develops new approaches to safeguard natural sounds and natural darkness, and identifies management solutions to restore these public resources. The Division works in partnership with parks and others to increase scientific understanding and inspire public appreciation of the value and character of soundscapes and star-filled skies.

nps.gov/orgs/1050/

DarkSky (formerly International Dark-Sky Association)

Note: The International Dark-Sky Association changed its name to DarkSky on June 1, 2023. The many references to IDA in this publication are to DarkSky.

DarkSky is dedicated to protecting the night from light pollution. It provides leadership and resources to promote responsible outdoor lighting and to reduce light pollution. Outdoor lighting can be beautiful, healthy and functional, but when used indiscriminately, it can come at a cost. Outdoor lighting can disrupt wildlife, impact human health, waste money and energy, contribute to climate change and block our view of the universe. With light pollution growing at 2% per year, the issue has never been more urgent.

darksky.org

Royal Astronomical Society of Canada

The RASC is Canada's leading astronomy organization, bringing together over 5,000 enthusiastic amateurs, educators and professionals. Its mission is to enhance the understanding of and to inspire curiosity about the Universe. It does this through public outreach, education and support for astronomical research. It acquires and maintains equipment, libraries and other property necessary for the pursuit of these aims. It publishes journals, books and other material containing information on the progress of astronomy. It receives and administers gifts, donations and bequests from members of the Society and others. It contributes and renders assistance to individuals and institutions engaged in the study and advancement of astronomy. One of its programmes is aimed at light pollution abatement, in particular through the certification of dark sky places across Canada. The RASC also promotes the use of lighting with low ecological impact through its Guidelines for Outdoor Lighting.

rasc.ca/lpa

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There are two kinds of light – the glow that illuminates, and the glare that obscures.
— James Thurber, Lanterns and Lances, 1961

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Foreword

When an earthquake struck at night in Los Angeles in 1994, people woke to find that electricity had gone out across the city. With no street lights on it had become very dark, revealing a previously invisible sky full of stars and planets. It was the Milky Way, and till then many people had never witnessed it. Artificial light at night from towns and cities reflects from atmospheric particles, even moisture, and creates skyglow, a haze of light that prevents us from seeing most stars and the seven galaxies visible to the naked eye. An estimated 60% of Europeans and 80% of Americans have never seen the Milky Way, even on a cloudless night.

Sea turtles lay and bury their eggs on beaches after dark, relying on cooler night temperatures to prevent overheating. After a couple of months, the hatchlings emerge to find their way to the sea. Under natural conditions they move away from the dark landward horizon to orient themselves to the water's edge. However, street and building lights along the shore can disorient them. Wrong turns can be perilous as they use up their limited energy to make it to water.

Birds are seriously affected by light pollution. They may suffer navigation problems from night lights during migration and become disoriented, tending to fly toward bright lights. The death-toll from collisions with lights or brightly lit windows and buildings has generated public concern over the accumulation of dead birds at the base of brightly lit towers. Their feeding habits, particularly of those that eat flying insects, can suffer from the effects of light pollution on their own behaviour as well as that of the insects upon which they feed. Insects suffer disorientation and death from attraction to artificial lights. Their numbers also decrease as they congregate under bright lights and become easy prey for insect-eating birds. Insects also suffer losses due to the interruption of their normal breeding habits by light pollution.

In what is now New Zealand, the Maori people consider astronomical knowledge to be a special treasure, important for many aspects of society, from spiritual practices to the growing of crops, fishing and navigation, telling the time and changes in season. Mataraki, also known as the Pleiades, is a star cluster that appears during mid-winter, marking the start of a new year. Spiritual leaders would look to Mataraki to foretell the next season's weather. The visibility of many stars promised a warm, successful crop season. Few visible stars foretold of cold weather and poor crops. Mataraki is still celebrated throughout New Zealand, with festivities highlighting the Maori world view, the cycle of life and the remembrance of ancestors. A revival of traditional skills guided by the night sky is evident today. The government is funding Te Mauria Whiritoi, The Sky as a Cultural Resource, a project that looks at Maori beliefs, practices and observations in relation to astronomy, ecology and ritual (Wilson, 2018, p. 7).These stories illustrate some of the many reasons why society should be aware of the value of an unpolluted night sky. Smog has long been recognised as a risk to human health and to the daytime enjoyment of landscapes and vistas, but light pollution also poses many impacts on species, ecosystems and humans. It threatens ecological and commemorative integrity, interferes with amateur and research astronomy, degrades the appreciation of mythologies and cultural practices related to the night sky, mars wilderness experience and landscape beauty, carries risks to human health, and wastes energy. Glare from over-bright light reduces visibility at night and can mask hazards. Most area lighting puts outdoor property on display, attracting vandals and thieves. Therefore, counterintuitively, excess outdoor lighting can actually reduce safety and security.

The International Dark-Sky Association was established in 1988. It promotes a model bylaw, offers specifications for night sky friendly outdoor light fixtures, and operates a programme to certify dark sky places. These are natural areas and communities that are managed to reduce light pollution and promote night sky protection for astronomy, ecology and public appreciation. In the 1990s astronomers and night sky enthusiasts became increasingly concerned about the loss of the night due to light pollution that they started more initiatives to combat this threat. This is when the Royal Astronomical Society of Canada began its Light Pollution Abatement and Dark Sky Preserves programmes, the world's first such programmes to recognise places that work proactively to remove light pollution that reduces the enjoyment of the night sky. Parks Canada and the United States National Park Service were early adopters of these principles, and still lead the way in protected dark skies within the worldwide protected area community.

Since 2007 the Fundación Starlight has worked with UNESCO and the International Astronomical Union to incorporate the heritage of natural night skies into the Outstanding Universal Values framework of World Heritage Sites. Fundación Starlight also promotes the protection of the world's leading astronomical observatory sites and recognises dark sky places that provide high-level opportunities for night sky enjoyment by tourists.

In 2009 the World Commission on Protected Areas suggested to its Urban Conservation Strategies Specialist Group that it work to bring night sky values and protection methods to protected areas and nature conservation throughout the world. The Dark Skies Advisory Group was formed to give guidance in this regard, and to advise astronomy groups about collaborating with protected areas, for both ecosystem protection and visitor engagement.

This report has been developed with those goals in mind. Intended mainly for conservation managers and other interested parties, it summarises the impacts of light pollution and the resources available to help combat it. It includes overviews of preferred outdoor lighting methods, and points to fully detailed resources available on the Internet that can guide the implementation of light pollution solutions. It offers ideas for public engagement and community outreach, and illustrates all of the above through case studies of dark sky places.

As more of the world urbanises and as more communities gain access to electrical grids, there is an ever-growing amount of light pollution on Earth. This trend is exacerbated by the onset of ultra-efficient LED lighting. While more energy efficient than former bulb types, it makes it easy to provide far more light than is needed, especially in the more impacting blue part of the spectrum. We hope that this report will encourage environmental managers to be aware of and to help abate light pollution. We also hope that it will help concerned citizens to spread the word about light pollution and for everyone to be able to enjoy a rapidly diminishing resource, the natural night sky.

Madhu Rao,
Chair, IUCN World Commission on Protected Areas

Debra Elmegreen,
President, International Astronomical Union

Preface

This report is organised into seven chapters and nine appendices.

Chapter 1 explains light pollution and its extent across the globe. It summarises the ecological and social impacts of artificial light at night, thereby providing reasons to reduce light pollution. It also shows how it interferes with the human enjoyment of the night sky, degrades the value of the night sky for traditional cultures and practices, and, of course, how it threatens the quality of observatory sites for scientific astronomy.

Chapter 2 lays out a six-class system for dark sky places designed to aid in overviews and comparisons. It follows a similar approach to that of the IUCN protected area class system, and with a similar purpose, which is to provide a standard classification in the face of a variety of naming systems and purposes around the world.

Chapter 3 uses this dark sky place classification to organise examples of real-world experiences in abating light pollution and bringing night sky appreciation to the public. The cases reflect as wide a geographic coverage as was possible at the time of writing.

Chapter 4 summerises the lessons learnt from the case studies. These will point the way to developing good practice guidelines to combat light pollution.

Chapter 5 offers dark sky guidelines for conservation managers to follow, be they in urban, natural or heritage areas.

Chapter 6 covers options for public engagement, for example through park interpretation, school and public education, community outreach and the media.

Chapter 7 discusses laws and policies that jurisdictions may consider to reduce light pollution. These include national, regional and municipal laws and bylaws. Several models are summarised.

Chapter 8 presents concluding remarks.

Nine appendices follow, including light pollution scales and measurement devices, recommendations for spectrum and illumination levels, examples of appropriate light fixtures and relevant IUCN Resoulutions and Recommendations.

This report reflects the latest science of light pollution and its management at the time of publication. However, progress continues in understanding light pollution, especially in respect of species and ecosystem impacts, at least for terrestrial systems. In marine and freshwater systems there is relatively little knowledge of light pollution impacts, and very few examples of best management practices. Lighting technologies are also advancing rapidly, sometimes for the better, sometimes for the worse such as white LED lights making light pollution cheaper. Hence the technical guidelines presented here may need updating in the future.

This report is the work of ten members of the IUCN Dark Skies Advisory Group, representing a wide range of skills and interests. They drew upon their expertise, the resources of the organizations they represent, and the printed and online literature. Readers wishing to go further with the abatement of light pollution and with bringing a valuable visitor experience to protected areas should seek out the on-line resources and citations offered in this report. They should also engage with their local astronomy societies or nearest astronomy research organization. You may email the Dark Skies Advisory Group at dsag.wcpa.iucn@gmail.com

Executive summary

Light pollution impacts

Light pollution is the human-caused alteration of outdoor light levels from those occurring naturally. It threatens ecological and commemorative integrity, interferes with amateur and research astronomy, degrades the appreciation of mythologies and cultural practices related to the night sky, mars wilderness experience and landscape beauty, carries risks to human health and wastes energy. Counterintuitively, excess outdoor lighting reduces safety and security. Artificial light at night reflects from atmospheric particles, even moisture, and creates skyglow, a haze of light that prevents seeing most of the stars and galaxies otherwise visible to the naked eye. Among its many ecological impacts, light pollution interferes with sea turtle hatching, navigation by migratory birds and the predator-prey dynamics of many terrestrial and aerial species. The death toll of birds from collisions with lights or the brightly lit windows of buildings affects bird migrations and is raising public concern. Insects suffer disorientation and death from attraction to artificial lights. They also congregate under bright lights and become easy prey for insect-eating birds. Light pollution weakens our connections with nature.

Many traditional societies incorporate features and rhythms of the night sky into their culture and seasonal practices. For example, New Zealand Maori consider astronomical knowledge to be a special treasure important for many aspects of society, from spiritual practices to the growing of crops, fishing and navigation, telling the time and changes in season. Even in contemporary times around the world, the cycles of the Moon, planets, meteor showers and other celestial phenomena form a major part of social customs and story-telling. The structures of many archaeological sites reflect this importance going back millennia.

Dark sky place programmes and the DSAG Class System

In response to these many threats, not just to astronomy, the International Dark-Sky Association, the Royal Astronomical Society of Canada and Fundación Starlight have operated programmes to certify places that have effective protections against light pollution, impact monitoring, public education and lighting management strategies. There are also several other initiatives outside these three leading programmes that have awarded dark sky status to protected areas. The lessons learnt presented in this report are drawn from case studies of dark sky places certified by the IDA, RASC, Fundación Starlight and other organizations.

These programmes use a variety of naming styles, such as dark sky parks versus dark sky preserves versus starry sky parks for essentially the same kind of place, or such as urban star parks versus urban night sky places, some of which may be up to 50 km from an urban boundary. To be able to draw valid comparisons and to facilitate a worldwide overview, DSAG developed a classification system which mirrors the protected area classification system of IUCN.

1. **Starlight Reserve:** Research grade astronomical observatory site and surrounding protected area
2. **Dark Sky Park:** Protected natural area
   2a. Park, reserve, habitat, natural area or other ecological protection
   2b. Unpopulated area set aside for traditional or sacred practices related to the sky
   2c. Rural area, area of outstanding landscape beauty
3. **Dark Sky Heritage Site:** Protected astroarchaeological heritage work of mankind
4. **Dark Sky Outreach Site:** A site managed for public night sky viewing
   4a. Urban or suburban site
   4b. Rural site
5. **Dark Sky Reserve:** A core of a protected area surrounded by a mix of cooperating community, rural and natural area jurisdictions, similar in concept to a UNESCO biosphere reserve
6. **Dark Sky Community:** City, town, village or populated rural area
   6a. City, town or village
   6b. Populated rural area without a formal protected area

About half of the world's dark sky places are in class 2, and most of the remainder in classes 4, 5 and 6. Over half are in North America and most of the remainder in Europe, a reflection of the greater financial and knowledge resources that developed nations can apply to light pollution abatement. Fortunately, the number of dark sky places elsewhere is growing steadily, so this geographic distribution is likely to evolve.

Case studies

The dark sky place case studies are chosen to represent: all DSAG classes; each of the three main dark sky place certification systems; and, to the extent possible at the time of writing, a global coverage. These places are in Africa, Australasia, East Asia, Europe, the Middle East and North and South America. Their specific lighting situations are not described, since all substantially meet the outdoor lighting guidelines set out below, allowing for some to have received provisional certification pending completion of an agreed lighting retrofit plan. What is included is the DSAG class and IUCN protected area category where identified, the agency and date of certification, a description of the place, its principal achievements in obtaining and delivering dark sky protection, night sky activities within the place, outreach to other communities and groups, and highlights of lessons learnt.

Lessons learnt

The case studies and related recommendations are central to this report. For convenience of reading they are grouped under several headings but, of course, there is some degree of overlap. Here are examples from the main text:

Astrotourism

- Present a broad range of night sky programming for visitors.
- Host public astronomy events open to the general public, not just protected area visitors.
- Use park and partner visitor centres as venues for night sky programmes.
- Monitor and publish the economic benefits of being a dark sky place.
- Provide night sky viewing facilities such as telescope mounting pads and unlit parking lots.
- Allow reasonably frequent public access at night to selected night sky viewing locations.
- Actively promote astrotourism, including giving public access to available telescopes.

Cooperation and outreach

- Seek IDA, RASC, Fundación Starlight or other arms-length certification.
- Link to other levels of government to find optimal lighting solutions.
- Reach out to local suppliers to encourage them to stock or catalogue dark sky compliant hardware.
- Work with businesses to provide a wide range of visitor opportunities.
- Partner with astronomy organizations and their volunteers to help deliver programmes.
- Reach out to local stakeholders and communities to promote night sky compliant lighting and appreciation of naturally dark night skies.
- Take astronomy programmes to local schools and communities.

Ecological connections

- Conduct a mix of site-specific and species-specific research and monitoring coupled with tracking of the broader literature on ecological impacts.
- Recognise the need for light pollution abatement to protect vulnerable species.
- Monitor night sky conditions to track progress toward achieving natural dark skies and to provide early warning of emerging threats.
- Promote research on the ecology of the dark sky place. Research centres and local universities can involve students in studying the effects of artificial light. For a protected area it would help to raise expertise related to its species and ecosystems.

Cultural connections

- Document the local and regional heritage related to the night sky.
- Maintain dark skies as part of protecting cultural heritage.
- Bring traditional cultural knowledge to the forefront of the visitor experience.
- Have management policies and practices in place to protect or restore natural darkness.
- Implement the Guidelines for Outdoor Lighting in protected areas and communities.

Governance

- Adopt a biosphere reserve model to preserve nature, the night sky and public access.
- Work with non-profit partners for funding and volunteer support.
- Learn from other dark sky places with similar situations to develop practical solutions and activities.

- Adopt dark sky compliant guidelines for outdoor lighting.
- Provide regular updates to staff, stakeholders and the public on progress toward protecting night skies and night ecology. This is particularly important to help understand delays and to ensure that staff are fully aware of their obligations.
- Ensure that visitor facilities strictly observe dark sky protection standards.

Guidelines for outdoor lighting

Nature-friendly outdoor lighting follows these principles:

- Use light only if it is needed. Consider how the use of light will impact the area, including wildlife interactions and habitats. Rather than permanent lights, use reflective paint or self- luminous markers for signs, curbs and steps. Outdoor lighting should not be used for aesthetic purposes.
- Use the least amount of light needed. The amount of light should be appropriate for the activity taking place. Be aware of surface conditions as some surfaces reflect a lot of light into the sky.
- Minimise blue and violet spectral components. Use lights with a colour temperature less than 2700K, preferably less than 2200K. This aids night vision by all animals, including people. Colour temperature is that of an ideal black body that radiates light of a colour comparable to the actual light source.
- Direct light so that it only falls where it is needed. Use shielding so that the light beam does not spill beyond where it is needed and minimises the contaminated area. Do not use lights that project any light directly into the sky. Rather, restrict beams to downward cones to reduce glare and skyglow. This improves the ability of drivers and pedestrians to see into shadows.
- Use light only when needed. Active controls such as timers or motion detectors help ensure that light is available only when needed. Examples include curfews for arena lighting, and motion sensing and dimming for pedestrian areas.
- Encourage neighbours to reduce their light pollution, particularly glare and light trespass into your domain.
- Use energy efficient lights, provided that they do not conflict with the other principles.

Outdoor lighting specifications are suggested for various situations typical of protected natural areas. These include park buildings, vending machines, washrooms, paths, roads, shorelines, signs, navigation towers and community enclaves. Specifications are also offered for other built situations such as historic sites, commercial zones, residential areas, billboards and roads. In general, artificial light at night should be avoided or reduced to the minimum required for public safety and to meet regional and national regulations.

Guidelines for visitor engagement and outreach

Some protected areas, like Montsec in Spain and Mont Mégantic in Canada, have elaborate visitor centres for the appreciation of the night sky. They include multi-media theatres, public telescopes and displays. Even without such facilities, however, there are many opportunities to bring the night sky and the ecology of the night to the attention and enjoyment of visitors. While most people go to see the natural and cultural values of a site, many also welcome the chance to learn about the night half of our world, the Earth's place in space, and the role of the night sky in traditional cultures and history.

A night sky event can be as simple as a host and visitors meeting after dark at a place shielded from glare, and having common stars and constellations pointed out. More elaborate versions of this are often called star parties, at which local astronomy enthusiasts volunteer their time and equipment to introduce people to star clusters, meteor showers, nearby galaxies and the structure of the Milky Way. Such events, of course, depend on dry and clear nights, so it is a good policy to have indoor substitutions available, such as slide shows, lectures, guided tours of displays in visitor centres, and even portable planetaria.

The ecology of the night also presents opportunities for both outdoor and indoor interpretation. Night walks require some careful thought as to making trails safe and visible in low light conditions, and equipping visitors with suitably shielded and filtered flashlights. Even where there are not many nocturnal creatures to be seen, visitors can come to appreciate how eyes adapt to the dark, and how the natural sounds of the night tell their own stories. As with astronomy interpretation, alternate plans are recommended for inclement weather, such as talks or displays about nocturnal nature. Many protected areas operate infra-red and low light cameras to record wildlife movements. Images from these cameras help reveal the full 24 hours of the local ecology.

In all cases of astronomy and ecology events and displays, both outdoors and indoors, the impacts of light pollution, and solutions to it, should be added as important messages for visitors to absorb and to take back to their homes and communities.

As with most aspects of protected area management, outreach presents great opportunities for cementing the role of an area within local and regional communities. Parks and reserves should collaborate with teachers, astronomers, ecologists and journalists to bring night sky and nocturnal ecology appreciation to schools and community programmes. This would be just one aspect of normal outreach, but with the added dimension of explaining light pollution and simple solutions that can be implemented by citizens.

Laws and policies

Several countries have enacted national laws to address light pollution, including Australia, Chile, Croatia, France, New Zealand, Slovenia and the United Kingdom. Some regions and states in Italy, Spain and the United States have their own light pollution laws. Unfortunately these laws remain the exception rather than the rule. Many towns and cities, however, have introduced outdoor lighting polices to curtail light pollution, albeit mainly to provide energy efficiency in municipal facilities rather than at all public and private properties. As well, protected area organizations like the US National Park Service and Parks Canada have internal policies that address light pollution. In general, these laws, regulations and policies codify the principles summarised above in the section on guidelines for outdoor lighting. Finally, all sites that are certified as dark sky or starlight sites implement practical measures to reduce light pollution, protect nature and bring enjoyment of naturally dark skies to visitors.

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Elk Island National Park at sunset. Source: JEeuwest, Wikimedia Commons

Acronyms and initialism

ALAN	Artificial (sometimes Anthropogenic) Light At Night
ALR	Artificial Light Ratio, the ratio of light at the zenith to an assumed natural night sky brightness
BCE	Before the Common Era, i.e. before the year 1
CE	The Common Era, i.e. starting at year 1 and extending to the present time
CIE	Commission International de l'Eclairage (International Commission on Illumination)
DSAG	Dark Skies Advisory Group
DSPr	Dark Sky Preserve
FCO	Full cut-off, as in a luminaire
IAC	Institute of Astrophysics of the Canary Islands
IAU	International Astronomical Union
ICOMOS	International Council on Monuments and Sites
IDA	International Dark-Sky Association
IDSP	International Dark Sky Park. Depending on the context, also used for International Dark Sky Places, an IDA programme
IES	Illuminating Engineering Society
IUCN	International Union for Conservation of Nature
K	Kelvin, a measure of temperature by which 0K is absolute zero and 273K is 0C. In lighting it is used to indicate the spectrum of a light source ranging from white or blue to yellow or amber
LED	Light Emitting Diode
LPS	Low Pressure Sodium, a light source that emits a monochromatic yellow light
NELM	Naked Eye Limiting Magnitude
NGO	Non-Governmental Organization
RASC	Royal Astronomical Society of Canada
RASC-GOL	RASC Guidelines for Outdoor Lighting
ShCO	Sharp cut-off, as in a luminaire
SI	Système International of measurement units, commonly known in English as the metric scale
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States of America
WCPA	World Commission on Protected Areas

Glossary

Airglow. A faint emission of light by the upper atmosphere. It causes the night sky to be never completely dark, even after the effects of starlight and diffused sunlight from the day side are removed. Airglow is caused by various processes such as the recombination of atoms ionised by the Sun, luminescence caused by cosmic rays, and chemiluminescence caused mainly by oxygen and nitrogen reacting with hydroxyl ions. Natural airglow is normally between 30 to 190 µcd/m^2, typically around 145 µcd/m2. Compare with Skyglow.

Asterism. A pattern or group of stars, typically having a popular name such as the Summer Triangle or the Winter Hexagon.

Astronomical darkness. When the Sun is at least 18° below the horizon and when the Moon is at least 10° below the horizon.

Astronomical twilight. When the geometric centre of the Sun's disk is between 12° and 18° below the horizon. To the naked eye, and especially in areas with light pollution, it may be difficult to distinguish astronomical twilight from nighttime. Most stars can be seen during this phase.

Bollard. As used in lighting, a short, thick post to mount a luminaire at approximately waist level.

Candela (cd). The base unit of photopic luminous intensity as perceived by humans, roughly equivalent to one standard wax candle. A one candela source emits 12.6 lumens.

Circadian rhythm. A biorhythm within animals that regulates the sleep-wake cycle and repeats roughly every 24 hours. It can refer to any biological process that displays an endogenous oscillation of about 24 hours.

Circalunar rhythm. A biorhythm that corresponds with the lunar cycle, approximately 29.5 days. The reproductive cycles of many organisms, especially marine organisms, are linked to changing levels of moonlight and the tidal cycle, both of which are governed by the phases of the Moon.

Civil twilight. When the geometric centre of the Sun's disk is at most 6° below the horizon. In the morning this phase ends at sunrise. In the evening it begins at sunset. As the Earth's atmosphere scatters and reflects much of the Sun's rays, colouring the sky bright yellow and orange, artificial lighting is generally not required under clear weather conditions to carry out most outdoor activities. Only the brightest stars and planets, like Venus and Jupiter, can be seen with the naked eye.

Collimated beam. A beam of light or other electromagnetic radiation that has parallel rays, and therefore spreads minimally as it propagates.

Cone cells. Photoreceptors in the retina are classified into two groups, cone cells and rod cells, named after their physical morphologies. Cone cells are capable of detecting a wide spectrum of light photons and are responsible for colour vision. Compare with rod cells.

Correlated Colour Temperature (CCT). The temperature of an ideal black-body radiator that radiates light of a colour comparable to that of the light source. Common perceived equivalents are amber for 1800K to 2200K, warm-white for 2700K, soft-white for 3000K, and cool or bluish around 5000K.

Cut-off. Describes the shielding of a luminaire such that no more than 2.5% of its light passes above the horizontal. See the definitions for full cut-off and sharp cut-off.

Dark Sky Compliant. Lighting that conforms to the Guidelines for Outdoor Lighting endorsed by the IDA and RASC.

Dolmen. A type of stone monument made of two or more upright stones with a single stone lying across them.

Full cut-off. Describes a luminaire that is shielded so that no light passes above the horizontal through the base of the luminaire, and less than 10% of the luminous intensity passes between 0° and 10° below the horizontal.

Gegenschein. Sunlight scattered by interplanetary dust particles. Part of the zodiacal light. It may be seen as a faint glowing spot in the sky, exactly opposite the position of the Sun, typically seen around midnight. Also called counterglow.

Illuminance. The total luminous flux of photopic light incident on a surface.

Initial lamp lumens. Also known as initial light output, it refers to the total amount of light produced by a lighting device when newly installed and before loss of operational efficiency has started.

K, Kelvin. A measure of temperature by which 0K is absolute zero and 273K is 0C. In lighting it is used to indicate the spectrum of a light source ranging from white or blue to yellow or amber.

Lumen. A unit of luminous flux, the quantity of visible light emitted by a source as perceived by the human eye. A standard 100 watt (W) incandescent bulb produces about 1680. This equivalent to the lumens produced by 30W incandescent bulbs, 30W halogen bulbs, 8W fluorescent bulbs, 7W compact fluorescent bulbs and 3W LEDs.

Luminaire. A complete lighting unit, including bulb, optics (mirror and/or lenses), power supply, internal control/driver electronics and support. Sometimes known as a light fixture or light fitting.

Lux. A measure of the lumens illuminating a given area. One lux is one lumen per square metre. Typical values are: overcast night with no artificial light sources 0.0001; starlight 0.001; quarter Moon 0.01; full Moon 0.1; deep twilight 1.0; twilight 10; very dark daytime sky 100; homes, theatres or warehouses 200; classrooms 300; offices or laboratories 500; supermarkets 700; hospital operating theatres or an overcast day 1000; daylight 10,000; and direct sunshine 130,000.

µCd/m^2. Microcandela per square metre, a standard unit in the measurement of skyglow, micro meaning one millionth.

Mie scattering. The scattering of light, without change of wavelength, by particles that have a diameter similar to or larger than the wavelength of the incident light. Mie scattering from sunlight produces white light, as from clouds, whereas Rayleigh scattering gives a blue effect as from a blue sky.

Nautical twilight. When the geometric centre of the Sun's disk is between 6° and 12° below the horizon. In clear weather conditions, the horizon is faintly visible during this phase. Many of the brighter stars can be seen, making it possible to use the position of the stars in relation to the horizon to navigate at sea, hence the name.

Naked Eye Limiting Magnitude. The highest magnitude (faintest) of stars visible to the naked eye. It declines with more skyglow.

Nit. A unit of measurement used to describe the photopic luminous intensity emitted by a surface or area as perceived by the human eye, and frequently used to specify the brightness of a display device such as a self-illuminated sign. One nit is one candela per square metre.

nm. Nanometre, one billionth of a metre, or 1×10-9 metre. It is used to describe the wavelength of light where light visible to humans ranges from 390 to 700 nm.

Noctilucent cloud. A high altitude cloud illuminated by sunlight when the Sun is below the horizon for the observer, and only visible during astronomical twilight. They typically occur between 76 to 85 km altitude.

Orrery. A mechanical model of the solar system, or of just the Sun, Earth and Moon, used to represent their relative positions and motions.

PC Amber. Phosphor converted amber lights which typically emit less than 1% of their illumination between 380 and 499 nm.

Planisphere. A star chart analog computing instrument in the form of two adjustable disks that rotate on a common pivot. It can be adjusted to display the visible stars for any time and date. An instrument to assist in learning how to recognise stars and constellations.

Rayleigh scattering. The wavelength-dependent scattering of light by particles in a medium, without change in wavelength. Since blue light is scattered slightly more efficiently than red, it accounts for the blue colour of the sky. Compare with Mie scattering.

Rod cells. Photoreceptors in retina that are highly sensitive to the brightness of light and function mainly in night vision. Compare with cone cells.

Sharp cut-off. Describes a luminaire that emits 0% up-light, and less than 1% between 80° and 90° from the nadir, i.e. more cut-off than FCO luminaires.

Skyglow. The diffuse luminance of the night sky. It is the sum of natural light such as airglow (see above), starlight and zodiacal light, together referred to as natural skyglow, plus artificial light at night reflected from atmospheric particles including moisture. It forms a haze of light that impedes seeing many of the planets, stars and distant galaxies otherwise visible to the naked eye. The light of stars on a cloudless, moonless night raises the natural skyglow to between 200 and 250 μcd/m^2. Anything above that on a moonless light is due to light pollution.

Solar flare. An eruption of high-energy radiation on the Sun's surface, causing electromagnetic disturbances on the Earth.

Solar wind. The continuous flow of charged particles from the Sun which permeates the solar system.

Sprites. Large-scale electrical discharges high above thunder clouds, giving rise to visual flickering in the night sky 50 to 90 km above the ground. They are usually triggered by the discharge of lightning between a thundercloud and the ground.

Starry sky. In many cultures with languages other than English, the literal translation of dark sky has a negative, foreboding meaning. In these other languages, starry sky carries a more positive connotation and hence is widely used to describe dark sky places.

Steradian. The SI (metric system) unit of solid angle, equal to the angle at the center of a sphere subtended by a part of the surface equal in area to the square of the radius.

Sunspots. A spot or patch appearing from time to time on the Sun's surface, appearing dark by contrast with its surroundings.

Tapetum lucidum. A layer of tissue in the eye of many vertebrates. Lying immediately behind the retina, it reflects visible light back through the retina, increasing the light available to the photoreceptors. The tapetum lucidum contributes to the superior night vision of some animals.

Zodiacal light. A faint hazy cone of light, often visible in the west just after sunset or in the east just before sunrise, caused by the reflection of sunlight from particles in the ecliptic plane.

Relevant declarations

La Palma declaration in defence of the night sky and the right to starlight

In 2007 at La Palma, Canary Islands, Spain, representatives of UNESCO, the UN World Tourism Organization, IAU, UNEP Convention on Migratory Species, Council of Europe, Secretariat of the Convention on Biological Diversity, Man and Biosphere Programme and the Ramsar Convention met with government, academic and non-governmental subject experts at the International Conference in Defence of the Quality of the Night Sky and the Right to Observe the Stars. The conference declaration reads, in part, as follows:

1. An unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights, due to its impact on the development of all peoples and on the conservation of biodiversity.

2. The progressive degradation of the night sky must be considered an imminent risk that must be faced, in the same fashion that the main problems concerning resources and the environment are addressed.

3. The conservation, protection, and revaluation of the natural and cultural heritage associated with nocturnal landscapes and the observation of the firmament represents a prime opportunity and a universal obligation for cooperation in safeguarding the quality of life. For all decision makers, this attitude implies a genuine challenge involving cultural, technological, and scientific innovation, requiring a major constant effort to enable everyone to rediscover the presence of the night sky as a living part of the heritage of mankind.

4. Access to knowledge, armed with education, is the key to allow the integration of science into our present culture, contributing to the advance of humankind. The dissemination of astronomy and the scientific and cultural values associated with the contemplation of the universe should be considered as basic contents to be included in educational activities, which require a clear and unpolluted sky and proper training of educators in these subjects.

5. The negative effects of emissions and of the increased intrusion of artificial light on the atmospheric quality of nocturnal skies in protected areas have an impact on several species, habitats, and ecosystems. Control of obtrusive light must be a basic element of nature conservation policies and should be implemented in the management plans of the different types of protected areas to fulfil their mission in protecting nature and biological diversity.

6. Mindful that a starry night sky forms an integral part of the landscape perceived by the inhabitants of every territory, including urban areas, the landscape policies established in the different juridical systems need to adopt the pertinent standards for preserving the quality of the night skyscape, thus allowing them to guarantee the common right to contemplate the firmament.

7. The intelligent use of artificial lighting that minimises sky glow and avoids obtrusive visual impact on both humans and wildlife has to be promoted. Public administrations, the lighting industry, and decision makers should also ensure that all users of artificial light do so responsibly as part of an integral part of planning and energy sustainability policies, which should be supported by light pollution measuring, both from the ground and from space. This strategy would involve a more efficient use of energy so as to meet the wider commitments made on climate change, and for the protection of the environment.

8. Areas suitable for unimpaired astronomic observation constitute an asset in short supply on our planet, and their conservation represents a minimum effort in comparison with the benefits they contribute to our know-how and to scientific and technological development. The protection of sky quality in these singular places must be given priority in regional, national, and international scientific and environmental policies. The measures and provisions must be made to safeguard clear skies and to protect such spaces from the harmful effects of light, radio-electric emissions, and air pollution.

9. Among others, tourism can become a major instrument for a new alliance in defence of the quality of the nocturnal skyscape. Responsible tourism can and should take on board the night sky as a resource to protect and value in all destinations. Generating new tourist products based on the observation of the firmament and the phenomena of the night, opens up unsuspected possibilities for cooperation among tourism stakeholders, local communities, and scientific institutions.

10. Sites included in the world Network of Biosphere Reserves, Ramsar Wetlands, World HeritageSites, National Parks, and all those protected areas which combine exceptional landscape and natural values relying on the quality of their night sky, are called to include the protection of clear night skies as a key factor strengthening their mission in conserving nature.

UNESCO astronomy and World Heritage thematic initiative

Created in 2004 within the framework of the Global Strategy for the Balanced, Representative and Credible World Heritage List, the Thematic Initiative on Astronomy and World Heritage aims to establish a link between science and culture towards recognition of the monuments and sites connected with astronomical observations. These are dispersed throughout all geographic regions, and include not only scientific but also traditional community knowledge. This Initiative offers to UNESCO member governments the possibility of evaluating and recognising the importance of this specific heritage, in terms of enrichment of the history of humanity, the promotion of cultural diversity and the development of international exchanges. It provides an opportunity not only to identify the sites connected with astronomy, but also to keep their memory alive and preserve the most representative properties through inscription on the World Heritage List. More on this initiative appears later in this report. whc.unesco.org/en/astronomy/#astronomy

IUCN Resolutions and Recommendations

IUCN has adopted two formal measures on controlling light pollution. See Appendix 1 for background and full texts.

Dark skies and nature conservation (2012). This IUCN Recommendation calls for natural resource management agencies to recognize that outdoor artificial light should be subject to effective standards to protect the integrity of natural areas and cultural sites.

Taking action to reduce light pollution (2020). This IUCN Resolution calls on IUCN's Secretariat, Commissions, and Members to promote the preservation of natural darkness.

CHAPTER 1.

Light pollution and its impacts

What is light pollution?

Light pollution is the inappropriate use of artificial light outdoors. It presents in three major ways. The first is glare, the excessive brightness of an unshielded lamp or illuminated surface that interferes with the ability to see other objects and that can also cause visual discomfort. Second, light trespass is when light falls where it is neither intended nor needed, such as when commercial or recreational floodlights spill light onto adjacent properties, or when a neighbour's floodlight shines into a house next door. Third, light that is cast upward and reflects off atmospheric particles causes artificial skyglow, the brightening of the night sky over inhabited areas which obscures all but the brightest stars.

It is made worse by several factors. Unneeded light is when artificial light shines when not needed, such as stadium floodlights are left on long after a game has finished, or when streets remain lit when there is no traffic. Another factor is light clutter which is bright, confusing and excessive groupings of light sources that add little to the needed visibility of an area. Finally, spectral pollution, when light below 500 nm wavelength causes unintended negative consequences. This blue to violet portion of the visible spectrum, at least for humans, reduces night vision acuity. It also disturbs sleep patterns, increasing the prevalence of several medical problems.

Light pollution is a side effect of modern civilisation. Its sources include exterior lighting on buildings, interior lighting allowed to escape outdoors, illuminated billboards, street lights, stadium floodlights, architectural lighting such as upward directed lights on monuments, decorative upward lighting such as on flags, or unshielded porch lights on houses. Much outdoor lighting is inefficient, overly bright, poorly targeted, improperly shielded and, in some cases, completely unnecessary. This light, and the electricity used to create it, is wasted, especially when directed into the sky or when it shines beyond site boundaries and over neighbouring properties, creating glare and light trespass. The International Dark-Sky Association (IDA) estimates that one third of all light in a developed country is wasted by poorly directed or unshielded lamps. [darksky.org/light-pollution/energy-waste] Worldwide it is thought that about one sixth of lighting energy is wasted into space.

There are, of course, many benefits to artificial illumination at night. One is safe navigation in its many forms, including street lights for pedestrians, vehicle headlights for drivers, navigation markers for shipping and tower hazard lights for aviation. Another is commercial and industrial operations after dark, such as in rail and storage yards, for shipping, and other modes of transport, building and manufacturing. Artificial light at night helps the appreciation of architecture, as long as it is confined to façades and is appropriate to the age and style of the building. For many people, outdoor recreation is only possible outside work hours if floodlights are used.

Figure 1.1. Firefly. Left: with flash. Right: without flash. Source: Wikimedia Creative Commons

However, there are many impacts of light pollution, and thereby reasons to reduce or eliminate it altogether. Ecological integrity is reduced, such as by interference with predator-prey relationships at night, or the disruption of the phenology (timing of life cycles) of plants. Commemorative integrity is impacted by inappropriate lighting of heritage places. Astronomy may be threatened, both for science and recreation, as when observations of stars and galaxies are hampered by glare and skyglow. Culture, traditions, mythology and ceremony that relate to the night sky are diminished by skyglow, whether they are passed down through generations of people, or of contemporary traditional societies and their practices. Artificial light at night may hamper landscape appreciation, such the enjoyment of nature at night in relatively remote areas that should not be marred by light domes from distant cities. Human health suffers from a lack of dark sleep and the resulting increased incidence of cancers and other illnesses in night shift workers. Energy efficiency is diminished by the waste of light and its energy that goes directly to space or trespasses onto areas where it is not intended. Safety and security are imperilled when glare obscures our detection of hazards, or when lit surfaces attract graffiti artists, thieves and vandals. All of these are discussed further elsewhere in this report.

For IUCN readers, the primary concerns are with ecological integrity and our experience of the world at night, for example when witnessing natural fluorescence (Cover photo and Figure 1.1). Nevertheless, nature conservation management should also exemplify sound and sustainable practices through good design of facilities in both protected and populated areas. Park visitor engagement and community outreach should explain the impacts of light pollution, and the benefits of enjoying a naturally dark environment and an unpolluted night sky. Urban planners and managers, be they of public, corporate or private properties, should apply good lighting practices that avoid the impacts highlighted above. Subsequent sections and appendices provide details on how to go about doing this.

The evolution of outdoor artificial light

For most of history, artificial light made no mark on the immensity of the night (Brox, 2015). Illumination depended on burning fat which is also a food, so it was used sparingly. Before the 17th century street lighting was virtually non-existent. Imperial Rome, and even Renaissance Florence, had no street lights. Law and order in the dark were often ensured by a night watch, as in Rembrandt's famous painting, local patrols that enforced curfews and protected communities against intruders.

Abundant outdoor lighting is barely more than 200 years old. The first stationary outdoor lights date to the 1600s when, for safety and commercial reasons, some European and American cities required householders to place an oil lamp or candle on their front windowsills. This began a new era of social interaction in the evenings, which in turn generated a desire for more public lighting. Oil lamps provided only limited illumination, but this changed when gaslight was introduced in early 19th century Britain and America. By the 1870s electrification had begun and the first generation of public electric lighting came in the form of arc lamps. They produced intense white light at less cost than gaslight, a harbinger of today's trend to LED lights. However, this proved too much for everyday streets. The central issue was glare for both human vision and, once automobiles became common, traffic safety (Hasenöhrl, 2015).

Concern over lighting as pollution dates back to the late 19th century but became widespread in the 1970s in response to the first oil crisis and the growth of environmental and heritage movements. Since 2000, lighting issues have been rekindled in response to trends in the extent and growth of light at night. Awareness of ecological effects has also surged in this millennium (following Longcore & Rich, 2004), as have the actions of various jurisdictions to regulate light pollution. Examples include Slovenia passing the world's first national law against light pollution in 2007. As Hasenöhrl (2015, p. 119) writes, these developments represent two paradigm shifts, from the dark night as a forbidding and dangerous environment prior to the industrial revolution, to its symbol as an emblem of backwardness in the 19th and 20th Centuries, then to its valuation as a desirable luxury in a densely populated and electrified world.

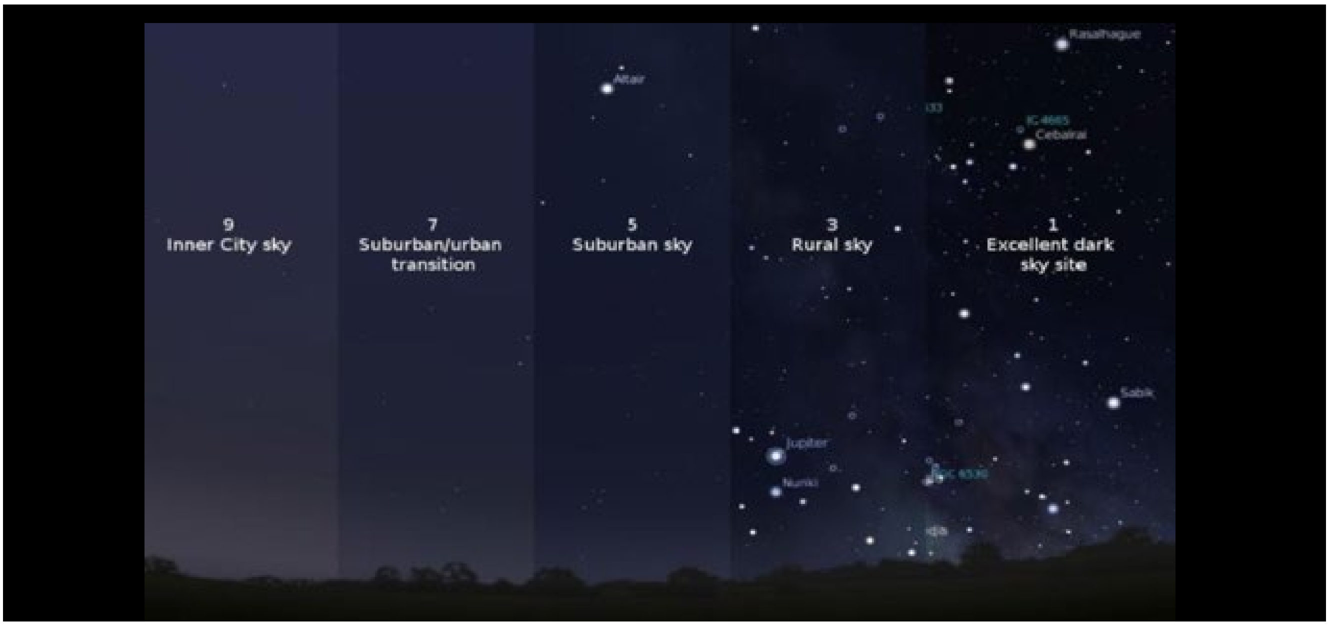


Figure 1.2. The night sky on the Bortle scale. Source: Bortle, 2001

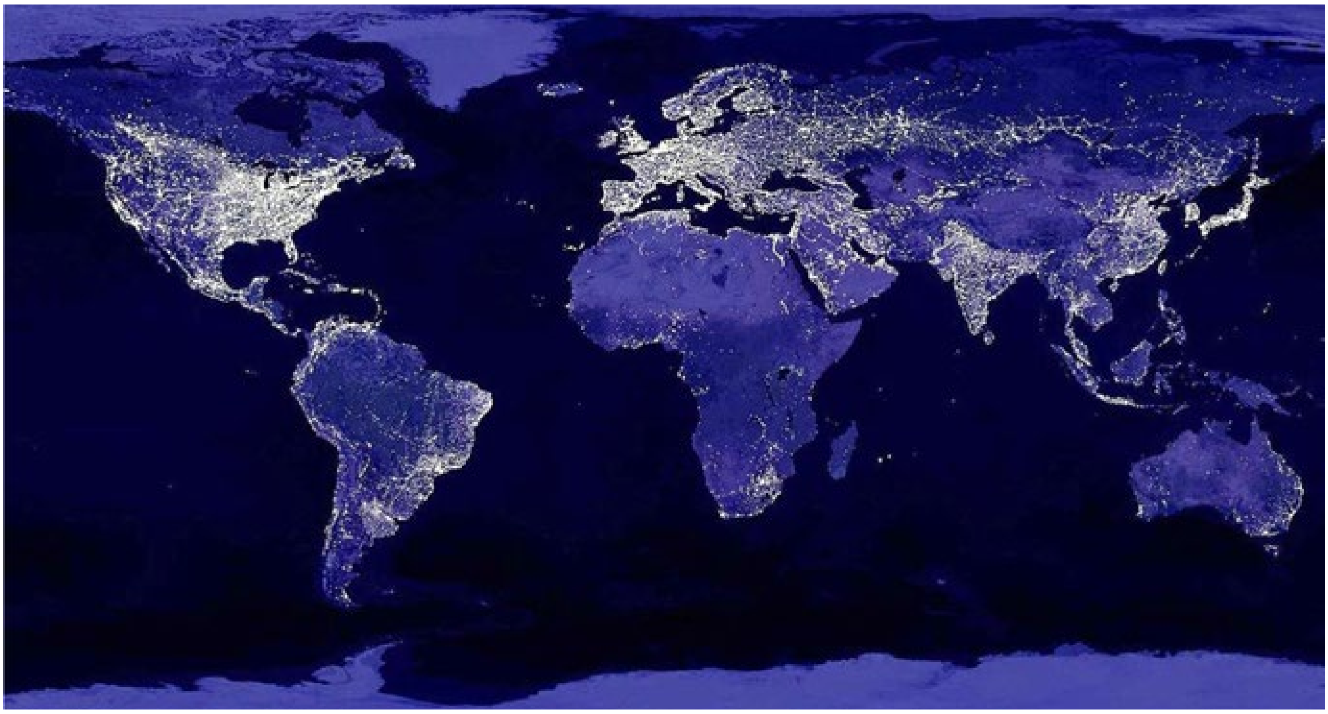


Figure 1.3. The Earth at night as seen from space.
Source: US National Oceanic and Atmospheric Administration (NOAA)

The extent of light pollution around the world

During the late evening or night with a partially clouded sky, if you see lighter clouds against a darker sky, you are in a light polluted area where artificial light reflects off clouds. Instead, what you should see is clouds as black patches and the stars as points of light in between. When you fly over a city at night and enjoy the scene of lights below, you witness light beamed up to space and serving no useful function on the ground below. Even on a cloudless night, artificial light reflects from atmospheric particles, even moisture, and creates skyglow, a subtle haze of light that obscures many of the stars and distant galaxies otherwise visible to the naked eye. Around the world, a majority of city and town dwellers never see the Milky Way, even on a cloudless night. Similarly, in mid- and high-latitude cities, urban dwellers see neither the *Aurora Borealis* nor *Aurora Australis.*

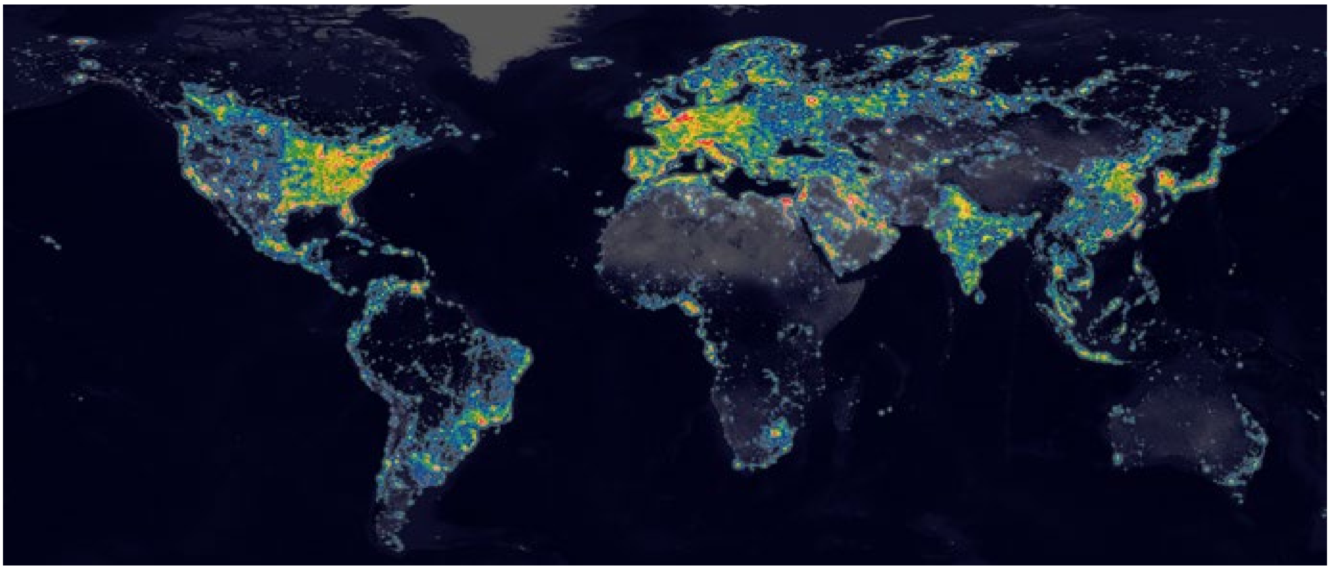


Figure 1.4. Light pollution map of the world, 2015. This map overlays the visual and infra-red data shown in Figure 1.3 with sky brightness data to model the skyglow. Source: Jurji Stare

In 2001 the astronomer John Bortle developed a night sky brightness scale for citizens and amateur astronomers. It is based on observations with the naked eye (Bortle, 2001; Figures 1.2 and A6.1). On his scale, class 1 denotes the darkest, least polluted skies and class 9 the most light-polluted. In rural areas with little or no light pollution most people will experience Bortle classes 1 to 4, in which several thousand stars may be seen by the naked eye. They will be able to make out the structure of the Milky Way and, in the southern hemisphere, see the Large and Small Magellanic Clouds. Conversely, most urban dwellers experience skies with Bortle classes 5 to 9, typically seeing at most a few hundreds of stars.

More detail on this can be found in Appendix 6 on measurement of light pollution. As noted above there are various types of light pollution, of which the most pervasive is skyglow. This can interfere with seeing the night sky even at great distances from cities. Figure 1.3 presents the well-known view of the Earth from space as seen by satellites. Figure 1.4 shows the extent of skyglow from those lights, calculated from satellite measures of illumination and modelled for diffusion and reflection back to the ground as skyglow.

The map shows nighttime visible and infrared data that has been filtered to remove stray light, lightning, lunar illumination and cloud cover. Image and data processing by the National Geophysical Data Center of the US National Oceanic and Atmospheric Administration, using Defense Meteorological Satellite Program data collected by the US Air Force Weather Agency.

The measurement and mapping of light pollution has been led by astronomers with a focus on seeing stars, but the many other things that may be seen under dark, unpolluted night skies should not be forgotten. While lightning, noctilucent clouds and satellites may be seen even through significant skyglow, many other celestial phenomena can only be seen clearly under unpolluted, dark skies. These include: the planets and their moons; comets and meteors; the rich detail of Earth's own Moon; two forms of sunlight diffusing off dust in space, namely zodiacal light, seen towards the setting Sun, and gegenschein; auroras; lightning and, rarely, sprites.

More germane to conservationist readers, there are many species and behaviours of wildlife that are nocturnal and which are negatively affected by light pollution. At the level of biomes, temperate broadleaf and mixed forests, including their protected areas, suffer the greatest light pollution exposure. At the geopolitical level this corresponds to Europe, east and south Asia, the Caribbean and eastern North America (International Union for Conservation of Nature (IUCN), 2009). More on these ecological effects appears below. Anyone concerned about natural heritage and its conservation is also likely to care about the preservation of heritage landscapes and structures, both to respect the authentic presentation of cultural heritage in the spirit of its time of origin, and also to favour the aesthetic appreciation of wilderness and rural landscapes after dark.

An emerging light pollution issue for astronomers is the potential impact of the constellations of communication satellites being launched over the next few years. Within less than a decade there will be tens of thousands of low orbiting satellites crisscrossing the night sky. In the long exposure images of astronomy, these will leave white trails of light across the sky, plus they will affect the total light collected by sensitive cameras.

Windows to the universe

The scientific aspect of a starry night is an essential part of the legacy of the sky. The ability of observatories to detect and interpret data from the distant reaches of the Universe is a resource of extraordinary value. Until recent decades, ground-based observatories provided all our knowledge of outer space. However, as we probe deeper into the distant and ancient universe, present-day technical and scientific requirements restrict suitable areas to limited locations which offer prime conditions for astronomy, particularly for optical and infrared astronomy.

There are only a few well-preserved places with very little alteration to natural starlight (Marin et al., 2010).

These conditions include the following:

- Limited turbulence, thereby reducing variable and unpredictable refraction through the air.
- Cloud-free, dry and unpolluted air, minimising aerosols that reflect light and blur images.
- A limited atmospheric column, hence fewer molecules and atoms that absorb sunlight and re-emit it at night, causing air glow.

These conditions are best met at high altitudes in mid latitudes on the west coast of continents or on isolated islands. There are only five such regions in the world (Figure 1.5).

Astronomy is not just a prerogative of the science community. Many past and contemporary traditional cultures placed, and still place, great cultural value on the ability to see a natural night sky. Two that are well known are the Mayan observatories in Mexico and the open ocean navigation skills of Polynesian cultures. And, of course, the enjoyment of an unpolluted night sky is an integral part of people's enjoyment of their natural world.

Even for just these astronomy reasons it is essential for all societies to extend protection of natural darkness. This can be through policies, regulations and social contracts that apply to all urban, rural and natural areas. It should be achieved by incorporating dark sky values into the management of all natural areas, including protected areas, ecosystem conservation, facility management and public engagement practices.

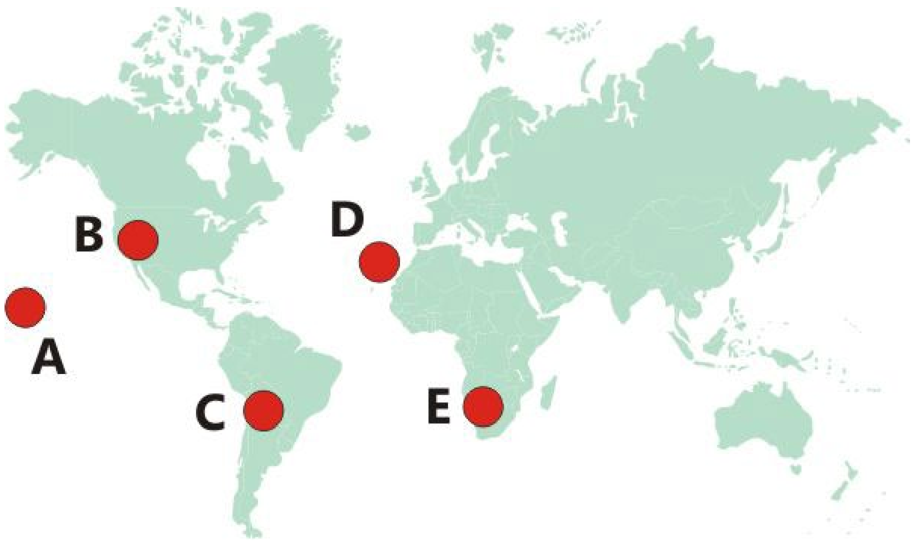


Figure 1.5. The five windows to the Universe. A) Hawaii, B) Southwest United States, C) Northern Chile, D) Canary Islands, E) Southwestern Africa.

Figure 1.6. A gathering of stargazers, astronomers and the general public. Torrance Barrens Dark-Sky Preserve, Canada. Source: Robert Dick

Figure 1.7. Shielded and unshielded lights, glare and the night sky. Source: Robert Dick

Amateur astronomy and stargazing

When enthusiasm, knowledge and curiosity are combined, astronomy can arouse a passion for nature that transcends the views through any telescope. Astronomy is not just for professionals. Nor is it just for amateur astronomers. Astronomy feeds and supports societies and cultures around the world by being part of their heritage of mythologies. It is an exploration of nature unfettered by concerns on Earth. It arouses a sense of wonder and curiosity, just by looking up (Figure 1.6).

But the night is dark and the stars are faint. Increasingly over the past century, more than half the world's population has been denied the personal benefits of a star-filled sky. As already noted, there are many examples of astronomy used in different cultures. There are many brands of commercial products that bear astronomical names, from candy bars to automobiles. A star-filled sky is one symbol of a pristine environment. A clear night sky has no boundaries and affects people differently. When viewed from an urban park, the celestial expanse reduces the sense of congestion felt in a suburban neighbourhood. It is a window for those who wish to look and a door enabling our imaginations to escape. This may be the reason why some people experience a sense of calm when under a star-filled sky.

Exposed bright lights constrict the iris and reduce the sensitivity of night vision, rendering much of a star-filled sky invisible. Professional astronomers experience similar problems at remote observatories. Their instruments provide a keener view, but data that is free of light and aerosol contamination yields the greatest insights.

There are two ways that artificial light at night affects how our eyes see the universe. First, night vision is sensitive to starlight, but bright lights in the field of view bleach the sensitive rod cells in retinas, preventing them from detecting faint light. Paradoxically, more stars may be seen from a suburban park with shielded lights than from a rural area with glaring lights (Figure 1.7). Furthermore, urban parks with a moderately starry sky may be more important for public education about light pollution than remote parks with darker skies but few visitors. In these cases, pedestrian access and navigation may be provided by shielded path lighting, and, on or off paths, skyglow reflecting off light-coloured surfaces.

Second, artificial light that shines from or is reflected off illuminated surfaces into the sky is partially scattered back to the ground by dust and aerosols, making the air appear to glow. This skyglow can be as bright as the full Moon, forming a luminous veil across the sky that obscures faint celestial objects.

The first problem can be addressed by shielding outdoor lights and covering windows. Also, one can see more by avoiding the emission of white light which includes the short, blue wavelengths to which human's night vision is most sensitive. The second problem can be addressed by minimizing the amount of scattered light. Site managers should ensure that all artificial light shines only onto the surfaces it is meant to illuminate. Also, they should reduce the amount of scattered light from the ground by using low illumination levels. These simple techniques will bring back the night sky to cities so that urban people will once again be stimulated by the view of the night. More details and recommendations are presented in Chapter 5, Guidelines for Outdoor Lighting.

Ecological values and effects

The sources and rhythms of natural light

Animals and plants* evolved to the rhythms of the Earth, the 24-hour day/night, or circadian, cycle and the 12-month seasonal cycle (Longcore & Rich, 2017; The Royal Commission on Environmental Pollution, 2009). A high proportion of many animal groups are nocturnal (Figure 1.8). They have developed senses that integrate their behaviour into the daily and yearly progression of light and dark. Light pollution interferes with this ability. Animals may experience temporal confusion when there is too much artificial light at night (ALAN), affecting behaviour governing mating, sleep, finding food and, of course, avoiding becoming food. In perhaps the best-known case, birds are attracted to lights at night during nocturnal migration. During long-distance nocturnal migration, birds that have adapted to navigate through forests can be confused by the artificial lights of high buildings (Figure 1.9), often with fatal consequences. In their migration, birds show an attraction to urban lights across the landscape. When they encounter individual lights, such as steady-burning lights on communication towers, lights on buildings, or spotlights directed upward, they are transfixed by those lights and circle them, often colliding with obstructions. In plants, circadian and seasonal rhythms of light and dark control flowering, seeding and senescence. Even humans may notice a change in their circadian rhythm when they travel between time zones, resulting in sleepiness, lethargy or a general sense that something is not right.

*Although the text refers to plants and animals, other kinds of organisms are affected by artificial light: fungi, bacteria, and protista such as algae and amoeba (Li et al., 2023).

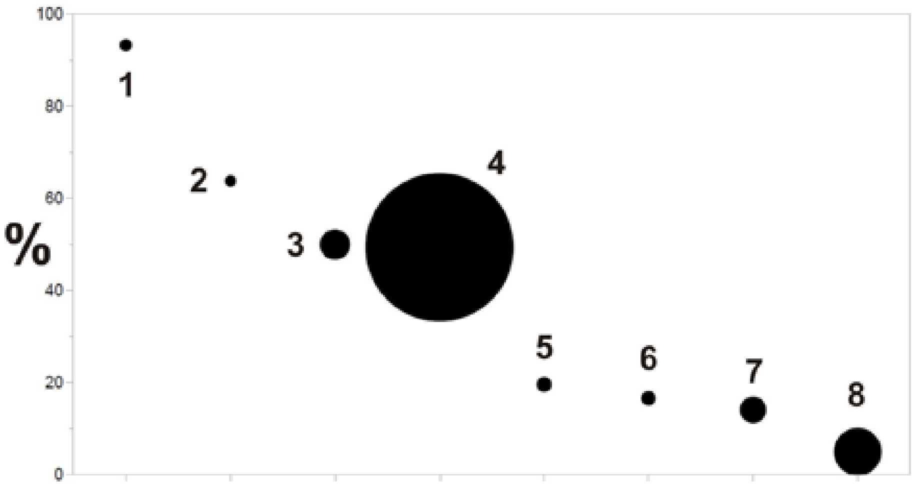


Figure 1.8. Percent of major animal groups that are nocturnal. The areas of the circles are proportional to the number of species known in the group. 1 Amphibians. 2 Mammals. 3 Crustaceans. 4 Insects. 5 Birds. 6 Reptiles. 7 Fishes. 8 Arachnids. Source: modified from Longcore & Rich (2017), based on data in Hölker (2010)

Figure 1.9. Forest versus towers at night. Birds can confuse openings in forests at twilight with the illuminated windows of high buildings, often with fatal results. Source: left, DarkSky; right, Wikimedia Creative Commons

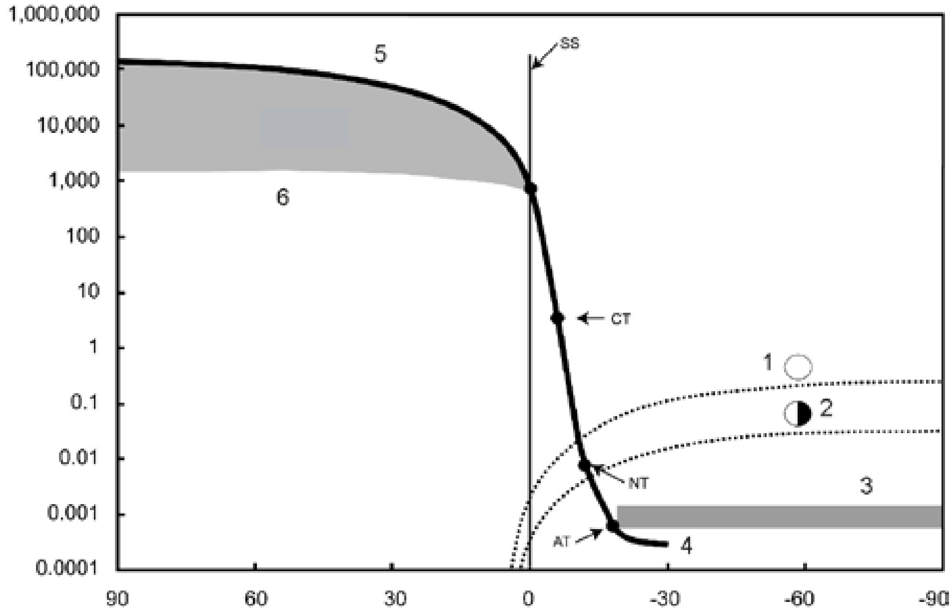


Figure 1.10. Natural horizontal illumination during the day, sunset and at night. Horizontal illumination in lux on the y axis; x axis shows elevation in degrees above the horizon for the Sun and Moon. SS = sunset, CT = civil twilight, NT = nautical twilight, AT = astronomical twilight. Full Moon 1, quarter Moon 2, starlight 3, overcast conditions 4, clear sky 5 and cloud cover 6 are indicated. Source: Longcore & Rich, (2017)

Natural sources of light are either the durable and predictable daylight and moonlight, or notably ephemeral such as lightning, wildfires, auroras and bioluminescence. Once night arrives, the brightest possible constant light source is a full Moon (Figure 1.10). The length of night varies by season and latitude. On the timescale of biological activity, this pattern is fixed. Outdoor illumination during the day ranges from 130,000 lux in full sunlight to 1,000 lux on a cloudy day. Dusk and dawn transitions are characterised by predictable changes in the relative intensities of the wavelengths of light. As dusk arrives, the proportion of blue light increases, especially when the Moon is new or not present. With moonlight, the enhanced blue at dusk is diminished. Although not perceived by humans, some animals are sensitive to this subtle change in colour. Variations in illuminance and colour give rise to many behavioural and physiological processes. Circadian, seasonal and lunar rhythms are linked to these predictable changes in the natural light environment. Light triggers can be at different illuminations depending on the environment. For example, the illumination at which activity takes place on a forest floor is normally dimmer than that for open grassland. Illumination that is within the natural range of variation on a beach may be far brighter than anything experienced at night in a dense forest. Disruption caused by ALAN occurs whenever the natural patterns of light and dark are changed. This means that very low lighting levels, far below that of the full Moon, can have important effects. Reviews of the effects of artificial night lighting on different taxonomic groups can be found in Rich & Longcore (2017). Information for a specific taxon is essential to devise lighting systems that minimise impacts on sensitive species when artificial lighting is necessary. Sensitive species should be identified relative to a specific area. This might include species that have a formal designation as being threatened or endangered, or for any species of concern that could be sensitive to changes in nocturnal illumination.

Examples of the interaction of ALAN on different taxonomic groups and habitat types follow and are drawn from Rich & Longcore (2006) and Longcore & Rich (2017). Much of the text is derived from Longcore & Rich (2017) with permission of the US National Park Service, which commissioned the report. See also Jägerbrand & Bouroussis (2021) for a more recent overview of the ecological impact of artificial light at night, as well as IDA (2022) and Sokol (2022).

Taxonomic groups

Plants

Not just light in general, but the intensity and spectrum of light affect plants (Bennie et al., 2016). Phototropism is the tendency of plants to grow towards light and is induced by blue light, the colour of the daytime sky. Red light governs many of the key stages in the life cycle of flowering plants, from germination, through shoot and leaf development and flowering, to dormancy in species that have dormant phases (The Royal Commission on Environmental Pollution, 2009, p.14).

Plants are as dependent upon photoperiods as are animals, perhaps more so. Even a short period of light at night simulates daytime for many plant species, even less than 1 lux over just a few minutes. Similarly, darkness during the day triggers a short day response, as might be expected by the onset of autumn. Continuous light weakens resistance to disease. Examples are: leaf chlorosis, the yellowing of normally green leaves due to a lack of chlorophyll; necrosis, or leaf blotching; impaired starch metabolism; and impaired chlorophyll synthesis. Experiments have shown that tomato plants are injured by continuous light altering their circadian rhythm. In chrysanthemums, growth normally occurs with sixteen hours of light and eight of dark. However, even with eight hours of light and sixteen of darkness, but with a ten second light interruption, the plant is fooled into sensing full summer and will switch to growth. When temperate trees such as oak, sycamore, ash and beech are bathed in light from street lamps, the seasonal start of their leaf growth starts several days early (Ffrench-Constant et al*.*, 2016; Meng et al*.*, 2022).

This can have a negative knock-on effect for migratory and hatching birds that time their activities according to expected leaf-out and budding times. Similarly, insects such as the winter moth Operophtera brumata, common in Europe, lay eggs so that the caterpillars hatch at the same time as the trees produce their first tender young leaves. If the trees leaf out a week too early, the caterpillars have to eat tough leaves that are less nutritious and that are packed with tannin, a natural defence against pests. That means there are fewer caterpillars for songbirds to eat.

In the southwestern United States, the saguaro cactus *Carnegiea gigantea* relies on a dark night for pollination and reproduction. Its flowers bloom only for a 24-hour period, opening at night and remaining open throughout the following day. With this limited pollination window, the saguaro depends on bats in the evening, as well as bees, birds and other pollinators during the day, to reproduce effectively. Any artificial light at night jeopardises this symbiosis. Another example in the same region is the various species of yucca plant and the night pollinating yucca moths *Tegeticula yuccasella* which established a relationship termed obligate mutualism. If one of these species were to go extinct, the other could not survive. Yucca moths and their larvae benefit from being able to feed on seeds inside the flower of the yucca. In turn, the plant receives pollination from the specialised yucca moths as they feed within the plant. The yucca flowers have adapted to produce more of their nectar at night, attracting these night pollinators. Both species need the darkness of night to thrive (Kodachrome Basin State Park, 2020, 29).

Insects and spiders

Insects are near the base of the terrestrial food chain and therefore are critical to many ecosystems. Anyone who spends time outside at dusk and after dark knows that insects are attracted to light. Some, such as moths, have a positive response to light while others, such as cockroaches, have a negative response. Insects take advantage of light to see, to attract prey and to trigger dormancy. These differences underscore the complexity of animal responses to light in their behaviour and survival strategies.

Spiders may construct their web near a light source to attract and capture prey that have a positive phototropic behaviour (Van Geffen et al*.*, 2015). Moths and other insects are attracted to artificial lights and may stay near that light all night. This activity expends much energy and interferes with mating and migration, causing population reduction (Van Langevelde et al*.*, 2017; Van Grunsven, 2020). It also makes them easy prey for bats and other nocturnal predators, further reducing their numbers. Studies in the United Kingdom have found more predatory insects, such as beetles and harvestmen (Opiliones), under street lights (Davies et al*.*, 2020). Such effects in turn impact all species that rely on insects for food or pollination (Boyes et al*.*, 2021).

Outdoor lighting is typically used where people congregate. However, it will also draw flying insects towards the area and this has led to the suggestion that outdoor artificial lighting may increase the incidence of insect-borne diseases (Barghini & de Medeiros, 2010; Pacheco-Tucuch et al*.*, 2012). The increase of outdoor lighting in tropical and temperate climates may promote the incidence of infectious diseases. Lighting, which invariably follows electrification, may help explain the proliferation of disease in these areas.

Amphibians

Amphibians can perceive increases in illumination that are impossible for humans to detect. Some amphibians forage only at extremely low light levels, and foraging times are partitioned among species with different lighting level preferences. The squirrel tree frog (*Hyla squirrela*) orients and forages at lighting levels as low as 10-6 lux and stops foraging above 10-3 lux (Buchanan, 1998). The western toad (*Bufo boreas*) forages only between 10-1 lux, the light of a full Moon, and 10-5 lux, while the tailed frog (*Ascaphus truei*) forages only during the darkest part of the night below 10-5 lux (Hailman, 1984). Reproductive activity is also typically nocturnal. In an experiment, African clawed frog tadpoles (*Xenopis laevis*) were found to metamorphose more in the darkest light exposure. In Ontario, Canada, green frogs (*Rana* *clamitans melanota*) reduced calling and increased movement under artificial light (Baker & Richardson, 2006).

A rapid increase in illumination causes a temporary reduction in visual acuity, from which the recovery time may be minutes to hours. In this manner, a simple flash of headlights can arrest the activity of a frog for hours. Amphibians are also sensitive to changes in ambient illumination from skyglow. Frogs in an experimental enclosure ceased mating activity when lights from a nearby stadium increased skyglow (Buchanan, 2006). In another experiment, male green frogs called less and moved more when exposed to the intermittent light of a flashlight (Baker & Richardson, 2006). As with many animals, including humans, excessive night lighting interferes with melatonin production, which is involved in regulating important functions including sexual development, thermoregulation, adaptation of eyes to the dark and skin colouration. Laboratory research has shown that artificial lighting slows larval amphibian development (Wise, 2007; Figure 1.11). The influence of artificial lighting on such physiological processes in the field is not well known, but the potential for lighting to harm amphibians and other wetland species is evident.

Reptiles

The best known example of the effects of artificial light on reptiles is the misorientation and disorientation of sea turtle hatchlings as they emerge from their nests on sandy beaches (Salmon, 2003). Adult female sea turtles also avoid beaches that are illuminated. The literature on this topic is considerable and points to a need to mitigate impacts through dimming, shielding, extinguishing and changing the colour of lights impacting beaches (Witherington & Martin, 1996).

The use of illuminated nocturnal environments by diurnal species was first described for lizards and defined as the “night-light niche” (Garber, 1978). Exploitation of the insects attracted to lights by invasive lizard species is presumably one of the keys to their success as invaders (Thawley & Kolbe, 2020). Research on physiological responses of reptiles to light at night is limited and complicated because reptiles synchronise their daily rhythms by both temperature and light (Grubisic et al*.*, 2019).

Snakes show lunar behavioural cycles that can also be triggered by skyglow and direct glare. Some snake species limit their activity to the darkest periods of the month to avoid the risk of predation (Perry & Fisher, 2006) so the risk of impacts from skyglow and direct glare, which reach similar intensities, is high.

Birds

Many bird species migrate at night and navigate by using of the Earth’s magnetic field, the stars and terrestrial landmarks (Gauthreaux & Belser, 2006). Their ability to use these directional cues is affected by light pollution. Tens of thousands of birds are attracted to city lighting and die from collisions with glass-clad buildings after being disoriented by direct and reflected lights (Loss et al*.*, 2012; Longcore et al*.*, 2012; Figure 1.9).

The city of Toronto in Canada lies along bird migration routes. Ten thousand birds are killed each year by exhaustion and collisions with buildings. To reduce bird mortality, building managers are required to turn off unnecessary lighting during the migration period. This phenomenon is also well documented in Chicago, New York and Washington DC. A notable example is the ongoing mortality of nocturnal migrant birds at the 169-mitre-high Washington Monument in Washington, DC, which started when it was illuminated (Overing, 1938). In a contrasting urban example, Senzaki et al*.* (2020) used United States data sets to assess how noise and light affect reproductive success in 142 species. They found that increased light-gathering ability was associated with advancements in reproductive timing and in reduced clutch failure, potentially creating phenological mismatches.

In 1999, Xantus murrelets (*Synthliboramphus hypoleucus*) nesting on Santa Barbara Island, part of Channel Islands National Park off the coast of southern California, were dying at twice the average annual rate (Carter et al*.*, 2000). Park managers suspected this increase in mortality was directly related to a recent increase in fishing boats equipped with dusk-to-dawn floodlights to attract squid. Squid boats typically have 30,000 watts of light per boat. The number of squid boats increased dramatically in the 1990s, and in 1999 intense squid fishing occurred during murrelet nesting season in spring near important murrelet breeding islands, whereas previous fishing was during fall and winter. Managers believed that the nesting seabirds, without the safety of darkness, were subject to increased predation, especially from barn owls *(Tyto alba)*. During 1999 an unprecedented 165 dead Xantus murrelets were found on Santa Barbara Island. Most were killed by barn owls, while five were victims of western gulls *(Larus occidentalis)*. Researchers also recorded high nest abandonment closest to the most intensive squid boat activity. Faced with these observations, managers closed the areas around the islands to squid fishing. Death rates for the birds returned to normal. The excluded areas were subsequently incorporated into a permanent marine preserve with no fishing allowed so as to foster the replenishment of fish stocks. Also, the California Fish and Game Commission listed the Xantus murrelet under the California Endangered Species Act, citing artificial night lighting as one of the major threats to the species.

The lights of a road bisecting wet grassland in the Netherlands influenced the spatial distribution of the rare ground-nesting black-tailed godwit *Limosa limosa* (De Molenaar et al., 2006). When road lights were turned on during a breeding season, the birds nested slightly farther away from the road, with the effect extending 300 m from the lights. Birds that arrived first to the breeding area nested farther from the lights while those arriving later nested closer.

A laboratory study of domestic pigeons (Columba livia) and wild-caught magpies (*Cracticus tibicen tyrannica*) showed that artificial light at night affects both rapid eye movement (REM) and non-REM sleep. Magpies were more affected by white light than amber light, losing 76% of their non-REM sleep. Pigeons lost on average about four hours of total sleep. These sleep losses can lead to behavioural and health problems, reduce reproductive success, or force the birds to find new habitats (Aulsebrook et al., 2020). The results demonstrate that amber lighting can minimise sleep disruption in some birds but that this benefit may not be universal.

Terrestrial mammals

Artificial light at night is not part of the natural environment in which mammals evolved and its presence affects behaviour and physiology across species with all daily activity patterns. At the landscape scale, the existence of lights is sufficient to influence wildlife movement (Beier, 1995; Beier, 2006). This phenomenon was illustrated by a radio telemetry study of young mountain lions in Orange County, California where light inhibited movement. Recent work on roadway underpasses suggests that light interferes with nocturnal wildlife movement (Bliss-Ketchum et al., 2016; Shilling et al., 2020).

Small mammals respond to illumination in their foraging activities. For example, artificial light of 0.3 and 0.1 lux reduced the activity, movement or food consumption of several rodent species (Clarke, 1983; Brillhart & Kaufman, 1991; Vasquez, 1994; Falkenberg & Clarke, 1998; Kramer & Birney, 2001). This phenomenon has also been shown for prey species in natural and laboratory conditions (Kotler, 1984; Bliss-Ketchum, et al., 2016; Wang & Shier 2017; Wang & Shier, 2018).

Exposure to light at night affects both the seasonality and daily rhythms in mammals through physiological responses. For example, lighting from a military base was shown to desynchronise the breeding time of tammar wallabies (*Macropus eugenii*) in Australia, as well as to suppress nightly melatonin production (Robert et al., 2015). Studies on the physiological effects of light at night on mammals are abundant, partly because of the implications for understanding human health (e.g. Zubidat et al., 2007; Zubidat et al., 2010). These studies show that artificial light at levels far less intense than previously assumed are able to entrain circadian rhythms and influence physiological functions such as immune response (Bedrosian et al., 2011).

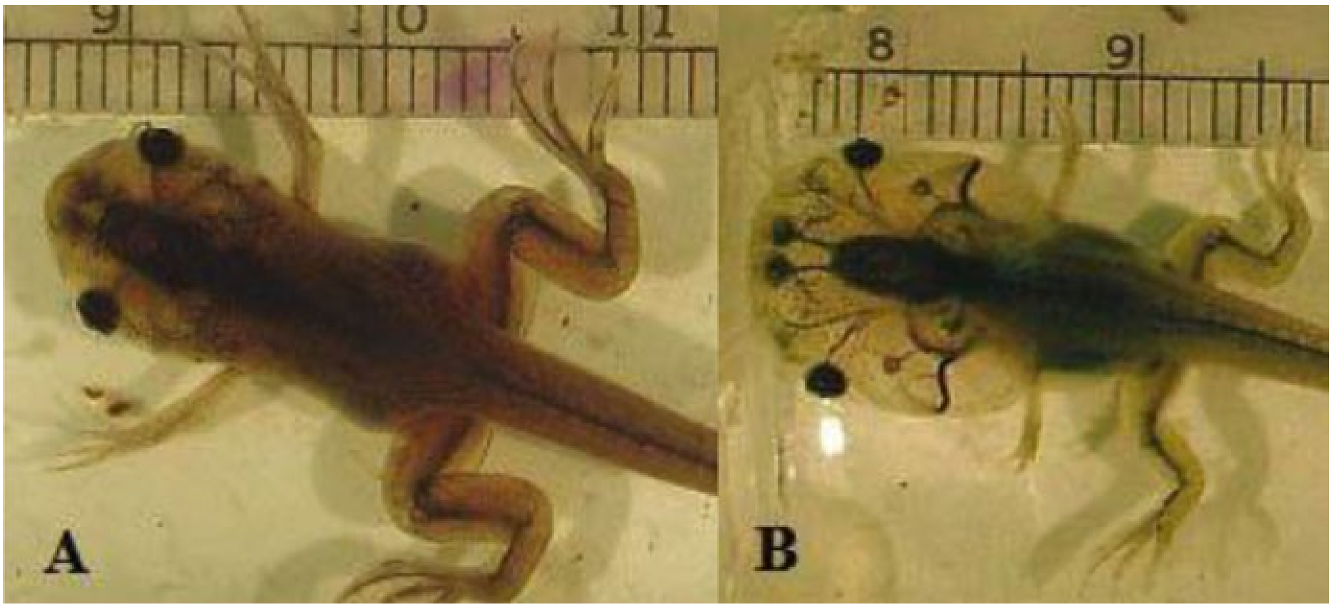


Figure 1.11. Two tadpoles of the same age and kept in 12 hr day and 12 hr night lighting. The tadpole on the left (A) was kept in the equivalent of a very dark night (10-4 lux), while the other (B) was exposed to bright illumination in the dark phase and is not yet metamorphosing. Source: Sharon Wise

Bats

The responses of different bat species to lighting are complex (Rydell, 2006). Some faster-flying and more manoeuvrable species will be attracted to lights, where they forage on insects also attracted to the lights. Slower and less manoeuvrable species will avoid lights, essentially being repulsed by their presence (Stone et al., 2009; Polak et al., 2011, Stone et al., 2012; Stone et al., 2015). Presumably this response is to minimise risk of predation. As is implied by the repulsion of some bat species by nighttime lighting, the presence of permanent outdoor lighting can sever landscape connectivity for wildlife species (Stone et al., 2009). Light at the entrance of a roost can keep bats from emerging for their nightly foraging (Boldogh et al., 2007). Part-night lighting, where lights are shut off after a curfew, is an improvement over whole-night lighting for bats but not adequate to reduce all impacts (Azam et al., 2015; Day et al., 2015). Guidelines for reducing impacts to bats include a limit of 0.1 lux of light at the edge of habitat, removing direct glare into habitats, and seeking to avoid light below 540 nm (blue spectrum): (Voigt et al., 2018). Red lights are used in Europe to minimise impacts to bats (Spoelstra et al., 2017).

Habitat types

As with the discussions of species effects, unless otherwise noted the following is derived from Longcore & Rich (2017) and Rich & Longcore (2006):

Coastal dunes, beaches and shorelines

Coastal dunes and beaches are generally open environments with low vegetation adapted to moving sand. Dunes present distinct conditions and are often populated by endemic species of concern to management because of development pressure on coastal ecosystems (Schlacher et al., 2007). Dunes are also ecological transition zones between land and water. Under natural conditions, the view toward the land is almost always darker than the view toward the water. This is due to vegetation blocking moonlight and starlight, and due to light sparkling off water and, sometimes, light from bioluminescent organisms (see cover photo).

Concern about adverse effects of coastal lighting dates to descriptions of the death of birds at lighthouses in the late 1800s (Allen, 1880; Miller, 1897). The mortality of sea turtle hatchlings disoriented by coastal lights was noted in the 1960s (McFarlane, 1963). Sea turtles move from water to land to nest, using onshore natural darkness for direction (Salmon, 2003). Artificial lighting has adverse consequences because the darkest horizon is no longer the landward horizon. Indeed, the lethal effects of lights on sea turtles have led to increased awareness of the adverse effects of artificial night lighting in general. Female sea turtles avoid illuminated beaches as nest sites, and hatchings are fatally affected by lights visible from beaches, since they naturally move toward what they think is bioluminescence, moonlight or starlight over water. They become easily disoriented by onshore lights or urban skyglow and may move in the wrong direction when seeking the sea.

Stray light and skyglow from coastal development spread across many dune and shoreline environments, where nocturnal activity is often significant. Beaches and coasts regularly experience foggy and high aerosol conditions which scatter light and thereby amplify the local effects of lights.

As a general rule, additional light increases the foraging efficiency of predators and reduces the activity of prey (Seligmann et al., 2007). A 2004 Florida investigation into the effects of lighting on foraging behaviour of beach mice used low-pressure sodium lights and yellow incandescent lights that limit backlight, uplight and glare (Bird et al., 2004). These are commonly employed on beaches in Florida because they have limited effects on sea turtle hatchlings. The study found that foraging by beach mice was significantly decreased in proximity to both types of turtle-friendly lights.

Similar behaviour by prey species has been shown for both natural and anthropogenic light. For example, ghost crabs are active only at night. They avoid activity under both the full Moon (Schlacher et al., 2007) and artificial light (Christoffers, 1986). The exception to this pattern is that prey species that flock or school together can be aided by additional light that facilitates communal vigilance. Effects from lights on beaches and shorelines may also affect the predator-prey dynamics of fishes and marine mammals (Hobson et al., 1981; Yurk & Trites, 2000). Presumably as a response to predation risk, the western snowy plover (*Charadrius nivosus nivosus*), an endangered shorebird, has a lower probability of roosting on beaches where light pollution exceeds 0.05 lux, while the beach-spawning fish California grunion (*Leuresthes tenuis*) is found less often with light pollution exceeding 0.1 lux (Simons et al., 2022).

Shorebirds sometimes forage at night, possibly as a defence against predation (Dugan, 1981; Burger & Gochfeld, 1991; Rohweder & Baverstock,1996). This is a response to higher invertebrate activity on beaches at night (Evans,1987), or a response to visual cues that are available due to more artificial light. Predator defences of shorebirds are different during the night compared with the day. For example, some dunlins (*Calidris alpina*) freeze and limit vocalizations as a defence at night, while during the day the entire flock will fly away in response to predators (Mouritsen, 1992). Owls are the major nocturnal predator of shorebirds and are aided by additional light when foraging (Clarke, 1983). Timing of foraging by shorebirds, therefore, probably depends on tradeoffs between risks of becoming prey against the ability to detect their own prey.

As well as these natural effects, park visitors often use beaches and dunes to gaze at the night sky. Beaches and dunes should be kept as free from the influence of artificial lights as possible. Special attention should be paid to ensure that any lights installed are truly necessary and that, with the exception of navigation aids, no lights are directly visible either from the beach or from points offshore.

Hot deserts and scrublands

Hot deserts and scrublands are open habitats with few barriers to the spread of light. Many animal species in these environments adopt nocturnal behaviours to conserve water and avoid the scorching heat of the day (Kronfeld-Schor & Dayan, 2003). The majority of species are nocturnal at high temperatures, and the open vegetation structure of dry scrublands allows for light to propagate over unusually long distances. Consequently, artificial night lighting has a high potential to disrupt the natural patterns of light and dark relied upon by many fauna.

Desert animals have narrow preferences for illumination levels. These may be related to foraging opportunities, predation risk or physiological requirements. For example, *Leucorchestris arenicola*, a trapdoor spider endemic to the Namib Desert, exhibits exclusively nocturnal activity patterns (Nørgaard et al*.*, 2006). Males are active only during dark moonless nights, when they are able to navigate hundreds of metres across dune environments using only the faint ambient light from stars, airglow and zodiacal light. The addition of illumination from any source within its habitat would eliminate its preferred habitat conditions.

Desert rodents also exhibit specific illumination preferences to manage their risk of becoming prey. Some species are active at twilight, others after twilight, and some during the darkest periods of moonless nights (Grigione & Mrykalo, 2004; Upham & Hafner, 2013). Anthropogenic light can disrupt these patterns. Even the light from a camp lantern equivalent to a quarter Moon, about 0.01 lux, is sufficient to inhibit foraging by some rodent species (Kotler, 1984). Those vulnerable to this disruption lack other predator avoidance abilities such as exceptional hearing. Because many desert animals exhibit circalunar patterns in their activities, especially predaceous arthropods such as scorpions (Skutelsky 1996; Tigar & Osborne, 1999) and grain-eating small mammals (Price et al*.*, 1984; Daly et al*.*, 1992), any artificial light that produces light equivalent to even a quarter Moon can alter these patterns.

In the scrublands of southern California, the nocturnal long-nosed snake (*Rhinocheilus lecontei*) showed a pattern of decline consistent with the gradient of light pollution (Perry & Fisher, 2006). Otherwise suitable scrub habitats, which support diurnal species of snakes, lack these long-nosed snakes. This is thought to be due to decreases in the numbers of the snakes' small mammal prey, also associated with light pollution.

Wetlands and rivers

Wetlands and lakes are often the last refuges of natural night, especially in urban areas. However, many aquatic organisms depend on daily cycles of light and dark, and artificial lights disrupt these behaviours (Perkin et al*.*, 2011; Meyer & Sullivan, 2013; Henn et al*.*, 2014). In addition, wetlands are often isolated patches or linear features stretching across the landscape. Linear wetlands are highly susceptible to artificial lighting because they have a high edge to area ratio. They also tend to attract development along their edges, which leads to urban lighting on either side. Small wetlands are similarly vulnerable to disturbances from their surroundings.

Aquatic invertebrates are important components of wetland ecosystems and provide an example of the sensitivity of wetlands to artificial lighting. Both insects and zooplankton are near the bottom of the food chain and their disruption puts the entire ecosystem at risk. Many aquatic invertebrates migrate vertically during the course of a night and a day. This migration is thought to be a way to avoid predation during daytime, since many zooplankton forage near water surfaces only during dark conditions. Light dimmer than that of a half Moon is sufficient to influence the vertical distribution of aquatic invertebrates. Indeed, this diel vertical migration follows a lunar cycle. When constant light from human development is added to natural nocturnal illumination, the darkest conditions are never experienced. The magnitude of diel migrations, both in the range of vertical movement and in the number of individuals migrating, is thereby decreased, as has been shown for water fleas, *Daphnia* (Moore et al., 2000). Disruption of diel vertical migration by artificial lighting may have significant detrimental effects on ecosystem health, since decreases in vertical migration of lake grazers may contribute to enhanced concentrations of algae. In turn, this often results in lower dissolved oxygen, and increased toxicity and odour problems.

The haze from skyglow extends far beyond the borders of a city, impacting the environment for miles, including wetlands, the natural habitat of amphibians. As noted above, they become confused and disoriented, resulting in decreased reproduction and therefore lower populations, reduced foraging for food and so lower body weight, and confusion of natural instincts that protect against predators and the elements.

Fishes are also highly attuned to natural ambient light conditions, with lighting levels influencing the distribution of predators and the foraging behaviour of prey. Laboratory experiments have shown that the timing of downstream migration of Atlantic salmon (*Salmo salar*) fry is significantly delayed and disrupted by lights of a similar illumination and spectrum as street lights (Riley et al., 2013). Nocturnal downstream drift of insects is also delayed by artificial lighting (Henn et al., 2014).

Islands, oceans and reefs

Light propagates unimpeded across open water and extends beyond the curvature of the Earth by reflection off high clouds. Fog also increases the local impacts of bright lights. Although light shining directly down onto water tends to penetrate rather than reflect, light coming in at a low angle is reflected. This is usually at less than 45° unless the water surface is disturbed by wavelets. This physical property of water exacerbates the effects of coastal lighting as it is reflected and propagates out from the shoreline. Island, ocean and reef environments are affected by artificial light sources including light-assisted fishing, urban skyglow, offshore hydrocarbon facilities and passing cruise ships (Davies et al., 2014; Figure 1.12).

Nearly all seabirds are nocturnal, and an adverse response to ALAN should not be surprising (Montevecchi, 2006). Nocturnal seabirds are less active during moonlit nights, and those that are active suffer more predation during those times. Seabird chicks are directly affected by lighting levels, as they are far less likely to be fed by adults during bright nights (Riou & Hamer, 2008). Seabirds are attracted to lights because they cue in on bioluminescent plankton to find prey. Therefore, they have long suffered from collisions with light sources on and adjacent to the ocean, including lighthouses, cruise ships, fishing vessels, lighted buoys, oil derricks and street lights on and near islands where they nest (Rodríguez et al., 2017). Many of these collisions are fatal. Where lights correspond with critical habitat or high-use areas such as feeding zones, breeding sites or migratory routes, the effects could be significant.

Cruise ships are pervasive, large and often brightly illuminated. Ships in the path of bird migrations, or near undersea food sources, may attract both migratory birds and foraging seabirds. When they collide with ships they can be stunned or killed. Anecdotal accounts have emerged where cruise ship staff frantically work to clear the decks of dead birds before passengers awake in the morning. Offshore hydrocarbon extraction platforms are also significant sources of light, and attract and kill birds through collision, exhaustion and even by incineration in flares burning off natural gas. Many of these birds are long-distance migrants, and the losses at oil platforms may affect regional and global breeding populations.

Coral reefs are also threatened by artificial night lighting. Corals are highly sensitive to light and synchronise spawning according to lunar cycles (Jokiel et al., 1985; Gorbunov & Falkowski, 2002). Many coral reef species exhibit marked light-driven diel cycles or synchronise reproduction by monthly cycles (Sebens & DeRiemer, 1977; Bentley et al., 2001; Levy et al., 2001; Bos & Gumanao, 2012). Predator-prey interactions are influenced by light levels, especially associated with diel vertical migration of both zooplankton and planktivorous fishes (Leis,1986; Yahel et al., 2005). Artificial light at a lagoon in Moorea, French Polynesia, reduced the growth and survival probability of coral reef fish, possibly due to increased predation (Schligler et al., 2021). Natural light signals, such as bioluminescence, are important to marine organisms, and can both attract and repel fishes (Holzman & Genin, 2003; Holzman & Genin, 2005). Artificial lighting is also known to affect the colonization of marine invertebrates on surfaces.

Figure 1.12. ALAN at sea. Left, Sea Rose oil platform and support vessel. Upper right, Sea Dream cruise ship. Lower right, squid boats. Source: Wikimedia Creative Commons

Grasslands

Like other open habitats, light has few barriers in grasslands. Depending on topography, lights spread general illumination and direct glare over hundreds of metres. Grasslands are vulnerable to disruption from even distant lights. In wet grasslands, mammals such as polecats, weasels and foxes are more likely to take paths near lights, while other species are either not influenced or prefer darker areas. Such differences in habitat use also have the potential to change predation rates and the distribution of prey species.

Fireflies (Figure 1.1), often found in wet grasslands, can have their signals disrupted or be excluded by high illumination (Owens & Lewis, 2021). Light is used for firefly communication, both for sexual behaviour and in some interspecific interactions where females attract males of other species to capture and eat them. Any disruption of the ability to see firefly light will therefore have adverse effects. Artificial light washes out the signals used for communication and potentially contributes to the decline of fireflies and other organisms that rely on bioluminescent communication (Bird & Parker, 2014; Van den Broeck et al., 2021).

Deciduous and evergreen forests

Although forest canopies block light, forest floor species are sensitive to illumination at levels appropriate to the darker night environment there. Salamanders in forests exhibit reactions to dim light equivalent to moonlight, <0.1 lux, under which foraging is reduced or delayed (Wise, 2007). Lighting experiments have also shown a delayed emergence time of nocturnal mammals and reduced foraging activity. For sugar gliders (*Petaurus breviceps*), a nocturnal forest mammal native to Australia, light equivalent to that produced by street lights, 7 to 12 lux, reduced the time that individuals were active at night (Barber-Meyer, 2007).

In other instances, reproductive behaviour can be affected by artificial lighting. The leafcutter ant (*Atta texana*) usually undertakes nuptial flights approximately fifteen minutes before dawn, but in instances where security lights on homes and businesses were visible, the colonies flew fifteen minutes after dawn (Moser et al., 2004). This change in timing interferes with behaviours that are carefully synchronised across colonies. Furthermore, artificial lights are also attractive to the flying ants and so may both decrease mating success and increase predation at the lights.

Alpine and tundra habitats

Alpine and tundra habitats are disproportionately represented in protected and conservation lands. Even outside protected areas, they are on average less developed than other habitat types. However, they are sometimes developed for recreation or industry. As in other habitats, control of artificial lighting in these habitats is important to avoid disruptions of predator-prey interactions and to avoid disrupting the annual rhythms that are linked to day length. The topography of mountains also makes them vulnerable to skyglow from distant sources, especially on steep slopes facing the source of the skyglow. Conversely, the slopes away from light pollution sources often provide opportunities for dark sky place certification within relatively easy reach of large urban populations.

As elsewhere, predator-prey interactions are mediated by illumination. For example, small mammals on the rocky outcrops typical of alpine regions are often nocturnal, foraging in open areas at night and retreating to the safety of outcrops for shelter. In experimental conditions one such species, the long-eared mouse (*Phyllotis xanthopygus*), foraged less under 1.5 and 3.0 lux when compared with a 0.0 lux control (Kramer & Birney, 2001). Full moonlight is 0.1 lux. Similar results have been found for snowshoe hares which are subject to more predation under brighter nocturnal conditions, especially during the winter (Gilbert & Boutin, 1991). Such small mammals depend on natural darkness for safe foraging (Vasquez, 1994).

In alpine and tundra environments, where conditions change so dramatically between the seasons, appropriate synchronization of activities is important. For example, the eyes of the caribou *Rangifer tarandus* change seasonally to reflect different wavelengths of light. The colour of its *tapetum lucidum*, a layer of tissue in the eye of many vertebrates lying immediately behind the retina, shifts from yellow in the summer to blue in the winter, which is associated with increased retinal sensitivity during the dark winter nights (Stokkan et al., 2013; Fosbury & Jeffery, 2022). Domesticated caribou, or reindeer, exposed to sodium vapour street lights just over the horizon are reported to have green eyes in the winter, not completing the normal transition from yellow to blue, and with reduced visual sensitivity (Yong, 2013).

Urban environments

Even though urban environments have many sources of artificial lighting at night, variations within already light-polluted environments still make a difference to wildlife. For example, the American crow *Corvus brachyrhynchos* chooses roost sites that are more brightly illuminated than non-roost sites (Gorenzel & Salmon, 1995). This is thought to enhance communal defence behaviours, reducing predation from owls. Elevated populations of this species have adverse consequences for other prey species for which the crows are predators.

Urban-tolerant bat species are influenced by the degree of illumination on the exit hole of their roosts. Nightly emergence is delayed by illumination of the exit, which reduces fitness of individuals in the colony and can eliminate the colony altogether (Boldogh et al., 2007). Because of the importance of bats as consumers of insects, and their conservation status, the adverse impacts of lighting are of great concern (Voigt et al., 2018).

As already noted, most birds have evolved to migrate at night, this for defensive reasons. However, lighted buildings are also sites of bird mortality as they perceive lit windows as passages through forest canopies (Figure 1.9). Birds die either in collisions with buildings at night, or during the day when they attempt to regain their orientation and continue migration. It is estimated that over 100 million birds die each year from building collisions in North America (Loss at al., 2012).

Attraction to lighted towers often results in death from collision with guy wires. In Hawai‘i, when endangered seabirds like Newell's shearwater *Puffinus newelli* and the dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) leave the nests for their first flight, baby birds are supposed to head towards the bright reflection of light on water. But when nearby street lights shine brightly the fledglings get confused. They fly towards the lamps and end up circling them until they drop from exhaustion or collide with buildings.

The profusion of light in urban areas also has spillover effects on surrounding natural areas and open spaces within cities. For example, extremely high levels of ambient light are measured in the Santa Monica Mountains National Recreation Area near Los Angeles, with all-sky brightness exceeding natural levels by 18.4 times and maximum nocturnal vertical illuminance 32.4 times. Although it is difficult to address the multitude of sources of light, it is worthwhile for parks to install dark-sky compliant lighting and incorporate the night sky as part of visitor engagement and outreach to nearby communities (Aubé & Roby, 2014).

Possible evolutionary trends

As with any resource, artificial light at night can be exploited by some species, which can result in harm to others. Particular examples of this include the expansion of diurnal species into nighttime hours, described as exploiting the "night light niche" (Garber, 1978). This can be associated with giving one species a competitive advantage over others, and can drive invasions of nonnative species (Thawley & Kolbe, 2020). Nocturnal species may preferentially use the conditions provided by artificial light, including the examples of bats consuming insects attracted to lights, prey species concentrating in brighter areas to detect predators (Ditmer et al., 2020), and nocturnal predators and herbivores concentrating in the presence of artificial light (McMunn et al., 2019; Nuñez et al., 2021; Rodríguez et al., 2021). Light-exploiting behaviours are seen across taxonomic groups, including birds (Rodríguez et al., 2021), reptiles (Garber, 1978), insects (Nuñez et al., 2021), and mammals (Voigt et al., 2018). These alterations in species distributions and abundance result in associated deleterious effects on other species arising from predation, herbivory, and competition. Plants also respond to artificial light at night, with evidence suggesting that some invasive species may benefit from it (Murphy et al., 2021; Speißer et al., 2021).

Conclusion

This section has illustrated how artificial light can impacts a variety of animal and plant species, especially insects, bats, birds and turtles. It has also given examples from a habitat point of view, from shorelines to wetlands, deserts to the open ocean, and grasslands to urban environments. As reported by Newport et al. (2014), global population growth and associated urban development have profound effects on biodiversity. In part this is due to light pollution. Light and other pollutants affect the physiology, behaviour and reproduction of many species. Effects also include changes in foraging behaviour, reduction in animal fitness and increased risk of predation. These could have consequences at the population and ecosystem levels. To reduce the effect of light pollution, there needs to be careful planning of urban areas in relation not just to protected areas but to biodiversity in general. Potential measures include strategic planning of developments and associated human activities, and implementing the light pollution abatement guidelines detailed later in this report.

Researchers may wish to evaluate the contribution of light pollution versus other factors, such as climate change and habitat loss, in the deterioration of ecosystems and the reduction of biodiversity, particularly of insect and bird species. Just as in giving a probability percent to the cause of extreme weather events to a due to climate change, it would be persuasive if the contribution of light pollution to environmental degradation of any kind could be given a statistical or quantitative weighting. There is also scope for more research into the effects of artificial light in a variety of habitats, especially wetlands, temperate and tropical grasslands, savanna and urban areas.

Human values and impacts

While conservation managers should focus on protecting the ecology of the night through appropriate lighting, they should also consider the social impacts and benefits of light pollution and its abatement. While many citizens are concerned about conserving nature at night, most people still need encouragement. This is most easily achieved by demonstrating the immediate human impacts of light pollution and these benefits of preserving natural night skies:

- Energy efficiency gained through the elimination of light where and when it is not necessary
- Human health improved by less sleep disturbance due to light spillage into homes
- Safety and security improved by getting rid of glare and excess lighting on pathways and roads
- Giving the public a right to enjoy the night sky and the nocturnal environment in their natural states
- Astronomical science enhanced by reducing skyglow and distant light sources that degrade the quality of telescope observations
- Fostering the intangible heritage of traditional practices relating to the night sky
- Better understanding of mythologies related to the night sky
- Improved appreciation of heritage structures through lighting appropriate to their era

The first three of these are the aspects that most resonate with people, be they visitors to protected areas, participants at urban star parties, or citizens more broadly concerned with environmental quality as it relates to their health and welfare. Most protected areas do not consume large amounts of energy for lighting. Nevertheless, energy efficiency messages should be integrated into visitor engagement and outreach. Visitors to, and neighbours of, protected areas present an opportunity for conservation staff to help influence the broader agenda of reducing light pollution. Protected area staff should also incorporate energy savings technologies into their demonstrations of sustainable development. Similarly, the threat of light pollution to human health is not an issue at protected areas, but related messages should be included in visitor engagement so that citizens may think and act more about reducing light pollution when they return to their urban environments, where light also impacts wildlife. This argument extends to messaging about how light pollution reduces safety and security in urban settings. For more context on the meld of healthy parks and healthy people, see [iucn.org/commissions/world-commission-protected-areas/our-work/people-and-parks].

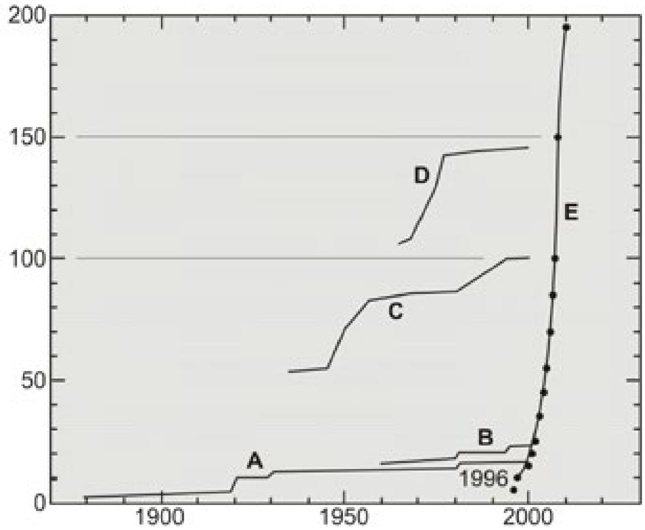


Figure 1.13. The historical increase of efficacy for a set of common lamps. Vertical axis in lumens/ watt. A incandescent, B halogen, C fluorescent, D sodium vapour, E white LEDs. Source: Robert Dick

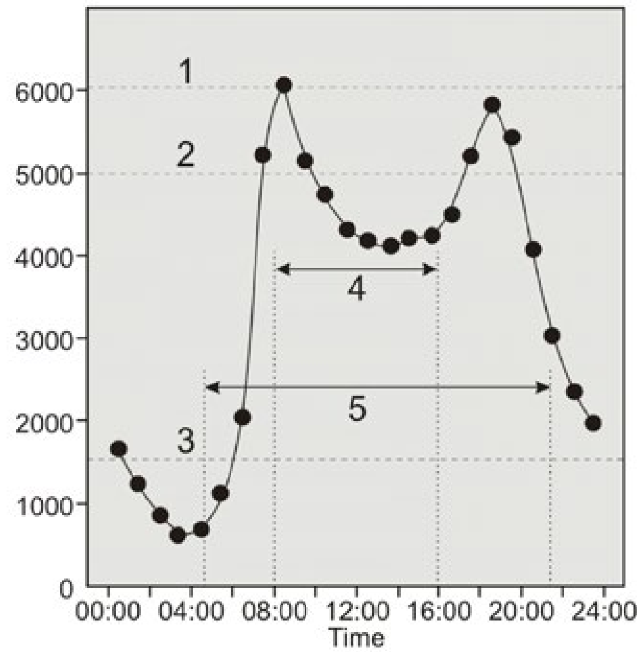


Figure 1.14. Typical weekday traffic pattern for an urban area. London, UK, September 2009. 1 workday peak, 2 workday average, 3 night average, 4 winter daylight hours, 5 summer daylight hours. Source: Robert Dick

Energy efficiency

Many people do not usually associate light with significant energy use. There are two reasons for this. In the past, energy was relatively inexpensive so the cost of powering light fixtures was low. Second, as the cost of energy increased, the efficacy (lumens/watt) of lamps also increased, further reducing the relative cost of light. Although the global market for lighting is hundreds of billions of dollars (Mills, 2002), social and cultural pressures drive the demand for outdoor lighting, so the use of outdoor lighting is generally uncoupled from the cost of electricity. Artificial light plays several roles from aesthetics to safety and security. It has become a symbol of social prosperity. The social acceptance of cheap light makes it difficult to wean societies off the increasing use of light. The needs and benefits of outdoor lighting have become an unquestioned social dogma.

Industry-recommended illumination levels are based on decades-old practices that do not take full advantage of current technologies, luminaire designs and understanding needs and impacts. Governments have based their lighting policies on these older practices, resulting in illumination levels that are unnecessarily bright.

Light Emitting Diodes (LEDs) are by far the best choice of light source (Figure 1.13). They are inexpensive when made in quantity, their light is easily directed to a target area, they are easily shielded and dimmed, and their colour (spectrum) can be controlled. Previous lamp technologies seem to have reached their maximum performance, whereas LEDs have the potential for further improvement.

The lighting industry's best practice documents are based on the performance of available luminaires and metrics at the time they were written, and ecological and health impacts were not considered. New guidelines for outdoor lighting, first published in 2008 by an organization independent from industry, are based on the ecological and health impacts of artificial light at night (RASC, 2020; Dick, 2020-2021). They form the basis of the guidelines presented below. Compliant light fixtures use about one-quarter the power of the typical industry-based practices.

Roadway lighting is designed for peak traffic density, i.e. rush hour. Figure 1.14 shows that rush hour in the temperate latitudes occurs during daylight for about half the year, and yet lights remain at full brightness all night. Dimming during times of low vehicular densities can reduce energy use by more than 50%. Using traffic as a proxy for human activity throughout the day, it shows that for most of the year peak activity occurs during daylight hours. Although outdoor lighting enables a 24-7 lifestyle, only about 15% of people are active outdoors at night. For most of the night, traffic densities are low so roads are over-lit and energy is wasted. There can be considerable energy savings, perhaps 50% to 75% annually, if road lights are dimmed during off-peak hours. Unfortunately, despite of improvements in lamp efficacy, outdoor lighting is increasing at 2.2% per year (Kyba, 2017), undermining energy savings from the use of better lamps.

By taking full advantage of new technologies, the energy used for outdoor lighting can be reduced to less than 50% of current levels. However, this applies only if one curtails increases in lighting levels and limits the proliferation of light fixtures across both urban and rural landscapes. Some municipal policies encourage dimming during periods of reduced vehicle and pedestrian traffic, but most do not. Governments should review recommended illumination levels and controls to minimise energy use. Brighter levels are rarely necessary.

Human health

For more than a billion years, life on Earth has been exposed to the day-night cycle and has evolved to benefit from and exploit the contrast between day and night. In humans, this circadian rhythm schedules many important biological functions. During the 20th century there was a significant brightening of artificial light at night, so that most of the planet's population no longer benefits from a naturally dark night. Historically, artificial light at night (ALAN) was considered benign, even beneficial. Artificial light was considered a symbol of prosperity. Emerging health issues were attributed to other social and environmental changes that increased reliance on public health systems. There were no critical health assessments when outdoor lighting was being considered. However, in the late 20th century, research into biology and ecology began to reveal that ALAN has a profound impact on human health (Chepesiuk, 2009).

After sunrise, hunger and alertness increase, peaking at about 10:00. Around 15:00 our coordination and reaction times are at their best. The cardiovascular system is at peak efficiency and muscle strength reaches it's hgighest point at 17:00. The deepest sleep is around 02:00 (Roberts, 2012). Artificial light changes the night into one for which no life has evolved. Human biology, as with plants and animals, is so determined by light and dark periods that biological processes are scheduled to occur at specific times during the 24-hour period. This daily rhythm is synchronised by the beginning of night, when the illumination of twilight falls below the threshold of approximately the full Moon, the brightest natural light of the night. To put this into perspective, this threshold is less than one tenth the illumination required to read.

Our bodies synthesise and accumulate the hormone melatonin during daylight and release it when our eyes' retinal ganglion cells sense that it is night. Melatonin secretion enables the release of other hormones that rejuvenate our bodies after a stressful and strenuous day. During daylight other biochemicals are released to ensure that we can cope in the day, whereas the hormones released at night help combat disease, particularly viral infections. These hormones also aid in the attack on incipient cancer cells to reduce the chance of tumour growth. Light at night, especially blue spectrum light, and even with eyelids closed, suppresses the release of melatonin. The lack of a good, dark sleep can also lead to heightened levels of stress, anxiety, reduced cognitive functions and increased symptoms of dementia (Roberts, 2012). All these side effects strain public healthcare systems and reduce the quality of life.

This evening light threshold is so critical that, as well as the well-known rods and cones, non-imaging but light-sensitive retinal ganglion cells also evolved to detect the fading twilight. These cells are primarily sensitive to the blue light of twilight (Gooley et al*.*, 2010) and are our subconscious twilight detectors. They support the regulation of the release of hormones that help fight infection, disease and some cancers. Ambient light is usually composed of a range of colours. White light has a bright blue component that subconsciously fools our twilight detectors into reporting that it is still daytime or early twilight, and inhibits the release of the restorative hormones. After a few hours these hormones begin to atrophy and are reabsorbed. Over time this undermines the natural biology that maintains physical and mental health. Studies into late night activity, using vehicular traffic as the proxy, show that most people sleep at night, and have no need for night lighting outdoors or indoors. However, the illumination through a window from outdoor lighting can light a room more than the full Moon outdoors (Figure 1.15).

The role of the twilight detectors is relatively new knowledge which flags the profound impact of ALAN. Minimizing this impact of bright, white and unshielded light is technically practical. Shielding the outdoor light so that it does not shine into buildings requires modifying existing luminaires, or requiring that all new luminaires be carefully shielded and dimmed, or turned off late in the evening. Society can once again adopt the non-white outdoor lighting that does not contain blue-light components. Although ALAN helps to extend daytime activity into the night, society should debate the priorities of late night activity against improved health for all, and require governments to educate and regulate accordingly.

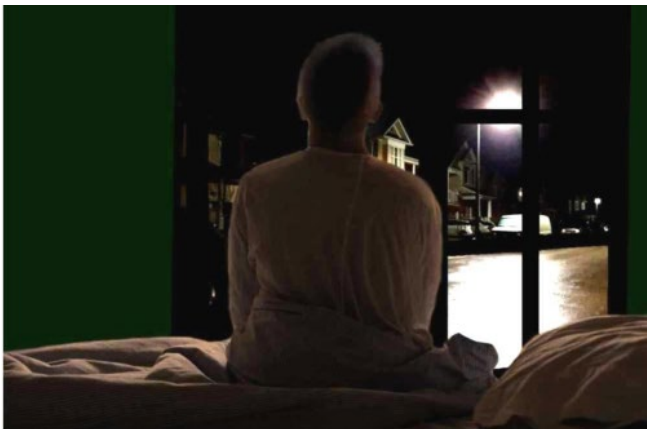


Figure 1.15. Bright and unshielded street lighting. Source: Robert Dick

Figure 1.16. Glare and distraction. Source: Robert Dick

Safety and security

Genetically, humans are still daytime creatures, hunter-gatherers who depend on daytime vision for survival. During the late evening the predators of the night begin to replace the predators of the day. More sensitive night vision helps people avoid late evening hazards. Our night vision is well suited to pedestrian activity, even under only starlight, but it is compromised by illumination less than one lux, equivalent to deep twilight, and especially by direct sources of glare. In response to perceived need for extra safety, cities and towns attempt to bathe streets in perpetual twilight (Besecke & Hänsche, 2015). Our evolutionary respect for the night and for avoiding danger has been replaced by a fear of darkness. However, extra light does not necessarily make streets safer. For example, a study of 62 local authorities in the United Kingdom found that there was no statistically significant evidence that any street lighting adaptation strategy was associated with a change in road collisions at night. Similarly, neither was there any evidence for an association between more crime and switch-off or part-night lighting. Conversely, there was some evidence for a reduction in the aggregate count of crime and dimming of lights (Steinbach et al., 2015).

Figure 1.17. Glare and situation awareness. Source: IDA

Excessive lighting hides hazards in plain sight. In Figure 1.16 the road is brightly lit, but the distractions and visual clutter of advertising signs draw the focus away from the road, and the glare of unshielded lights reduces the ability to see into shadowed areas. Together, these may impede seeing potential hazards. The nearer street lights are full-cut-off luminaires. The more distant lights are unshielded, and the glare from those lamps and from commercial lighting distracts and blinds drivers to the less-lit pedestrians and vehicles entering the main road from the side.

Reading is one of the eye's most demanding challenges. The resolution required to see letters at a distance requires the high visual acuity of daytime vision. This has an illumination threshold of about three to five lux, about mid-twilight, at which our reaction rate is about a third of a second. In response to the speed of vehicles and the reaction times of motorists, roadways are illuminated to ten times higher levels than needed for reading. However, response time at thirty lux is still only about one forth of a second, not significantly faster. Coupled with a two second response delay due to roadside distractions, much lower light levels that allow night vision to function properly are arguably just as safe (Triggs et al., 1982), while consuming less energy and reducing light pollution.

The glare from a single isolated light can undermine visibility of the entire scene. By blinding our night vision we see only the immediate area around the unshielded light, and not into the dark shadows that it creates (Figure 1.7). However, security comes from awareness of our entire surroundings. Bright light floods our night vision that would otherwise reveal hazards such as running animals, wind-blown trash or people lurking on the side of the road or path. Indeed, the glare from unshielded lights can cause people to look away, which further undermines the utility of the light. This situation awareness is a critical safety concern, such as being able to see into shadows (Figure 1.17). Illumination of detail confuses our ability to assess the situation. It slows assimilation of information, turning a benign situation into a dangerous one. So, paradoxically, bright outdoor lighting that is not restricted to the area of concern reduces safety. This can be particularly dangerous outside towns and cities, where sensitive night vision is needed.

Glare and poorly installed artificial lighting limit a sense of place. Our eyes can detect a wide dynamic (brightness) range, but bright lights blind us from seeing into dim areas. Even after moving away from the source of glare, our eyes require several minutes to recover full night vision capability. Many urban dwellers are not conscious of their night vision until they journey to a natural environment without artificial lighting, or when there is a major power failure. All this suggests that well-shielded lighting that provides modest illumination, typically less than three lux, is more important to safety than brighter illumination with glaring floodlights and light trespass over adjacent properties. Safety is best provided by a modest light level that is directed only to the target area, and that is carefully shielded to prevent glare.

Conclusion

Even small amounts of white or blue light in our bedrooms, when repeated over months and years, have significant implications for our health, both in the sense of chronic illness and in the sense of reduced vigour and alertness in the following day. Glare and light clutter lead to decreased ability to see into shadowed areas and so increase hazards for driving and less awareness of obstacles and hazards when walking.

The tangible heritage of cultural practices relating to astronomy

All astronomy takes place in a cultural context, whether it is modern scientific astronomy or a much wider range of cultural practices relating to the sky. In this sense, all astronomy is cultural astronomy. Astronomical heritage appears in a wide variety of forms, both tangible and intangible. The tangible heritage of astronomy includes immovable facilities such as observatory buildings, fixed instruments, ancient stone carvings, astronomically aligned architecture and urban layouts (Cotte & Ruggles, 2010). It also includes moveable instruments and artefacts, such as records of observations, sky maps and archives. Astronomy is, by its very nature, intangible, so intangible heritage is also important, whether as scientific theories and calculations, traditional star knowledge, calendars or other practices related to the sky. These different forms of astronomical heritage are strongly linked to each other and to dark skies. Wherever naturally dark skies were essential for the observations that helped make a place significant, and are still preserved, they form a key component cultural heritage. Limiting light pollution is an important aspect of its preservation.

Two ICOMOS Thematic Studies on the Heritage Sites of Astronomy and Archaeoastronomy (Ruggles & Cotte, 2010; Ruggles, 2017) and the UNESCO-IAU Portal to the Heritage of Astronomy [astronomicalheritage.net] highlight many types of tangible astronomical heritage. These range from prehistoric sites and artefacts to historical and modern observatories and even heritage relating to space exploration. Many more examples are contained, for example, in the Springer *Handbook of Archaeoastronomy and Ethnoastronomy* (Ruggles, 2014). Here are some key types and examples of immovable tangible heritage.

Ancient sites aligned with astronomical phenomena

Many prehistoric tombs are aligned to sunrise at some point in the year. Examples include all 177 of the seven-stone antas in Portugal and Spain built during the 4th millennium BCE (Figure 1.18; Hoskin, 2001). They are examples of dolmen, a distinctive type of stone monument common worldwide. Better known internationally are solstitially aligned temples such as Stonehenge in the UK and the temple of Amun at Karnak in Egypt, both World Heritage Sites (WHS). There is no evidence that Stonehenge functioned as a calendar, and it did not mark the solstices precisely in time, but it and similar sites were apparently related to seasonal ceremonies that took place around the solstices. The thirteen towers of Chankillo WHS in Peru were built in 200 BCE. Their north-south line of towers within a large ceremonial complex represents a solar horizon calendar on a monumental scale. Sunrise could be measured against

Figure 1.18. A seven-stone anta, near Valencia de Alcántara, Spain. Source: Clive Ruggles

the towers over the entire year from an observing point accessible only to elite individuals. The calendar appears to have operated as part of a warrior and solar cult (Ghezzi & Ruggles, 2007). Chankillo was inscribed on the World Heritage List in 2021.The so-called Governor's Palace at Chichen Itza WHS, Mexico, faced the most southerly rising point of the planet Venus around the date of its construction in the early 10th century. This is known from an inscribed Mayan Long Count date. The façade of the building contains numerous iconographic representations of the Venus cycle and of the Mayan zodiac.

Orchestrated displays of light

While not directly about the night sky, these sites are equally valued as part of cultural heritage related to astronomy. Newgrange Passage Tomb WHS in Ireland was built in the late 3rd Millennium BCE. It is oriented so that sunlight enters and shines down the length of its passage for a few minutes just after sunrise around the time of the winter solstice. At all other times the passage is dark. This is presumed to reflect a perceived connection between death, ancestors and ancestral spirits and the Sun, seasonality and seasonal renewal (Ruggles & Chadburn, in press). The temple of Abu Simbel at Karnak WHS was constructed in Egypt in the 13th century BCE.

A beam of sunlight enters the temple at dawn on 22 February, a date of possible significance in the Egyptian calendar. The beam illuminates the carved figure of the god Amon-Re who is associated with the Sun. It is not certain that this was intentional, but it appears to represent an orchestrated sacred display. Another example is the vaulted dome of the Pantheon in Rome. It contains an 8 m diameter hole, or oculus, at the top, through which a beam of sunlight enters. On April 21st the beam lights up the entrance at noon, apparently so that the emperor could enter with the Sun during celebrations of the foundation of Rome. Xochicalco WHS, a fortified political, religious and commercial centre in Mexico, reached its apex in the 7th to 10th centuries. It contains a carefully constructed zenith tube that allowed the Sun to shine directly down into an artificial cave on days when it passed directly overhead at noon (Figure 1.19). This may have been another sacred display but it could also have functioned as a calendrical device.

A cave sanctuary at Risco Caído WHS in Gran Canaria, Spain, was constructed by the Indigenous population prior to the arrival of Europeans in the 15th century. It was hollowed so as to have a smooth paraboloidal roof. Its walls are decorated with numerous cup marks and other carvings. Between the spring and autumn equinoxes, morning sunlight enters the cave each day through a specially constructed opening and lights up various sequences of carvings. This appears to have combined both fertility symbolism and calendrical significance (Cuenca et al., 2018). Risco Caído and the Sacred Mountains of Gran Canaria was inscribed on the World Heritage List in 2019.

Sites important in the development of modern scientific astronomy and astrophysics

These are immovable pre-telescopic observing instruments such as the 13th century giant gnomon at Dengfeng in China (Figure 1.20), a 40 m high meridian quadrant that once formed part of Ulugh Beg's 15th century observatory in Uzbekistan, and the 18th century Jantar Mantar observatory at Jaipur in India. All are on the World Heritage List.

Better known today are the classical observatories built from the time of Galileo through to the birth of astrophysics, originally mostly in Europe but later also in colonial locations. Among the most outstanding examples are: the Royal Observatory at Greenwich, UK; the Paris Observatory, France; and the Royal Observatory at the Cape of Good Hope, South Africa (Wolfschmidt, 2009). From the late 19th century onwards astronomical observations were being transformed by the emergence of astrophysics. Many observatories were built during this time, including the Observatory of Paris-Meudon in France, the Mount Wilson Observatory in California in the US, and the Einstein Tower in Potsdam, Germany. Many observatories are World Heritage Sites, as is Jodrell Bank in the UK, built for astronomy at radio wavelengths.

High-mountain observatories are built to take advantage of exceptional atmospheric conditions. One of the earliest examples is Pic du Midi Observatory in France, built originally as a meteorological station in the late 19th century. Modern examples include La Palma Observatory in the Canary Islands of Spain, Maunakea Observatories in Hawai'i, US, and several observatories in northern Chile.

Space heritage

Places related to the process of carrying out science in space and to manned space flight and exploration include launch sites such as Baikonur, Kazakhstan, and Cape Canaveral, US. Human cultural heritage that remains off the surface of the Earth, either in space or on other bodies such as the Moon or Mars, are exemplified by the Hubble Space Telescope, the Lunar and Martian rovers, Neil Armstrong's footprints on the Moon, and several probes now voyaging in interstellar space.

The term observatory implies that astronomical observations were the sole or primary purpose of a given site or construction. This is rarely demonstrable outside the context of the world's great literate cultures and the history of modern scientific astronomy. Indeed, astronomical heritage, even the heritage of modern scientific astronomy, rarely exists in isolation. It is typically embedded in a range of cultural practices that may also produce a variety of other tangible heritage. A good example is the Einstein Tower in Potsdam, Germany, noted above, which is exceptional both as scientific and architectural heritage.

Only in a few cases has the astronomical knowledge of our forebears left its mark in the form of recognisable and significant tangible remains. But some level of interest in celestial objects and events was undoubtedly a feature of the great majority, and perhaps all, of human societies over many millennia. A truly dark night sky, where it can still be seen, serves as a poignant reminder of this.

Where a heritage place of astronomy has a direct connection with observations of the stars, be it an ancient Hawaiian navigation temple or a modern optical observatory used to

Figure 1.19. Light beam through a zenith tube, Xochicalco, Mexico. Source: Oldracoon, licensed under Wikimedia Creative Commons

Figure 1.20. Dengfeng Observatory, 'The Centre of Heaven and Earth', China. Source: Liu Yantao and Yang Jiali

explore the distant universe, enduring dark skies form an important component of cultural heritage. This means that tackling light pollution is a crucial part of conserving that heritage. But even at sites which, like the majority of those mentioned above, relate to the Sun rather than to the stars, there is still a general argument for keeping the night sky as dark as possible in order to help visitors comprehend the place in its natural context. Indeed, maintaining any prehistoric cultural landscape in its authentic setting, including dark skies at night, helps the modern visitor appreciate how these ancient sites and monuments would originally have been viewed. In and around Stonehenge, for example, reducing light pollution from car headlights and keeping additional road lighting to a minimum has been an important element of road improvement schemes.

Traditional cultures and the night sky

Throughout human history a wide range of cultural practices related to the sky, and specifically to a dark night sky, are as much a part of people's everyday world as their terrestrial surroundings. Some traditional practices relating to a starry sky persist in Indigenous cultures even to the present day. Obvious examples are navigation by the stars and calendrical regulation. But for Indigenous cultures, objects in the sky are not just points of reference. Skies are typically seen as full of living entities that influence, and are influenced by, earthly events. Sky knowledge is not a separate category of knowledge, like modern astronomy, but forms an integral part of a people's understanding of the world. Aboriginal Australians, for example, have songlines that anchor knowledge, stories and ceremonies to strings of places, both across the landscape and across the sky (Hamacher, 2022).

Some of the best examples of traditional navigation practices relate to the vast Pacific Ocean, colonised by Micronesians and Polynesians over many centuries prior to the advent of European voyagers. They used the stars, ocean swells and a variety of other indicators to cross great distances of open ocean and to arrive at particular islands. One of the most important methods for long-distance voyaging was the star compass, a memorised picture of the rising and setting positions of stars around the horizon that could be compared at any time with what was actually observed. A modern Hawaiian version has been developed by the Polynesian Voyaging Society [hokulea.com] following instruction in the 1970s by the Micronesian navigator Mau Piailug. Since 1975 the Society's voyaging canoe named Hōkūleʻa, the Polynesian name for Arcturus, the guiding star for the Hawaiian Islands, has travelled around the world using traditional navigation methods. Tangible manifestations of long-distance voyaging include the Pānānā sighting wall on Maui, either a memorial to earlier voyages south to Tahiti or to a specific voyager (Kirch et al*.*, 2013). Some traditional star names in the Pacific are modern variants of names of considerable antiquity. Thus the Pleiades star cluster (Figure 1.21) is Matariki, Mataiki, etc. in Polynesia, and Makeriker, Mairiker, Mweriker, etc. in Micronesia (Johnson et al*.*, 2015)

The cycle of lunar phases is the most obvious cycle in the night sky, and the most commonly used to regulate Indigenous calendars. But the need for the occasional addition or omission of a month to keep such a calendar in line with the seasonal year necessitates observations of other seasonal markers. These can include the stars. Until at least the 1960s the Mursi of Ethiopia, for example, used the successive setting at dusk of the four stars that they called Imai (*Delta Crucis*), Thaadoi (*Beta Crucis*), Waar (*Beta Centauri*) and Sholbi (*Alpha Centauri*) to time their migration to the banks of the River Omo to plant a sorghum crop. Each star name was also that of a correlate in the terrestrial realm. Thus Sholbi is a flower whose petals were carried away by the receding floodwaters. Imai is now the international name for the star *Delta Crucis*. The Borana, also of Ethiopia, kept track of the days and months using the position and phase of the Moon among the vertically rising stars (Turton and Ruggles, 1978). See also [virtualmuseum.ca/edu/ViewLoitLo.do?method=preview&lang=EN&id=5185].

For the Anishinabe people of northwestern Ontario, Manitoba and Saskatchewan, Canada, knowledge of the stars is found in many aspects of their culture including storytelling, symbolism and religious traditions [virtualmuseum.ca/edu/ViewLoitLo do?method=preview&lang=EN&id=5185]. Some spiritual leaders have special knowledge of the stars and the planets. In ancient times, these Indigenous astronomers helped guide the day-to-day affairs of their communities. To this day, Anishinabe stories are remembered by these respected storytellers. With the coming of the first snow, families gather around their elders during the long winter evenings and the time for storytelling begins. These stories are not told in the summer, when plants awake and animals roam, since they might hear and be offended. The storytellers speak of these things only in the winter when the spirits are resting.

These practices require a dark night sky. So too do traditional methods of timing water shares using the Sun and stars, once commonplace within the arid Middle East, and still extant in parts of Oman. Nighttime regulation involves the use of a variety of makeshift devices to determine the time of night by observing the movement of bright stars such as Sirius and Arcturus.

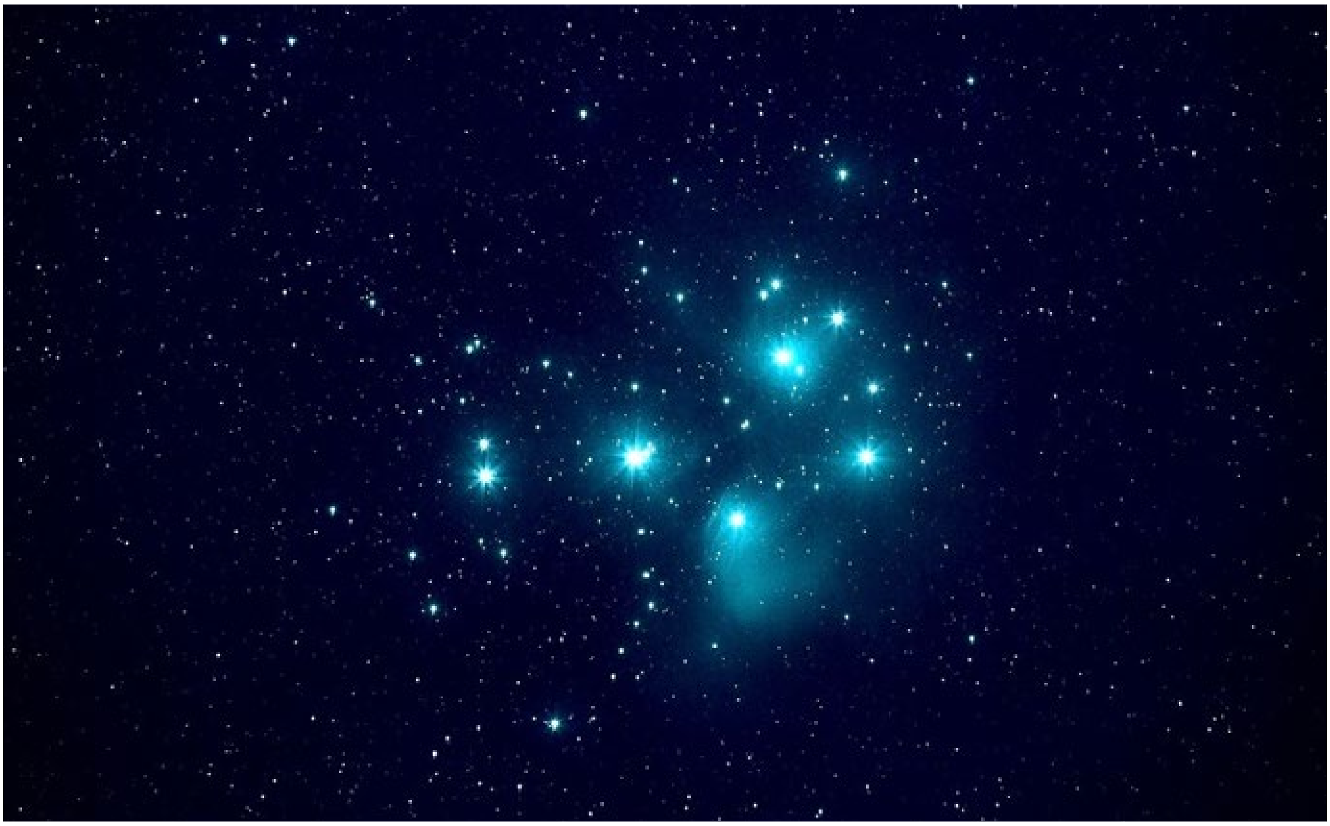


Figure 1.21. The Pleiades (Source: Wikimedia Creative Commons)

In New Zealand, Maori ancestors had an extensive knowledge of the night sky and the movements of constellations and stars. This knowledge has been passed down through generations and is considered a Maori treasure. It was important for many aspects of daily life ranging from the spiritual to the growing of crops, fishing and navigation, and telling time and changes in season. Of particular importance is Matariki, the Maori name for the Pleiades. It rises in mid-winter and for many Maori it heralds the start of a new year. Spiritual experts would look to Matariki to predict how productive would be the upcoming years. Bright clear stars promised a warm and successful season. Hazy stars warned of cold weather and poor crops (Matamua, 2018).

Today, Matariki is celebrated right across New Zealand. People come together to remember their ancestors, share food, sing, tell stories and play music (Wilson, 2018). A revival of traditional skills guided by the night sky is evident today. The New Zealand government is funding Te Mauria Whiritoi, The Sky as a Cultural Resource, a project that looks at Maori beliefs, practices and observations in relation to astronomy, ecology and ritual. Researchers from New Zealand and Hawai'i will collect and preserve a significant body of Maori astronomical knowledge.

The high visibility of the Pleiades star cluster has guaranteed it a special place in many cultures, both ancient and modern, often marking important calendar points. In northern Java, its rising marks the arrival of the Mangsa Kapitu, or seventh season, the beginning of rice planting. In Swahili in East Africa it is called Kilimia, the verb meaning 'to dig' or 'to cultivate,' as its visibility was taken as a sign to prepare for the approaching rainy season. The Basotho people of Southern Africa call the Pleiades Seleme Se Setshehadi, the female planter. Its disappearance in April and the appearance of the star Achernar signal the beginning of the cold season. Like many other southern African cultures, Basotho associate its visibility with agriculture and plenty [en.wikipedia.org/wiki/Pleiades_in_folklore_and_literature].

Two-Eyed-Seeing (TES) is a guiding principle introduced in 2004 by Elder Dr. Albert D. Marshall of Eskasoni First Nation in Nova Scotia, Canada (Hatcher et al., 2009; Dick, 2020). He teaches that TES is learning to see from one eye with the strengths of Indigenous knowledge and ways of knowing, and from the other eye with the strengths of scientific knowledge and its ways of knowing, and learning to use both eyes together for the benefit of all. There is a wealth of information on TES at [integrativescience.ca/Principles/TwoEyedSeeing].

In an astronomical context, the Mi'kmaw Moons Project in Canada (Chapman & LeBlanc, 2017) applied TES to connecting the succession of full Moons to ecological activities such as fish spawning, birds laying eggs and berries ripening. A full Moon has an astronomical explanation, but it also has a traditional explanation that relates to the season and the weather that can be expected at that time of year. For example, Kjiku's (Chief Moon) is the full Moon closest to the December Solstice and in the northern hemisphere it is the full Moon that reaches the highest point and spends the longest time in the sky. A particular full Moon informs the time to plant, to harvest and when particular species are available for hunting. For example, in Mi'kmaw territory a full Moon in February helps in the hunting of larger animals such as moose as they get bogged down in the deep snows of late Winter.

Astronomy and World Heritage

Recognising that astronomy was under-represented on the World Heritage List, UNESCO created a Thematic Initiative on Astronomy and World Heritage in 2004 as part of its efforts to make the List more balanced and credible. In 2008 it joined forces with the International Astronomical Union (IAU) to be jointly responsible for implementing the initiative. In order to encourage national governments to develop World Heritage nominations relating to astronomy, the IAU also joined forces with ICOMOS to produce two thematic studies.

These studies develop principles for assessing the value of different types of astronomical heritage. This guidance helps UNESCO's member governments to identify plausible candidates for nomination and stimulates them to work with stakeholders to develop management plans, to include the relevant places on their national World Heritage Tentative Lists, and to nominate them.

The first thematic study covers a wide range of types of astronomical heritage from prehistoric remains with a relationship to the sky through to historical and modern observatories (Ruggles & Cotte, 2010). It also includes space heritage and dark sky sites. Dark sky places cannot in themselves be considered as potential World Heritage. The reason is clear. What creates a dark sky is not the presence of anything tangible such as a cultural monument or natural feature, but rather the absence of light pollution. Nor is it possible to list the sky itself, as the physical universe is not contained within the territory of any particular country. However, "given that an important aspect of the heritage of many ancient and historical sites is the observation of certain naked-eye astronomical phenomena, the possibility of actually observing these phenomena today is a relevant consideration in valuing and preserving that heritage" (Ruggles & Cotte, 2010, p. 266).

The second thematic study explored a number of key issues in greater depth, using ten extended case studies structured in the form of segments of draft nomination dossiers (Ruggles, 2017). As listed in Table 1.1, five of these focus on how best to recognise and preserve the value of dark skies. The Oman case focuses on the use of observations of stars for timing shares of irrigation water. This practice demonstrates a direct connection between a subsistence economy and a dark night sky that has continued uninterrupted for hundreds, possibly thousands, of years. The progressive erosion of dark skies by light pollution has made it increasingly difficult to undertake the necessary stellar observations and threatens to drive this cultural practice to extinction.

Dark skies at modern observatory sites are not only crucial for continuing their scientific research but also as a strong reinforcement of their value as cultural heritage. Dark skies also respect and complement natural heritage in the form of stunning landscape features. Preserving them can become a key management issue in conserving the value, and enhancing the public's appreciation, of an outstanding natural place.

This second thematic study identifies ways in which dark sky values enhance either or both of the natural or cultural values of a place. In this sense it contributes to identifying a potential Outstanding Universal Value, the basis for inclusion on the World Heritage List. The five extended case studies also explore ways in which light pollution issues can be addressed within management plans.

Alongside the two Thematic Studies, the UNESCO/IAU initiative launched the Portal to the Heritage of Astronomy in 2012 [astronomicalheritage.net]. As well as containing many more case studies than the two Thematic Studies, with two-way links to UNESCO's website for places that are already World Heritage Sites, the Portal contains a range of information and advice on developing a World Heritage nomination.

Change is inevitable in a location valued for its science, and tends to increase rather than decrease its value. This is one of a number of principles established in the two Thematic Studies that apply not only to astronomical heritage sites but more broadly to science heritage sites in general. Recognizing this, UNESCO has recently expanded the initiative and renamed it the Thematic Initiative on the Heritage of Astronomy, Science and Technology.

Table 1.1. Five examples of world heritage and astronomy.

Property	State(s)	Main theme and issues
Astronomical timing of irrigation in Oman	Oman	Cultural landscape: cultural practices explicitly dependent upon dark night skies
Pic du Midi Observatory	France	Cultural site: high-mountain observatories
Leading optical observatories	Chile, Spain, US	Cultural sites: modern optical observatory sites under direct threat from light pollution
Aoraki-Mackenzie International Dark Sky Reserve	New Zealand	Natural site: pristine dark-sky area with broad cultural connections
Eastern Alpine and Großmugl starlight areas	Austria	Natural site: relatively dark-sky areas with few or no direct cultural connections

Another reason for this renaming is that the Astronomy and World Heritage Initiative has come of age. Two new astronomically related World Heritage Sites were inscribed on the World Heritage List in 2019. One is Jodrell Bank Observatory in the United Kingdom for its pioneering radio astronomy. The other is Risco Caído and the Sacred Mountains of Gran Canaria, Spain, a cultural landscape featuring archaeological sites and traditional practices relating to astronomy. More astronomical heritage places are appearing on national Tentative Lists. There is every prospect of a steady flow of new astronomical World Heritage Sites in the years to come, and that these will include both cultural and natural sites together with their dark skies [whc.unesco.org/en/astronomy/#astronomy].

Conclusion

The many aspects of astronomical heritage and traditional practices may not connect directly to nature conservation. Rather, they are integral to respecting local societies and their traditional practices. This theme that should be integrated with interpretation to protected area visitors, especially regarding the links to agricultural and subsistence hunting. This is underscored by the fact that society now recognises how Indigenous cultures helped shaped the ecosystems that we now try to restore and protect. Furthermore, alternative meanings and stories embodied in asterisms and the value of Moon, planet and star calendars help animate the interpretation of the night sky at star parties and night sky talks.

Public enjoyment

As well as caring about the ecological integrity of the natural world, human health and the scientific and other benefits of nights without light pollution, there is the simple pleasure of being able to enjoy natural views and heritage sites in their original, authentic state. The appreciation of clear views of protected areas and areas of outstanding natural beauty benefits from programmes aimed at reducing smog and improving visibility. The United States National Park Service is a leader in this field with its programme to monitor and report on aerosols and visibility. Daytime appreciation of wilderness has also benefited in eastern Canada and the northeast United States from decades of treaty-based reductions of smog precursors, like particulate emissions and volatile organic compounds from electricity generating stations. The value of visibility applies equally to nightscapes, be they horizontal across the landscape or upwards to the stars. Skyglow, glare and light trespass interfere with the visual enjoyment and sense of place in natural areas, be they rural or wilderness, natural or cultural. For an overview of astrotourism see Collison & Poe (2013).

Two examples of the surprising benefits of eliminating artificial light at night come from Jackson Lake State Park, Colorado. The Park used to spend US $17,000 annually to combat mosquitos in the campground. Observing that mosquito populations were less inclined to go to heavily used areas that either had no lights or motion sensed, properly shielded lights (Colorado Parks and Wildlife, 2020, 12-13), campground lighting was changed accordingly and the expense eliminated. Also, without lighting, campers go to bed earlier and there has been a noticeable reduction in disruptive behaviour and vandalism.

Beyond general landscape appreciation, an outdoor experience without light pollution can reveal many specific phenomena that may be degraded or hidden by excess artificial light. The following lists many of these that are available to the naked eye or, at most, basic binoculars.

Looking up

- The five naked-eye visible planets, Mercury, Venus, Mars, Jupiter and Saturn. Binoculars can also reveal Jupiter's moons and Saturn's rings.
- Comets are usually invisible from urban areas, but their tails may be seen from dark sites.
- Meteors and meteor showers.
- While the Moon is easily seen from within urban areas, a clear, dark sky improves the enjoyment of the fine details of its craters and mountains. How moonlight bathes a landscape is dramatically different in a dark sky place. Lunar eclipses are more spectacular in dark sky places.
- Zodiacal light and the gegenschein, the light of the Sun reflected by extraterrestrial dust, are only visible from very dark sites.
- Artificial satellites may not be part of nature, but seeing them does enhance a sense of technological achievement and exploration of Space. On the other hand, the constellations of Internet satellites will be a distinct nuisance for viewing a natural night sky.
- Auroras, either boreal or austral, can only be seen from rural and wild areas at mid to high latitudes. Urban dwellers will never see them, either from their homes or city parks.
- Like the Moon, lightning is well witnessed even in town, but it's upper atmosphere counterpart, sprites, need very clear skies over long distances from the thunderstorm to be able to catch a rare glimpse.
- Noctilucent clouds (clouds that shine at night, usually very thin high altitude clouds observable in summer twilight) are only seen through clear, dark sites.

Looking down

- The presence and activities of nocturnal life can still be enjoyed even in light polluted areas if one is close to a plant or animal to see it after dark. However, light pollution changes wildlife relationships and population numbers, thereby reducing nocturnal appreciation of the ecology of the night.
- The faint light of bioluminescence, be it from diatoms along the shore or fireflies in the woods, is best enjoyed when our eyes are fully tuned to night vision (Cover image and Figure 1.1).

Ways to enjoy the night

- Visits to urban star parks or other places shielded from glare and light trespass
- Star parties, typically held at dark protected sites and organised by astronomy societies and their members who bring high-end personal telescopes to share with the public (Figure 1.6)
- Night nature walks led by a knowledgeable person with the skills to reveal nocturnal animals, to explain the ecology of the night, and, of course, with the local knowledge to guide around hazards
- Vicarious pleasure, as when appreciating other people's images, or simply just knowing that an unpolluted place exists and is protected

Conclusion

There are many ways to enjoy the night sky, even in moderately light-polluted areas, and the nocturnal aspects of life on Earth. Chapter 6, "Guidelines for Public Engagement" presents many ways that protected area staff can convey the night sky and ecology of the night. The underlying lesson is that most visitors to parks and reserves are interested in the totality of their environment, not just its biology, anthropology or history.

Chapter 3 presents case studies of the ways that protected areas and communities have acted to protect and present dark skies. First, however, Chapter 2 sets the stage for the reasons why those particular examples are selected.

Saving the night sky is a giant step toward healing the earth. All creatures depend on the cycles of light and dark. Yet, no creature has a voice except us.

— Creston, Colorado, application for IDA Dark Sky Community certification.

CHAPTER 2.

Dark sky places

What a dark sky place is

A dark sky place is part or all of a protected area, cultural site or community which meets two main criteria. First, it has protocols and practices for light pollution prevention, including management plans, site plans, outdoor lighting guidelines, light pollution monitoring and periodic compliance reviews. Second, it has formal certification by an independent body, such as a national or international astronomy society, or a national or sub-national governmental body.

Typically, a dark sky place also has one or more of the following:

- Clear and unpolluted night skies permitting good and frequent night sky viewing (Figure 2.1)
- Night sky appreciation and education activities such as star parties or astronomy talks
- Nocturnal ecology interpretation, guided observations, research and monitoring
- Education and outreach programmes and agreements to address light pollution in the viewshed
- Cultural or ecological values closely linked to night sky viewing
- Provision for easy and frequent access for independent night sky viewing by the general public

Dark sky communities, such as villages, towns and small cities, may not have sufficient darkness for research or amateur astronomers, but do have outdoor lighting management plans to restrict unnecessary light. They include urban parks that are shielded from glare so as to permit reasonable public viewing of the night sky. They may have tourist destinations such as hotels and campgrounds that offer dark sky programmes and demonstration projects. These types of dark sky places recognise the role of outreach and education to foster appreciation and protection of naturally dark places elsewhere, but which many citizens may not get to easily or frequently.

Light pollution prevention is a low-cost, high-gain opportunity, especially in terms of environmental quality, public participation, conservation messaging, sustainable development, cooperative science and learning. As the saying goes, it is a "low-hanging fruit." Dark sky certification brings many benefits to protected areas:

- It supports their prime mandate to restore and protect ecological integrity.
- It complements the protection of historic structures and pre-industrial cultural traditions.

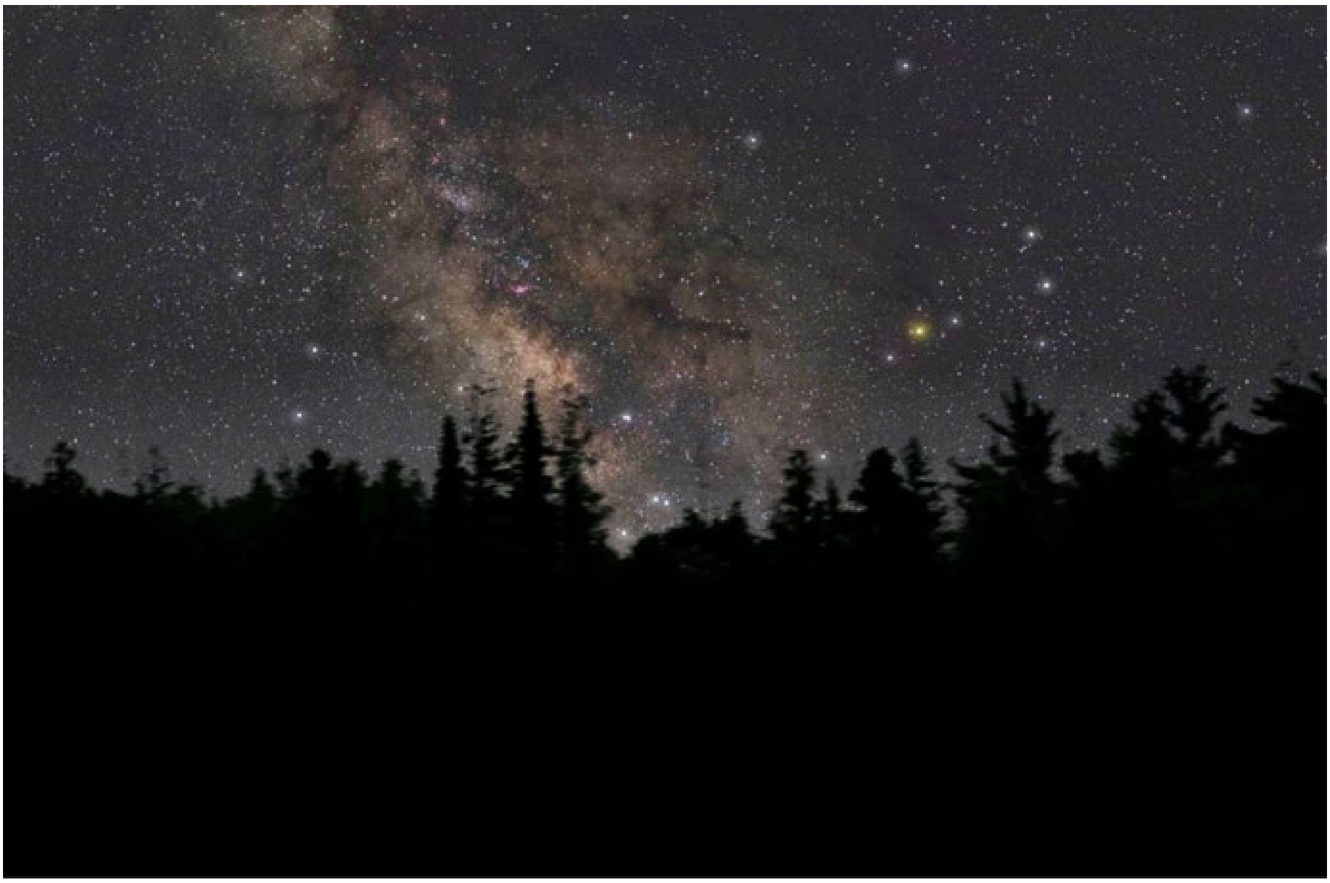


Figure 2.1. The Milky Way. Seen from a bird observation tower, Bruce Peninsula Dark Sky Preserve, Canada. Source: Robert Dick

- It enhances visitors' appreciation of nature, local culture and traditions.
- It increases visitation levels, for example by offering stargazing events during off-peak seasons. This is especially true for repeat visits by local and regional residents.
- It may increase capital investment by astro-tourism operators.
- It is a simple and cost-effective way to demonstrate sustainable development.

Both amateur and scientific astronomy communities benefit from light pollution prevention initiatives of dark sky places. The latter provide opportunities for wilderness astronomy and naked-eye appreciation of the night sky in truly natural areas. Front-country access, such as parking areas to set up heavy telescopes, is often available and free from intrusive lighting. Protected areas attract visitors who are interested in, and engaged with, the natural world, and who can be introduced to the importance of an unpolluted night sky for ecological integrity and cultural traditions. Dark sky signage, leaflets, interpretive talks and walks attract many visitors, and do so even on repeat visits. Park staff are usually available to facilitate public events and coordinate with volunteer astronomy guides.

Dark sky certification programmes

As of June 2022 there are three major programmes which certify dark sky places, two of which are international in scope and one national:

- The International Dark-Sky Association's (IDA) International Dark Sky Places Program, with five categories in twenty-three countries
- The Fundación Starlight programme with four major categories related to nature conservation in six countries
- The Royal Astronomical Society of Canada (RASC) with three categories, all in Canada

There are several other arms-length recognition cases, typically applied in one-off situations or to sub-national jurisdictions. For example, the US state of Michigan has legislated six dark sky places. One of them is Lake Hudson Recreation Area which became the world's first dark sky place in 1993. There are other categories, not addressed in this report, related to tourist facilities such as hotels, resorts and camps.

Here is a brief chronology of dark sky place developments:

1993 World's first dark sky place, Lake Hudson Recreation Area, US

1999 First dark sky place established under an independent dark sky programme, Torrence Barrens, Canada, certified by the RASC.

2001 First IDA International Dark Sky Community: Flagstaff, US

2007 First IDA International Dark Sky Park, Natural Bridges, US

2008 First IDA International Dark Sky Reserve, Mont Mégantic, Canada

2011 First Fundación Starlight Reserve, Monfragüe, Spain

2012 First dark sky places outside Europe and North America, Namibrand, Namibia, and Aoraki-Mackenzie, New Zealand

2015 First dark sky place in Asia, Yeongyang Firefly Eco Park, Republic of Korea

2021 June, 298 dark sky places in 31 countries

IDA International Dark Sky Places Program

As noted on page iii, in June 2023 the International Dark-Sky Association changed its name to DarkSky, and the many references to IDA in this publication are to DarkSky. IDA was established in 1988 as a non-governmental organization in Tucson, US, with a mission "to preserve and protect the nighttime environment and our heritage of dark skies through environmentally responsible outdoor lighting" [darksky.org]. IDA addresses the global problem of light pollution through programming in three broad categories: conservation, public policy and technical. International Dark Sky Places is IDA's flagship programme (Welch & Dick, 2012). It was established in 2001 with the certification of Flagstaff, US, as the world's first dark sky community. The programme recognises the efforts of sites worldwide to protect the night sky through conservation, public policy, public outreach and education. By June 2022 it had accredited 192 sites [darksky.org/our-work/conservation/idsp].

Table 2.1. International Dark-Sky Association (IDA) International Dark Sky Places Program summary, 31 December 2022

Category name	First site	Number	Eligibility criteria	Designation requirements
International Dark Sky Community	2001	38	Self-governing municipalities and similar entities; typically lacks an existing dark-sky resource	Outdoor lighting public policy, resident education, remediation of municipally owned lighting
International Dark Sky Park	2006	115	Protected landscapes under unitary authority with an existing dark-sky resource	Lighting management plan, policy statements, lighting inventory, retrofitting compliance, lighting improvements, on-site interpretation, public accessibility
International Dark Sky Reserve	2007	22	Protected landscapes and surroundings consisting of public and private lands with an existing dark-sky resource	Lighting management plan, policy statements, lighting inventory, retrofitting compliance, lighting improvements, on-site interpretation, external communications, public accessibility
International Dark Sky Sanctuary	2015	16	Protected landscapes under unitary authority with an exceptional dark-sky resource. Differs from a park by remoteness and limited or no visitor programming	Lighting management plan, policy statements, lighting inventory, lighting compliance, external communications, public accessibility, although this may be waived when conservation priorities preclude regular visitation
Urban Night Sky Place	2019	6	Public or private land, whether legally protected or not, situated within a certain distance of a conurbation of particular number of inhabitants; typically lacks an existing dark-sky resource	Lighting management plan, policy statements, lighting inventory, lighting compliance, on-site interpretation/ education, public accessibility

Consideration of current or anticipated future IDA certification influences lighting decisions in protected areas around the world (D'Agostino et al., 2017; Papalambrou, 2018). Some of the sites are also recognised for other types of landscape protection such as UNESCO World Heritage status (Smith, 2015). Actions fall into two broad areas: policy interventions in cities, and conservation of existing dark-sky resources in parks and similar protected areas. Significantly, programme awards are based on effort and not on results or outcomes with respect to light emission or night sky quality. The programme now comprises five designations (Table 2.1).

The IDA does not actively solicit nominations. Instead, it accepts nominations made by its members on behalf of prospective sites. Application documents are prepared according to the guidelines published on the IDA website. These documents are then reviewed by the IDA Dark Sky Places Committee. Most applications require minor edits and/or some additional action on the ground. The process usually takes one to three years. Certifications are maintained through mandatory annual reporting including night sky brightness monitoring data. For places that struggle to meet certain narrowly defined programme requirements, provisional status may be offered that allows up to three additional years to achieve full compliance.

A need clearly exists to determine whether the programme is effective in reducing light pollution. This is done through studies of satellite remote sensing, ground-based measurements of skyglow and other indicators. Data from eleven IDA dark sky places indicates that light pollution at or near dark sky places does indeed diminish after certification (Kyba & Coesfeld, 2021).

Feedback from research continues to influence programme management, exemplified by the 2018 decision to strengthen night sky quality requirements for international dark sky parks and reserves. The future of the IDSP Program may include additional categories, while keeping in mind the negative potential to dilute the programme's value by having too many categories.

The RASC Dark-Sky Site Programme

While not international in scope, this Canadian initiative is described here since it provides a model for other national organizations that may wish to establish their own dark sky place certification programme.

The Royal Astronomical Society of Canada (RASC) has two main programmes to support its national Light Pollution Abatement initiative. These recognise the efforts of both commercial

Table 2.2. Royal Astronomical Society of Canada (RASC) Dark-Sky Site programme summary, 31 December 2022

Category Name	First site	Number June 2022	Eligibility Criteria	Designation Requirements
Dark Sky Preserve	1999	27	Protected area	Compliance with the RASC-GOL Lighting inventory and plan Interpretation of the biological impacts of artificial light Public and municipal outreach Partners MoU and local support
Nocturnal Preserve	2015	2	Protected area but no infrastructure or active management	Compliance with the RASC-GOL Lighting inventory and plan Public and municipal outreach. Partners MoU and local support
Urban Star Park	2011	2	Protected area and buffer zone	Compliance with the RASC-GOL Lighting inventory and plan In or near an urban area Public and municipal outreach Managed by one agency Partners MoU and local support

entities and municipal, provincial and federal agencies. The first is a Certificate of Merit programme that recognises non-RASC initiatives in the public and private sectors. It is bestowed on organizations for implementing outdoor lighting projects with low ecological impact, and is leveraged with a media component to increase public awareness. A typical recipient would be a business manager, mayor or other government official. It increases their public profile as a leader in sustainable development and environmental protection. The award ceremony is arranged to have at least local news coverage.

The second programme is the Dark-Sky Site programme. A dark sky preserve (DSPr) designates a significant area protected against glare, light trespass and the biological and behavioural impacts of artificial light. It is based on compliance with the Guidelines for Outdoor Lighting (GOL) originally developed by the RASC for Parks Canada (RASC, 2020). A dark sky preserve designation requires stargazing and astronomy opportunities for visitors, and public and municipal outreach beyond the area of the preserve. Influencing the policies of neighbouring municipalities helps protect the preserve in the long term. The programme also requires outreach about the impact that artificial light at night has on the biology and behaviour of wildlife and, where applicable, human health. Table 2.2 summarises this RASC programme.

As well as dark sky preserves, the RASC programme also recognises urban star parks and nocturnal preserves. All have a core area surrounded by a buffer zone, together encompassing the entire property under a single management agency. The buffer zone protects the core area from light emanating from outside. Both the buffer and the core lighting must comply with the GOL.

An urban star park is close to or within an urban area, making it easily accessible to the public. Consequently a USP will have more skyglow than a dark sky preserve. Their buffer zones shield the area from the glare of external lights. Visitors are then able to use their night vision and see the major constellations. Skyglow may even allow the public to move around safely without in situ artificial lighting. All lighting within the park must comply with the GOL. Skyglow from the urban area will still reduce the visibility of the night sky, but the limits placed on glare, light trespass and colour of illumination within the park make the stars much more visible than from the surrounding neighbourhoods. As such, the park becomes a focus for awareness building. With the outreach programmes, the public is made aware of the impact of artificial light at night. Support from the municipality increases the chance that it will adopt lighting policies to reduce urban light pollution.

The nocturnal preserve designation is for managed areas that do not have the infrastructure or resources to provide a viable public outreach programme. There must be outreach to local municipalities to encourage the reduction of light pollution, to help maintain the pristine nature of the preserve, even if access to the area grows.

The Guidelines for Outdoor Lighting report is the major contribution of the RASC to light pollution abatement both nationally and internationally. The guidelines codify recommended lighting in semi-urban, semi-rural, rural and protected areas. Based on extensive international biological and behavioural studies, they address spectrum, brightness, shielding and timing of outdoor illumination, and have become the basis of other similar documents. They are used in, and endorsed by, this IUCN WCPA report.

Complying with the RASC GOL can be difficult. Municipal governments are complex organizations and different policies can be in conflict, misinterpreted or ignored by municipal staff. Prior to applying for DSPr status, the idea of a DSPr should be discussed widely in the municipality. Without this, relatively few people understand the ramifications of a DSPr designation. Even after designation, many citizens still do not know or care about the designation, and there have been demands for more outdoor lighting. Fortunately, forested and hilly terrain means that roads and villages are often located in valleys, limiting light pollution to villages, residential and commercial properties.

Fundación Starlight

The Institute of Astrophysics of the Canary Islands of Spain (IAC) operates observatories on Tenerife and La Palma with telescopes and instruments from over sixty institutions in nineteen countries. La Palma has the largest and most advanced optical-infrared telescope in the world, the Gran Telescopio Canarias. The IAC follows three strategic challenges. First, concerned about light pollution from settlements on the Canary Islands, the IAC's fight against light pollution prompted a law to protect the night sky over La Palma and Tenerife. Passed by the Spanish national government in 1988, it became a precedent for similar regulations in other countries.

Second, in 2007 the IAC held the first International Starlight Conference to explore the need to defend the night sky from light pollution and find ways for its enjoyment by society. This includes a clear night sky's outstanding, universal cultural value and a vital condition to promote and develop astrotourism. The principles and recommendations that emerged from this conference are brought together in the Declaration in Defence of the Quality of the Night Sky and the Right to Starlight, described under Conventions, Agencies and Declarations after the table of contents of this report.

Third, in 2009 Fundación Starlight was created with four objectives fundacionstarlight.org:

- Protection of the night sky, as expressed in the La Palma Declaration noted above, promoting smart lighting through local, national and international initiatives to prevent light pollution, thereby also enabling energy savings and mitigating the effects of climate change
- Promotion of astrotourism as a sustainable, high-quality segment of the tourism industry. Places where sky quality, infrastructure and organised activities favour astrotourism are accredited as Starlight Tourist Destinations. The Foundation also awards Starlight Reserve status to places that maintain natural lighting conditions and clarity of the night sky, and incorporate the starscape into their existing cultural and natural assets. There are also various other categories such as starlight villages and camps.
- Dissemination of cultural astronomy through activities such as tourism related to the stars, certifying Starlight Rural Houses and Hotels, astronomical festivals and activities, and astrophotography contests
- Fostering intelligent lighting and energy savings to help conserve energy, develop astrotourism, and protect species that need a dark sky for their conservation

Starlight Reserves are protected natural areas with a commitment to protect the quality of the night sky and where access to view the night sky is provided. They have a core zone where the natural lighting conditions and clarity of the night sky are kept intact, a protection zone near the core area that cushions against the adverse effects of light and air pollution, and a buffer zone outside the reserve where smart lighting should be used. Like the IDA's International Dark Sky Reserves, these zones reflect the principles embodied in UNESCO biosphere reserves.

Starlight Tourist Destinations have controls over light pollution, as well as the infrastructure and trained staff that make them logical destinations for astrotourism and appreciation of the ecology of the night. A starlight reserve may also be certified as a starlight tourist destination.

These and other dark sky place categories are summarised in Table 2.3.

Other dark sky place certification programmes

In 1993 the US State of Michigan legislated the Lake Hudson Recreation Area Dark Sky Preserve, making it the world's first dark sky protected place. In 2012 the State adopted its Dark Sky Coast Bill, under which it has created five additional dark sky preserves. Also in the US, the Indiana and Pennsylvania governments have each legislated a dark sky park. The Pennsylvania case has also received IDA certification. In 2009 Indiana legislated recognition

Table 2.3. Fundación Starlight dark sky sites programme summary, 31 December 2022

Category Name*	First site	Number	Eligibility Criteria	Designation Requirements**
Starlight Reserve	2012	17	Core protected area, buffer and outer general area with dark sky lighting management	Can be one or more of: heritage astronomical site; natural site; nocturnal landscape; cultural site; or mixed site. Lighting management plan by all stakeholders.
Starlight Stellar Park	2016	12	Permanent infrastructure of night sky appreciation	Good night sky quality Interpretive infrastructure and programmes
Starlight Tourism Destination***	2011	51	Protected night sky with amenities suitable for astrotourism	Lighting management plan Accommodations and facilities for night sky enjoyment Trained interpretive staff
Starlight Wilderness	2016	7	Dark skies in a protected landscape	No immediate plans for astrotourism

* Other categories include Starlight Town, Starlight Camp, Starlight Farm, Starlight Walking Trail and others.
** A site may have more than one designation, e.g. Starlight Reserve combined with Starlight Tourism Destination.
*** Includes 40 destinations, 7 municipalities and 4 towns.

of a dark sky place, now also matched by certification from the Indiana Council on Lighting Education. Similar to the Pennsylvania case, Zselic in Hungary is recognised both by the Hungarian Astronomical Union and the IDA.

There are also two transboundary dark sky parks shared by Czechia and Poland, Beskydy and Izera. In both countries recognition is by a consortium consisting of two science and four governmental organizations. In China, an environmental non-government organization, an astronomical observatory and four governmental bodies have together certified two dark sky areas.

As of December 2022, 28 out of 302 dark sky places are certified by other agencies apart from the three systems noted above. It may help to seek certification by one of those three but it is not necessary. Practical and political considerations may legitimately lead dark sky place proponents to seek alternate arms-length recognition.

The DSAG class system and world list of dark sky places

Protected area systems around the world use a wide variety of naming designations such as park, reserve, preserve, refuge and sanctuary. To provide a common language and a framework for cooperation IUCN has adopted standard management categories and governance types that are described inside the front cover of this report.

As with protected areas, the dark sky place systems described above use a variety of naming designations. These include dark sky coast, dark sky preserve, dark sky community, dark sky park, dark sky sanctuary, starlight tourism destination, starlight theme park, starry sky park, urban night sky place and nocturnal preserve. Some of these different names mean the same thing on the ground. For example, a dark sky preserve as named by the RASC is equivalent to a dark sky park under the IDA system. Similarly, the RASC's urban star parks and the IDA's urban night sky places are essentially the same genre. Starlight Reserves as recognised by Fundación Starlight include individual national parks, a cultural park, and combinations of parks and UNESCO biosphere reserves.

To avoid confusion, DSAG developed a common classification system for a World List of Dark Sky Places. The system is based on principles similar to those of the IUCN protected area categories. To qualify for the World List, a dark sky place should satisfy at least these criteria:

- Management policies and practices in place to protect or restore natural darkness
- Recognition either by an arm's length authority, such as the IDA, Fundación Starlight or a national astronomical society, or by legislation, regulation or policy of the appropriate national, sub-national or local jurisdiction

Because of the importance of light pollution abatement initiatives where most people live, not just in protected areas, a class for dark sky communities is added. This recognises IDA dark sky communities, RASC urban star parks and the broader need for light pollution reduction to help conserve nature in urban areas. Such sites are important for public engagement and outreach, so even without natural protected area status they are included in the system.

The DSAG classes are:

1. Dark Sky Astronomy Site:

Having a research grade astronomy observatory and surrounding protected area

2. Dark Sky Park:

Protected area
2a Park, reserve, habitat, natural area or other ecological protection
2b Unpopulated area set aside for traditional or sacred practices related to the sky
2c Rural area such as an area of outstanding landscape beauty

3. Dark Sky Heritage Site:

Protected physical heritage works of mankind
4) Dark Sky Outreach Site:
4a Urban or suburban outreach site
4b Rural outreach site

5. Dark Sky Reserve:

A mix of cooperating community, rural and natural area jurisdictions

6. Dark Sky Community:

6a Village, town or city
6b Populated rural area without a formal protected area

These classes are used in the World List of Dark Sky Places maintained by DSAG and accessible on its website. Once a place has received certification, classes are assigned by DSAG to fit the best overall class definitions. Some dark sky places could fit into more than one class. In such cases the DSAG class system is treated as a binary key, starting with class 1 and proceeding through the classes and sub-classes until a match is found. Note that, like the IUCN protected area categories, the numeric label does not reflect relative importance.

Many of the world's dark sky places are based on an existing national, state, provincial or similar protected area. Dark sky classes 1 and 2 are compatible with IUCN protected area categories II and III, and class 5 could correspond to IUCN categories IV, V or VI. All DSAG

Table 2.4. Dark sky places by DSAG class, 31 December 2022

CLASS AND SUB-CLASS NUMBERS				
Total = 302	**Class**	**Sub-class a**	**Sub-class b**	**Sub-class c**
Class 1	17	n/a	n/a	n/a
Class 2	156	108	4	44
Class 3	16	n/a	n/a	n/a
Class 4	32	7	25	n/a
Class 5	28	n/a	n/a	n/a
Class 6	53	46	7	n/a

Table 2.5. Dark sky places by country, 31 December 2022

Australia	3	Austria	1	Brazil	1	Canada	31	Chile	5	China	6
Columbia	1	Croatia	3	Czech Rep.	2	Denmark	2	France	4	Germany	7
Hungary	3	Ireland	2	Israel	1	Italy	1	Japan	3	Mexico	1
Namibia	1	Netherlands	2	New Zealand	6	Poland	3	Portugal	3	Slovakia	2
S. Africa	1	S. Korea	1	Spain	49	Sweden	1	Taiwan, POC	1	UK	19
US	135										

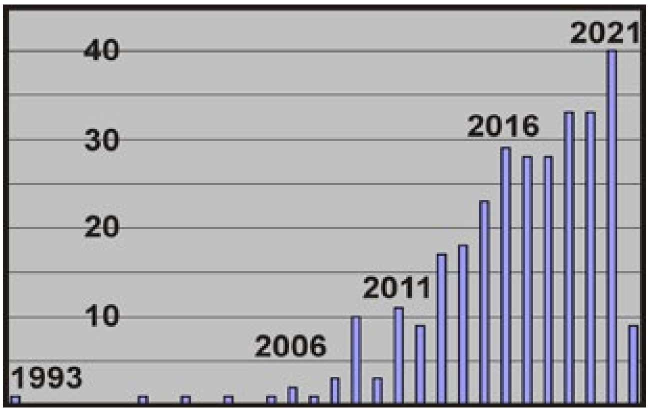


Figure 2.2. Growth of dark sky places to March 2022

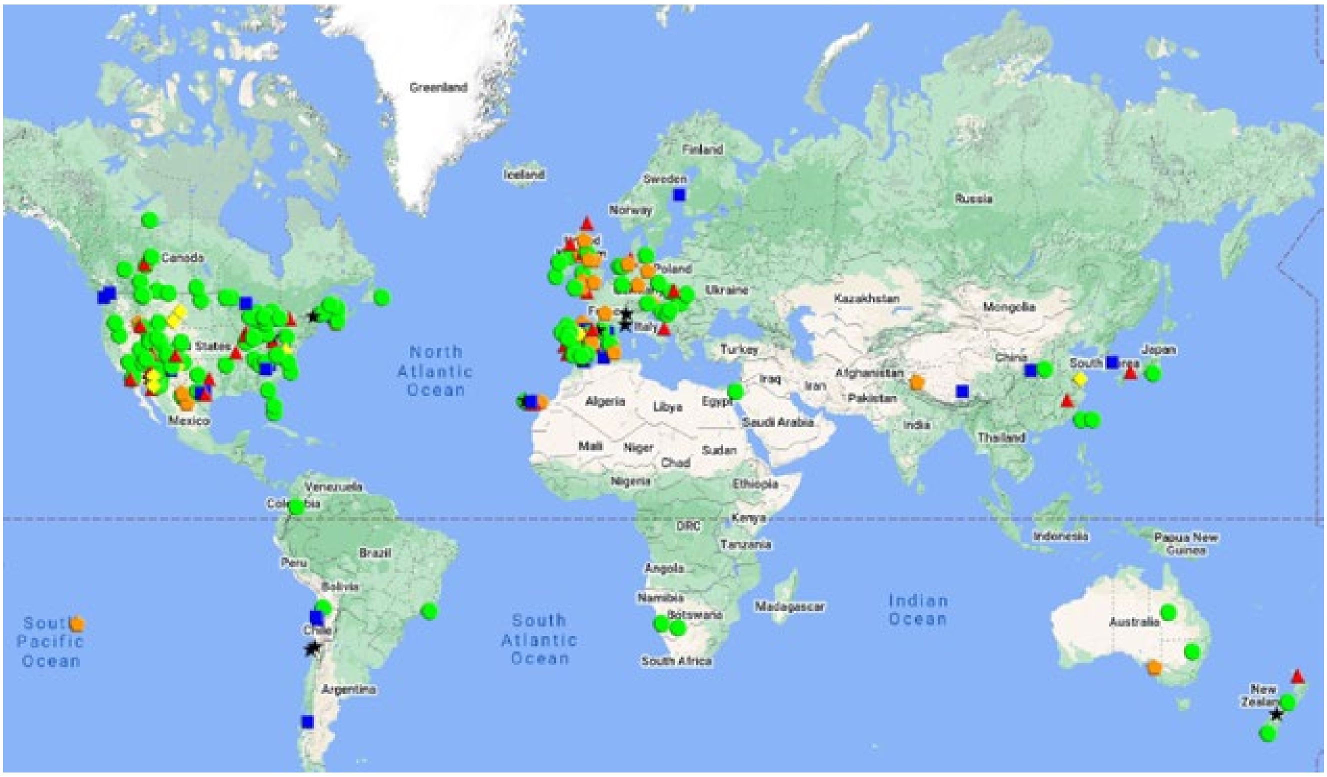


Figure 2.3. World map of dark sky places, November 2021

classes have some degree of active use such as astronomy or rural settlement, and all allow reasonable public access. Therefore, no dark sky place would be in IUCN category I.

Conservation managers may wish to consider how their area would fit a particular class as they seek the best way to achieve such arms length certification. The World List includes the dark sky place name, included or overlapping protected areas, location identified by central latitude and longitude, total area of the place, the total area of protected areas contained therein, other heritage designations such a World Heritage Site or biosphere reserve, and the DSAG class. The list can be found at [darkskyparks.org/dark-skies-and-nature-conservation].

The Tables 2.4 and 2.5 show the number in each DSAG class and in each of 31 countries as of January 2023. Figures 2.2 and 2.3 plot the growth of dark sky places and their geographic distribution.

The world's first dark sky place is Lake Hudson Recreation Area, recognised in the US under Michigan state legislation in 1993. It is DSAG class 2c as a natural recreation area. Since that time, Michigan has also created five additional dark sky places, all coastal sites on Lake Huron and Lake Michigan. The second site to be certified, and the first by an astronomy organization, was the Torrance Barrens Conservation Area in Ontario, Canada, in 1999 by the RASC. It is class 2a in the DSAG system in respect of its basic ecological mandate.

Up to June 2022, most sites have been established by the IDA, 192, and Fundación Starlight, 56. One site, Mont-Mégantic, has been certified by both the IDA and RASC, respectively as an International Dark Sky Reserve and a Dark Sky Preserve. It is DSAG class 1 in respect of its research grade astronomical observatory, even though it is within Mont-Mégantic National Park, Québec, Canada. The IDA has also jointly recognised a site with the Hungarian Astronomical Union, Zselic Landscape Protection Area, DSAG class 2a, and one in the US with the Pennsylvania Department of Conservation and Natural Resources, Cherry Springs State Park, DSAG class 2a.

Most dark sky places are in North America and Europe. This reflects proactive leadership to seek certification in the US by its National Park Service and several state park departments, by Parks Canada, and by the Fundación Starlight in Spanish-speaking countries. It also reflects the relative affluence of those mostly industrialised countries where nature protection agencies, private protected areas and local communities have the resources to pursue dark sky status and conduct outdoor lighting retrofits. With some exceptions, Central and South America, Africa and Asia present large gaps in worldwide distribution as of 2023.

Adding dark sky park status to an existing park

One of the prime mandates of a protected area is to preserve the natural environment, both to preserve its integrity and to provide compatible visitor experiences. As noted already, natural systems operate half their time at night, so a dark sky without artificial light at night (ALAN) is one marker of ecological integrity. It follows that a protected area should also be a dark sky site. Certification as such achieves three goals. One is to broadcast the role of the protected area in preserving the ecology of the night and bringing related experiences to the public. The second is to gain the knowledge and advice of night lighting experts to help achieve that goal in a way that maintains visitor enjoyment and safety. The third is to demonstrate sustainable development and energy efficiency.

Historically, in protected areas the night environment was not given the same attention as the day environment. Other than diminishing the aesthetics of a starry sky, park staff were often not aware of the impact of ALAN on the ecosystem. There are three reasons for this. First, most park managers were raised and educated in towns and cities where outdoor lighting is ubiquitous and goes unquestioned. Virtually every retail, commercial and industrial light fixture has been designed and marketed for high light output. Secondly, park managers often started their careers as biologists and ecologists, but very few learnt how outdoor lighting impacts wildlife. This is a relatively new concern, primarily since the early 2000s. When the impacts are explained in terms of ecology, managers quickly understand its importance, but they are uninformed how to make the decisions required to reduce these impacts by changing their park's infrastructure. Thirdly, most facility managers, and the electricians who select and install the lights, only have experience with urban lighting. Also, local equipment suppliers have often never heard of low-impact lighting and generally do not understand why anyone would want a low-impact light. They have the received wisdom that outdoor lighting should eliminate the night, so they guide their clients towards those solutions, rationalizing this with preconceived notions of safety and security.

To become a dark sky park, staff must first become aware of how light disrupts night ecology. Then they must reconsider and change their practices for built facilities and develop a programme to reinforce and sustain those changes. In particular, they need specifications for outdoor lighting and visitor outreach programmes that take advantage of the night environment and turn its ecology into memorable teaching moments. Park personnel can make visitors more aware of the aesthetics of the night, its sounds, smells and a sky full of stars. The night environment can be used to expand public programmes beyond the already busy daytime. Such programmes are discussed in a later section of this report. With these in place, managers are in a good position to build public support for the preserved night environment. They can also accumulate metrics of public interest that can be used to support and maintain the protection of the night within their mandate.

There are three reasons for outdoor lighting in natural areas. Unfortunately, they are usually based on these urban considerations:

- **Safety.** Some visitors complain about exposure to risk. Therefore, public safety is given a high priority. Since there is ample experience with accidents and litigation in cities, industry guidelines are based on urban situations. These have become the default requirements even in rural and wilderness settings. However, this urban-based approach takes no account of the ecology of the night.

Table 2.6. Typical table headings for a lighting inventory report

Identification	Use	Type	Mounting height	Shielding	Controls	Compliant with guidelines
E.g. building name or location	E.g. purpose and timing	E.g. LPS, LED E.g. bollard, post, sconce	E.g. metres above ground	E.g. fully, partial or unshielded	E.g. timer, switch, photosensor	Yes or No

- **Security.** As well as ecological values, protected area managers are also often responsible for preserving and enhancing the monetary value of their park, e.g. as measured by visitor numbers, in-park concessions and regional economic benefits. However, as yet there is no accepted value placed on the natural world. Thus outdoor lighting is installed to provide a perceived protection for built infrastructure. The amount of lighting is usually based on what has been deemed necessary for securing properties in urban areas.
- **Aesthetics.** Humans give value to the aesthetic qualities of the landscape. Some visitors may travel across the globe to experience a natural wonder. However, humans are daytime species with colourless, though sensetive, night vision. To see colour and experience a place at night in light similar to daytime, people need illuminating levels over ten to one hundred times the maximum natural night illumination of a full Moon. However, this is at the expense of the natural environment.

These three uses of light are ingrained in people's expectations. Park managers must decide whether they will protect the natural environment or cater to these expectations. Only when this decision is made in favour of the natural environment can they start to transform the area into a dark sky park.

Steps towards a dark sky park

The process leading to dark sky park certification begins with the recognition by management that the night environment is critical to a balanced and sustainable ecosystem. A timely decision is important since outdoor lighting is being installed continuously. Debating the rationale without corrective action will permit further degradation to occur. It will increase the eventual cost to the environment and of lighting retrofits to be compliant with the Guidelines for Outdoor Lighting.

The first step is to perform an inventory of all outdoor light sources in the park. This enables planning for the removal of unnecessary lights or retrofitting lights to comply with lighting guidelines. It is typically labour-intensive but the least expensive step in the process. This inventory creates the framework for budgeting and scheduling actions. Table 2.6 is a guide on what to include in an inventory. Also, it is helpfull to consult the inventories in some of the applications for certification on the IDA website [darksky.org]. Since outdoor lights accumulate over many years and are rarely removed managers are often surprised at how many lights are installed in their parks.

With the table completed, managers may critically assess each light. Based on a better understanding of their impact on the environment, each light can be prioritised for removal, modification or replacement with a compliant luminaire. These assessments will allow a budget and schedule to be developed for the work.

The second step is to take the corrective actions identified by the light fixture inventory. Three activities follow from this:

- Removal of unnecessary luminaires. This is the least expensive activity. Removal of light fixtures and their wiring also reduces safety risks from old and damaged power lines and mounting poles.
- Modifying non-compliant light fixtures. Compliance can be achieved with shields, filters, lower-wattage lamps and timers. It should be noted that sometimes the labour costs may exceed the material cost of the parts.
- Replacing non-compliant luminaires. New fixtures may cost less than the labour to modify older units. This effort may extend over several years, so it requires a priority in multi-year plans to prevent the work from being delayed or abandoned. The removal of unnecessary luminaires and the replacement of non-compliant luminaires is a key step towards a dark sky place certification. It implies the use of modern LED lights, although caution must be taken to avoid blue spectrum components. Priority should be given to low environmental impact both within the park and during the manufacturing and transportation of the fixtures and their end-of-life disposal. This approach should reduce greenhouse gas emissions and the use of toxic and hazardous components in which a landfill deposit is the end of life scenario. The recycling of the material being removed could have local economic benefits, promoting a circular economy approach.

The third step is to design and deliver a public engagement programme. This could encompass interpretation for park visitors and/or outreach to local communities and the general public. This engagement adds value to the effort and will help to differentiate a park's public offering from other destinations in the area. In some regions there has been a decline in park attendance over the past half century. Sometimes, however, a dark sky designation has halted or even reversed this trend.

Summary

There are two basic requirements for obtaining a dark sky park designation and realising financial benefits from this process. One is to provide only low-impact lighting. The other is to have public engagement and outreach programmes. The environment and visitors' appreciation of the world at night will benefit from even a modest approach toward this goal.

CHAPTER 3.

Case studies

This chapter presents seventeen short examples of light pollution abatement and presentation of night ecology and astronomy at dark sky places drawn from the list of dark sky places recognised by the organizations described in Chapter 2. They represent each dark sky class and a diversity of locations, size and certifying agencies. Also noted are related protected areas as defined by IUCN, and other forms of recognition such as World Heritage, biosphere reserve or Ramsar wetland site. As well as a basic description of each site, there are highlights of achievements in outdoor lighting management, visitor engagement related to both the night sky and the ecology of the night, and outreach and community relations with neighbouring jurisdictions.

Although typically not part of a natural protected area, examples of dark sky communities are included for two reasons. Urban environments can benefit from hosting a range of plants and animals, and light pollution is a major ecological stress in cities and towns. Secondly, in developed and developing countries most citizens live in urban areas, and their political and financial support is needed to maintain protected areas. Local engagement and night sky appreciation opportunities assist with this. The lessons learnt from these case studies are compiled in Chapter 4.

Aoraki Mackenzie International Dark Sky Reserve

New Zealand

DSAG class 1: Dark Sky Astronomy Site, having a research grade astronomy observatory and a surrounding natural area. Includes Aoraki/Mt Cook National Park, IUCN category II.

Contributed by John Hearnshaw, University of Canterbury, New Zealand

Recognition. The Aoraki Mackenzie International Dark Sky Reserve was created in April 2012 with certification from the International Dark-Sky Association (IDA). It was the third reserve to be recognised by the IDA and the first in the southern hemisphere.

Description. Aoraki Mackenzie International Dark Sky Reserve (AMIDSR) is in the centre of New Zealand's South Island and comprises most of the Mackenzie Basin and all of Aoraki/Mt Cook National Park. The Mackenzie Basin lies to the east of the Southern Alps and west of a lower range called the Two Thumb Range. At 436,700 ha it is the third largest IDA Reserve, after Greater Big Bend in the US and Mont Mégantic in Canada. There are plans to expand the Reserve by about 50% which would make it the second largest. The Reserve protects the exceptionally dark skies of the Mackenzie Basin and Aoraki/Mt Cook National Park. Maintaining dark skies helps those who come for stargazing, as well as research astronomers using the University of Canterbury's Mt John Observatory next to the shores of Lake Tekapo.

The Reserve is run by a Board of about a dozen members. Its aim is to educate the public about the dangers of light pollution and the benefits of dark skies. The Board advocates for lights that do not waste electricity or that do not shine into the sky. Some 30% of electricity costs for street lighting can be saved if lights only shine below the horizontal.

Achievements. The success of the Reserve is shown by the rapid rise of astrotourism in the Mackenzie District and at Aoraki/Mt Cook. About 1.5 million tourists come through the Mackenzie District annually, of whom about 10% come explicitly to see the beauty of pristine starlit night skies or to visit the Mt John Observatory by day. Many of these tourists are from Asian countries with severe light pollution and they have never seen the Milky Way. They are often astounded by the beauty of the night sky in the Reserve. In recognition of the importance of astrotourism to the District, in 2017 the New Zealand Transport Agency named the highway through the Reserve the Starlight Highway. Tourist numbers jumped about 20% after the reserve was established. Astrotourism companies such as Earth and Sky at Tekapo and Big Sky Stargazing at Mt Cook have thrived. Other companies are now springing up inside the reserve to show visitors the night sky. There are now a dozen firms in the reserve offering guided night sky tours. Several accommodation providers offer telescopes or small

Figure 3.1. Road sign at the entry to Aoraki Mackenzie International Dark Sky Reserve, New Zealand. Source: Maki Yanagimachi

observatories for their guests, such as the Pukaki Observatory at the Mt Cook Lakeside Retreat. Over half of all accommodation providers in the Reserve cite stargazing or AMIDSR on their web sites. In 2018 the reserve received the IDA Dark Sky Place of the Year award.

Activities. The AMIDSR Board is excited that the Reserve is now one of the top places in the world for stargazing, with a reputation second to none for dark skies and for a wealth of experiences provided by night sky guides. In addition there is a major research observatory at Mt John, a planetarium at Mt Cook village, and an astronomy centre built by Earth and Sky and Ngai Tahu Tourism that adds to visitor astronomy experiences. It features a fully renovated and operational 46 cm refractor telescope dating from 1897, brought to New Zealand in 1963 from the University of Pennsylvania.

In October 2019 the Board hosted an international audience at the New Zealand Starlight Conference at Lake Tekapo. The Conference addressed all aspects of dark sky protection, astrotourism, lighting technology and health and environmental aspects of light pollution. See [starlightconference.org.nz].

Outreach. Public outreach is another major aspect of the Board's work. Since 2013 it has run three Starlight Festivals, each lasting three days. They entailed public lectures by international visiting speakers, videos on light pollution, stargazing sessions, exhibitions, workshops and cultural activities such as musical concerts with a starlight theme. The Board has also run public lectures and a public forum with a panel discussion. Two years after becoming a Reserve, AMIDSR acquired the status of a New Zealand charity. This tax-free status helps it finance many of its activities.

The Board continues to discourage those who pollute with light at night. If necessary it explains to them that the Mackenzie District has had a lighting ordinance since 1981. It discourages and outlaws harmful light pollution through poorly installed security lights or streetlights. The modern trend is to replace many older sodium streetlights of orange colour with more efficient light-emitting diodes (LEDs) which often emit a harsh blue-white colour. It is the blue component that is the most harmful to the environment and to human health. Furthermore, it contributes the most to unwanted sky brightness, thereby hindering stargazing. Fortunately, newer LED lights are readily available with a warmer yellow colour. In 2018, the Mackenzie District Council struck a landmark agreement with the New Zealand Transport Agency to have amber 2200K LED street lights installed in all three communities in the reserve, namely Lake Tekapo, Twizel and Mt Cook Village, and also in the nearby town of Fairlie. It is hoped that the use of these replacement LEDs for street-lighting in the Aoraki Mackenzie Reserve will help it to retain its international leadership as a place for astro-tourism.

Urban residential streets in the Reserve are already lit with specially designed LED or low-pressure sodium bollards. In the next few years these will all change to LEDs with a colour temperature of 2200K.

In 2019 a successful forum was organised by the Mackenzie District Council for mayors of other districts in New Zealand. Sixteen other councils with their mayors and chief executive officers participated, and many resolved to follow the success of Aoraki Mackenzie for dark skies and astro-tourism. As of December 2020 there are six IDA dark sky places in New Zealand, and about a dozen communities that aspire to gain IDA accreditation.

Dark sky protection and astrotourism are growing fast around the world. Many other places are applying for dark sky certification, including other categories recognised by IDA, such as dark sky sanctuaries, parks and communities. However, reserves like Aoraki Mackenzie may be regarded as the premier places for astrotourists, this because of the large areas under cooperative management to limit light pollution and provide stargazing opportunities. The AMIDSR Board is determined to retain its reputation as a world leader in this field, for the benefit of both visitors and tour operators. Indeed, astrotourism in the Reserve is one of New Zealand's top tourist draws (Figure 3.1). Since the certification of Aoraki MacKenzie several other dark sky places have been established in New Zealand, and there is a campaign to establish New Zealand as a dark sky nation.

Lessons learnt highlights

- Acquiring the tax-free status of a New Zealand charity, making many activities possible
- Active promotion of astrotourism, including public access to a high-end telescope
- Working with businesses to provide a wide range of visitor opportunities
- Fostering cooperation with communities to retrofit lighting

Montsec Starlight Reserve
Spain

DSAG class 1: Dark Sky Astronomy Site, having a research grade astronomy observatory site and surrounding natural area. Includes: Montsec Mountains Natural Area, IUCN Category V; Fauna Reserve of Sant Llorenç de Montgai; Natural Reserve of Noguera Ribagorçana-Mont-Rebei; and six other protected areas partially within the reserve.

Contributed by David Welch, Dark Skies Advisory Group and reviewed by Salvador Ribas, Parc Astronòmic Montsec

Recognition. Starlight Tourism Destination was granted in 2013 by Fundación Starlight.

Description. Montsec lies in the foothills of the Pyrenees. It contains a diversity of mountains, deep valleys, caves, rivers, reservoirs and fossil sites. It hosts a transition between Eurosiberian and Mediterranean vegetation. Within its nine protected areas it is home to many protected plant and animal species. These include *Spiraea crenata* and the rosaceous shrub *Aquilegia montsiciana*, as well as five monumental trees of national interest. The scarps and cliffs of the Montsec range offer hiding places for both diurnal and nocturnal birds of prey such as peregrine falcons, vultures and golden eagles.

Montsec Starlight Reserve hosts two astronomy facilities. The first is the Parc Astronòmic Montsec (PAM), an initiative of the Catalan Government for the popularization of science, particularly astronomy. It consists of three buildings: a central building housing a permanent exhibition, classrooms and administration; the Eye of Montsec, a multimedia digital planetarium and platform for direct observation of the night sky with a retractable dome 12 m in diameter; and the Telescope Park devoted to sky gazing night and day, since it includes a device for observation of the Sun.

The other facility is the Observatori Astronòmic del Montsec, operated by the Institut d'Estudis Espacials de Catalunya for basic research and university education. It is located on the summit of the main escarpment at 1,570 m above sea level. It features two observatories with several telescopes, automated weather and air quality stations and an all-sky camera for meteor detection.

Figure 3.2. Parc Astronòmic Montsec, Spain. Top: Observatori Astronòmic del Montsec, the research facility. Source: David Welch Bottom: Parc Astronòmic Montsec, the visitor centre and public telescopes. Source: Parc Astronòmic Montsec

Achievement. Funding, building and completing the Parc Astronomic Montsec, Figure 3.2.

Activities. A highlight for visitors is the planetarium with its multimedia shows and static displays. A show is completed with a display and explanation of the current local night sky, and then the dome opens to reveal the actual sky and to allow the viewers, assisted by an instructor, to see the most relevant objects of the night. This also presents a teaching moment about skyglow and light pollution. Outside the planetarium is El Parc de Telescopis where visitors learn about the equipment. Depending on the weather, visitors can observe some of the most outstanding objects of the night, such as the Moon, the planets and nebulae. PAM offers a full programme of educational activities complementary to all levels of school education.

These programmes can be matched to stays of one to three nights. Nearby private lodges offer cabins for accommodation and sky viewing. Visitors can dine at the nearby Monestir de les Avellanes where a special menu is available, upon request, in which each dish is arranged to illustrate something of the night sky, such as planets or comets.

Lessons learnt highlights

- Collaborating with local communities to promote both ecotourism and astrotourism
- Developing a major astrotourism facility

Grand Canyon International Dark Sky Park
United States

DSAG class 2a, Dark Sky Park: park, reserve, habitat area or other ecological or geological protection. Corresponds to Grand Canyon National Park, IUCN category II

Contributed by Adam Dalton, formerly International Dark-Sky Association (IDA)

Recognition. With a history of night sky interpretation coupled with exceptional night sky quality, the Park approached the IDA in 2013 regarding a potential International Dark Sky Park (IDSP) designation. Pending retrofits of its outdoor lighting, the IDA granted provisional dark sky park status in 2016. Once sufficient retrofits were completed in 2019, the Park was granted full certification.

Description. Considered one of the seven natural wonders of the world, the Grand Canyon spans a length of 446 km across northern Arizona and reaches depths of over 1,850 m. The Colorado River cut the Canyon through the rocks of the Colorado Plateau in stages between six and seventy million years ago (Karlstrom et al., 2014). Founded in 1919 to protect and preserve the Canyon in perpetuity for future generations, Grand Canyon National Park is managed by the US National Park Service (NPS) and protects roughly 5,000 km^2 of land in and around the Canyon. It is one of the most visited parks within the NPS system, with as many as 6.4 million visitors in 2018. Owing to its remote location the Grand Canyon experiences some of the least light polluted night skies in the US (Figure 3.3).

The scale at left shows colours according to corresponding ranges of artificial light ratio values. Regions outlined in green indicate boundaries of land units managed by the NPS. 1: Havasupai Indian Reservation. 2: Kaibab National Forest. 3: Grand Staircase-Escalante National Monument. Skyglow from Las Vegas (4), Nevada, is visible from many places along the canyon rim within the National Park. Map data courtesy of the NPS Natural Sounds and Night Skies Division Night Sky Team.

Achievements. Grand Canyon National Park has achieved many firsts and superlatives within the US National Park Service related to dark sky preservation. When the IDSP nomination effort began, it had more buildings and lights within its boundaries than any other US national park that had applied to the IDA. Counting the lights and characterizing them in terms of retrofitting needs was a daunting undertaking. In 2014 the Park became the first US national park to create a full-time staff position dedicated to night sky preservation. Fundraising efforts by the Grand Canyon Conservancy (GCC), the Park's non-profit partner organization, supported the

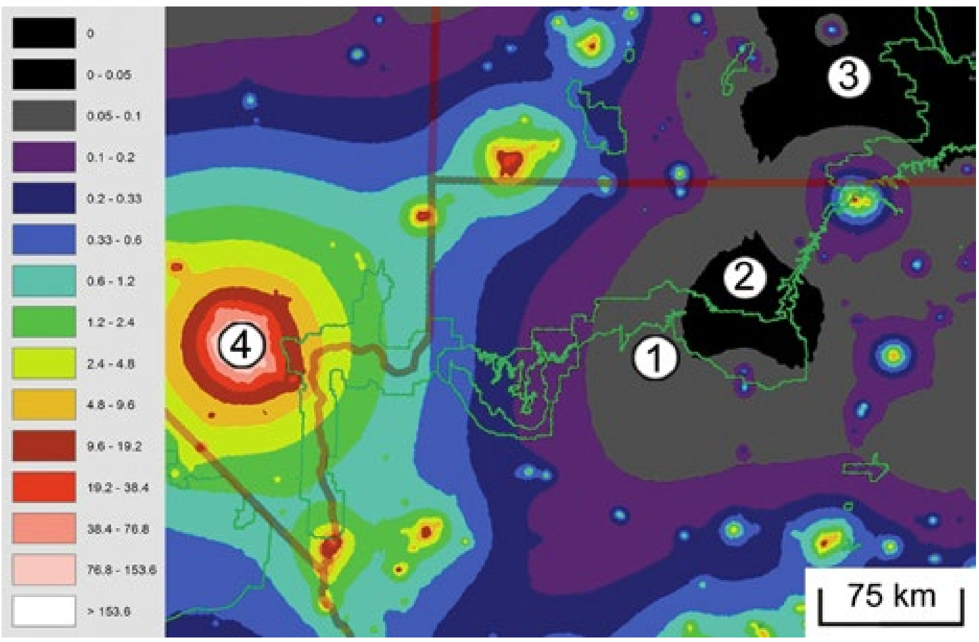


Figure 3.3. The artificial light ratio in the vicinity of Grand Canyon National Park, US. Source: International Dark-Sky Association

creation of a two-year Night Skies Inventory Coordinator. The robust financial and volunteer partnership between GCC and the Park has since become a model for other NPS sites applying for IDA accreditation.

As part of the initial phase of its IDSP nomination, Park staff completed an inventory of 5,156 outdoor light fixtures. The majority of inventoried luminaires are located in Grand Canyon Village, a community within the park housing 2,000 people including Park staff and their families. The presence of this town within the boundaries of an otherwise naturally dark place is a special challenge for protecting night skies. When the inventory was completed in 2014, 35%, 1,796, of the inventoried luminaires were dark sky compliant. Owing to the IDA requirement to attain 67% compliance with the Park's lighting management plan, and given the scope and complexity of necessary retrofits, the Park received a Provisional International Dark Sky Park designation in June 2016. Consistent with the conditions of the Provisional IDSP status, the Park was granted three years in which to demonstrate full compliance with all programme requirements, after which it would gain full International Dark Sky Park status.

Park staff and partners worked diligently to achieve the required 67% compliance. Lighting retrofits were funded through a US$1 million campaign managed by the GCC. Following two rounds of retrofitting, in June 2019 Park staff reported that 69%, 3,552, of the Park's outdoor luminaires complied with the lighting management plan. Figure 3.4 shows an example of the improvement to exterior lighting made during the Park's Provisional status.

Activities. For the past 29 years the Park has hosted the largest annual star party within the National Park Service. The Star Parties implemented novel ideas to extend the Park's night sky preservation message through various methods such as: the formation of an astronomy-themed play list on the Park's Science on a Sphere media platform; five nights of night sky photography workshops; outreach booths from various astronomy entities; a series of guest speakers; and a video-scope section in its telescope lots. In 2019 attendance over eight nights of the annual star party theatre presentations totalled 4,500. This was achieved by purchasing and installing an outdoor projection system that simulcasts the presentation to hundreds of visitors outside the theatre who otherwise could not enter inside due to the building's fire code.

The Park has also installed an audience-centred experience on the theme that many cultures believe that when their loved ones die they become stars. The Park placed a table, a chair and an old rotary phone under the stars for visitors. Visitors were invited to dial S-T-A-R, pick out a special star in the sky, and leave a message for their lost loved one. The responses were compiled in a short film and shared on social media sites. At least once a week during the busy summer months there are programmes about night skies, light pollution and/or natural darkness as a resource to preserve. The Park also maintains a social media presence and regularly posts about night skies.

Lessons learnt highlights

- The Park's financial and volunteer connection with their main non-profit partner serves as a funding and support model for other parks with similar existing or planned partnership arrangements.
- Adequate financial and staff capacity combined with deliberate and targeted planning yielded a successful outcome with respect to achieving IDA accreditation, showing that dark sky designation is indeed possible for locations with substantial existing outdoor lighting stocks.
- Active and innovative visitor engagement activities to promote the dark sky concept.

Figure 3.4. A lighting retrofit at Grand Canyon National Park, US. Before (left) and after (right) photos demonstrating the improvement to exterior lighting at the El Tovar guest lodge resulting from retrofits funded by the Grand Canyon Conservancy. Source: IDA

Hortobágy Starry Sky Park
Hungary

DSAG class 2a, Dark Sky Park: park, reserve, habitat, natural area or other ecological or geological protection. Corresponds to Hortobágy National Park, IUCN category II.

Contributed by István Gyarmathy, Hortobágy National Park Directorate, Hungary

Recognition. In 2011 Hortobágy was recognised as an International Dark Sky Park by the IDA. This was based mostly on the undisturbed nighttime landscape, the shepherd tradition related to starry skies, and the protection of its high biodiversity, especially the great number of nesting and migrating bird species and nocturnal insect species. Many of the breeding and nesting bird species, such as geese, cranes and spoonbills, and many rare insect species are sensitive to light pollution. IDA recognition is an important tool to promote the protection of nocturnal wildlife habitats.

A note about the term 'starry sky.' In many cultures with languages other than English, the literal translation of 'dark sky' has a negative, foreboding meaning. In their own languages, 'starry sky' carries a more positive connotation and hence is widely used.

Description. Hortobágy is one of the darkest places in Hungary. It was the first proclaimed and is the largest Hungarian national park. Its important wetlands are the basis of its recognition in 1979 as a wetland of international importance under the Ramsar Convention. Hortobágy is also one of the last European guardians of a living shepherd tradition. Shepherd culture has a deep interdependence with the natural environment. Its pastures are scattered with traditional buildings of ancient pastoral activity, and there is much evidence in ethnographical works of the starry-sky knowledge of the shepherds. The Hortobágy people's knowledge of stars and their related folk traditions is richer and more colourful than anywhere else in Hungary (Figure 3.5). The shepherds knew the hours from the procession of stars. They used Nagygoncol (Big Dipper), the Pleiades, Kaszáscsillag (Orion), Santa Kata (Sirius) and the Milky Way to indicate their location at night. Hortobágy's culture of traditional land use and ancient shepherd culture, along with its natural capital, are reflected in its status since 1999 as a UNESCO World Heritage Site and since 1979 as a UNESCO international biosphere reserve.

Description. Hortobágy National Park covers 82,000 ha on the former flood plain of the Tisza River. It consists of mosaics of alkaline marshes and dry pastures. After the Volga Delta, Hortobágy is the second largest alkaline grassland in Europe. It is Europe's largest continuous

Figure 3.5. Stargazing horse-herds, Hortobágy, Hungary A postcard from the early 1900s. Source: István Gyarmathy, © Hortobágy National Park

Figure 3.6. Migratory birds, Hortobágy National Park, Hungary. The environment free of light pollution is essential for wildlife, e.g. insects at night and migratory birds. Source: Attila Szilágyi

remnant native grassland area with traditional grazing and shepherd life. The Park is most famous for its rich avifauna (Figure 3.6). With 159 nesting species and 178 regular or irregular visiting species, it is the best birding site in Hungary. Each year 100,000 to 300,000 grey geese (*Anser spp.*), about 100,000 cranes (*Grus grus*), and 50,000 to 200,000 shorebirds stop at Hortobágy.

Achievements. Hortobágy has established lighting regulations based on the RASC/IDA Guidelines for Outdoor Lighting summarised elsewhere in this report. These relate to shielding, colour temperature, illumination levels and timing. The Park has incorporated these regulations into its management plan and several retrofits have been implemented. Biomonitoring has begun of the effects of artificial light on nocturnal insects.

Activities. The dark sky status also serves to advertise the Park as an astrotourism destination. It organises popular night walks and interpretive programmes related to dark sky values. Astronomy is now a part of the Field Study Centre curriculum, with a public astronomical observatory including an all-sky camera and online Sky Quality Meter to monitor light pollution. There are about thirty public programmes annually including open air astronomy camps for school children, stargazing tours and observatory workshops. A new visitor centre is planned which will feature an exhibition dedicated to dark sky values. The park also participates in the UNESCO Astronomy and World Heritage Theme.

Outreach. The Park has established cooperation agreements with local stakeholders and communities and local and national conservation NGOs and astronomy groups to help protect the area's dark sky values. So far, though, there has been little progress in retrofits outside Hortobágy.

Lessons learnt highlights

- Building on a long cultural heritage based on traditional pastoral activities which include awareness of the night sky
- A broad range of visitor activities including access to a public observatory
- Establishing cooperative agreements with local stakeholders to manage outdoor lighting
- The Park received a separate zone with lighting restrictions in a new regional plan and in 2020 a buffer zone was created around the Park with lighting regulations

Kejimkujik Dark Sky Preserve
Canada

DSAG class 2a, Dark Sky Park: park, reserve, habitat, natural area or other ecological or geological protection. Corresponds to Kejimkujik National Park, IUCN category Ib.

Contributed by Robert Dick, Royal Astronomical Society of Canada (RASC)

Recognition. In 2010 Kejimkujik was designated a Dark Sky Preserve by the RASC.

Description. The Preserve is a 404 km^2 national park in the southern part of the province of Nova Scotia, Canada. It lies 174 km, about two hours driving, from Halifax, the provincial capital of 400,000 people. It is centred on Kejimkujik Lake in a mostly wilderness area. The park contains 46 lakes and ponds and more than thirty streams and rivers. The lakes and smooth-flowing rivers are a result of the last glaciation and make up approximately 15% of the park's area. Its old growth forests are a transition zone between deciduous and evergreen zones. Its iconic wildlife includes the endangered Blanding's turtle *Emydoidea blandingii*, many freshwater fish species and the common loon *Gavia immer*. It hosts about 35,000 visitors per year and forms the core of a UNESCO international biosphere reserve.

Achievements. In the decade since its dark sky designation the park almost doubled its attendance. It developed formal agreements with astronomy and First Nations representatives, adding value to regular night sky appreciation, stargazing, guided night walks and cultural experiences. The dark sky designation is integrated into the park's online and written promotional literature.

The only artificial outdoor lighting is at visitor facilities near the boundary of the park, especially the main campground which is also a source of skyglow. This lighting is primarily from the parking lots, public service buildings such as toilets, and lamps from campers. As budgets allow, this lighting is slowly being replaced in accordance with the RASC Guidelines for Outdoor Lighting (RASC, 2020). Lighting retrofit is the greatest difficulty in obtaining and maintaining a dark sky preserve designation. Parks require at least a year to plan, budget and begin converting to low-impact lighting. Changes in staff and managers can result in further delays in lighting conversion.

Activities. There are astronomy programmes and facilities that cater to increasing the public's experience of both the night sky and the nocturnal environment. A simple but effective addition is the Sky Circle (Figure 3.7), a place to congregate for formal programmes and informal discussions about the night sky. The Park owns and operates a 250 mm reflecting telescope that is used at the twice-weekly night sky programmes led by Parks Canada staff at the Sky Circle. Outdoor shows ponder extraterrestrial life and interstellar phenomena alongside images,

Figure 3.7. Kejimkujik Sky Circle, Canada. This simple structure is an excellent rendezvous for daytime and evening talks and discussions. Source: David Chapman

music and stories. Night hikes and campfire programmes examine how artificial light affects humans and wildlife, as well as the value of dark sky places. Night canoe excursions offer a magical night sky perspective.

The RASC Halifax Centre collaborates with park staff to host activities including an annual Dark Sky Weekend in August. This festival includes activities for children, a keynote speaker, night sky viewing through volunteers' telescopes, telescope clinics and related activities. Each year eight to twelve volunteers have assisted in ten such weekends, each with 700 to 900 participants.

Outreach. As a national organization, RASC has an extensive system of centres which other organizations may call upon for astronomy outreach activities and presentations. RASC Halifax and Kejimkujik entered into a formal partnership that delineates each party's responsibilities and rights regarding night sky programmes in the Preserve, including a biennial audit of the outdoor lighting. Members of RASC Halifax also provide voluntary consultation and material supporting night sky activities, including basic astronomy training when needed.

Lessons learnt highlights

- Regular updates on progress to both understand delays and to ensure that staff are fully aware of their obligations.
- The Park keeps the RASC informed through regular updates on its programming activities, improvements and problems. For example, in 2020 the main park campground was temporarily closed to enable the renewal of washroom facilities and install outdoor lighting compliant with the RASC Guidelines for Outdoor Lighting.

NamibRand International Dark Sky Reserve

Namibia

SAG class 2a, Dark Sky Park: park, reserve, habitat, natural area or other ecological or geological protection. Corresponds to NamibRand Nature Reserve, IUCN Category not reported.

Contributed by Adam Dalton, International Dark-Sky Association

Recognition. In 2012 NamibRand became the first International Dark Sky Reserve (IDSR) in Africa and the first established in a developing economy. The Reserve was quickly accredited by the IDA after a process lasting less than a year. The reasons for this include its geographic situation with few neighbouring sources of artificial light at night, full support for the accreditation bid by regional stakeholders, and rapid promulgation of the Reserve's lighting management plan facilitated by a single administrative agency overseeing the site.

Description. NamibRand Nature Reserve is a privately owned nature reserve established in 1984 to protect the unique ecology of southwest Namibia. It is among the largest private nature reserves in Africa, encompassing nearly 185,000 ha along the eastern edge of the Namib Desert. The Reserve shares boundaries with the Namib-Naukluft National Park to the west and the imposing Nubib Mountains to the east. The nearest communities are approximately 100 km away and the Namibian capital, Windhoek, is six hours away by car. As a result, NamibRand is far from sources of artificial light at night and it's entire of territory has a pristine night sky quality.

Dozens of native species range across four landscape types in the Reserve: dunes and sandy plains; inselbergs and mountains; gravel plains; and the sand and gravel plains interface. At the Reserve's heart, the Namib Desert Environmental Education Trust Centre (NaDEETC) receives roughly 15,000 visitors a year and offers educational programming about the land's character and conservation needs (Figure 3.8).

Achievements. The education centre provided high-quality night sky education programmes over several years leading up to IDA recognition. NamibRand has since become a regional leader and a well-recognised site to view the darkest of night skies. In 2019 two nighttime accommodations were built within the Reserve, in accordance with the adopted lighting management plan, to serve the needs of the increasing number of astrotourists visiting the site.

The designation of NamibRand IDSR marked a turning point for the IDA International Dark Sky Places Program. Until then it focussed primarily on rehabilitating protected places where threats due to artificial light at night already existed. NamibRand was the first designation of a large-scale landscape lacking a significant, pre-existing threat from artificial light. This IDSR designation was intended to help preserve the integrity of a landscape largely devoid of artificial light. NamibRand's nomination marked an emerging IDA strategy of preempting the arrival of the threat by developing public awareness of the value of a dark night sky and the threats posed by light pollution. This concept later evolved to become the IDA's International Dark Sky Sanctuary category.

In essence, the NamibRand case and the subsequent creation by IDA of a Dark Sky Sanctuary category address a common issue facing extremely remote dark places in the 21st century. The restoration and maintenance of their sky quality requires that high levels of artificial light at night are not deployed within their own boundaries. NamibRand has adopted comprehensive policies and procedures to address such issues before lighting is installed. This example shows how simple it can be to conserve the few remaining vast pools of darkness in an ever more light-polluted world.

Activities. The enterprise is self-sustaining through tourism concessions that pay a daily, per-bed fee to the Reserve, and the tourism impact on the landscape is limited through an annual quota system. As a result, the Reserve has become a leader in southern African private conservation by balancing holistic biodiversity conservation with financial sustainability.

Outreach. The greatest threat to sky quality stems from the rapid increase in astrotourism developments in and near the Reserve. In 2019 a new tourism development opened south of the Reserve. While promising their guests an opportunity to discover the stars from their numerous telescopes, little consideration was given to light pollution and the effect this will have on their guests' experience of the night sky. Lights from this new lodge can be seen from several locations within NamibRand, including from its core area more than 27 km away. Initial dialogue between the Reserve and the external tourism operator is encouraging and there is hope that a lighting solution can be found that satisfies all parties.

Lessons learnt highlights

- Establishing an education and environmental centre that runs well-subscribed night sky programmes.
- Proactively seeking IDA certification as the first dark sky place in Africa and, along with Aoraki Mackenzie in New Zealand, one of the first two in the southern Hemisphere.
- Working with neighbouring developers to mitigate light pollution in and around the Reserve.

Figure 3.8. Namib Desert Environmental Education Trust Centre. Source: IDA

!Ae!Hai Kalahari International Dark Sky Sanctuary
South Africa

DSAG class 2b, Dark Sky Park: unpopulated area set aside for traditional or sacred practices related to the sky. IUCN Category not reported.

Contributed by David Welch, Dark Skies Advisory Group, IUCN

Recognition. It was certified by the IDA in 2019. A dark sky sanctuary is like a dark sky park but at a very remote location so that public access is difficult and there are no visitor programmes but, conversely, with few nearby threats.

Description. The park is part of the Kgalagadi Transfrontier Park and is part of the ‡Khomani Cultural Landscape World Heritage Site. It is jointly owned by the Mier and ‡Khomani San communities. The area is semi-desert, but after good rains it has extensive tracts of savanna grazing. These support a diverse population of large predators, herbivores, birds of prey, insects and reptiles. Desert animals become nocturnal to avoid the worst heat of the day. Plants adapt to avoid water loss to the Sun, and some birds and insects develop social living habitats to survive the extremes of the desert. Life in the wilderness is perfectly adapted to the area's natural dark skies.

The quality of the area's night sky is due in part to its latitude, dry air, low levels of pollution and the large tracts of land in the region that have low or no artificial lighting. The !Ae!Hai Kalahari Heritage Park is under the conservation authority of South African National Parks, which intends this area to be South Africa's leader as one of the best places on Earth to see the night skies.

Part of the cultural heritage of the ‡Khomani San is their spiritual and cultural connections to the night sky and its celestial bodies. For the San, the stars are the lights of the departed animal and human kinfolk. They believe that the sky is covered by an intricate web along which their ancestors travel. Of the living, only shamans can travel up the web to visit the stars. A significant number of their traditional folk tales involve the stars and other celestial bodies. This is part of the traditional culture at the heart of the Park's World Heritage status.

Achievements. The only permanent accommodation in the park is !Xaus Lodge, a 4-star lodge of twelve stand-alone chalets and a small range of communal facilities perched on a sand dune and overlooking a salt pan. The Lodge has retrofitted all outside lights so that they are shielded and light is kept below the horizontal. The only other development in the Park is Imbewe, a Nature School (Figure 3.9). Imbewe closely resembles the traditional ‡Khomani structures of grass huts, without the conveniences of running water or electricity. A simple stockade surrounds the area to ensure safety from predators. There is no lighting infrastructure at the camp. Night lighting is provided by a fire and a limited number of portable lanterns.

Figure 3.9. Imbewe Lodge. Source: IDA

Activities. !Xaus Lodge caters to tourists looking for a remote wilderness destination where they can experience the vast Kalahari Desert, meet its people and see the animals. Electricity is only provided for five hours in the evening, ending at 23:00 hrs. As well as daytime safari experiences the Lodge provides telescopes for viewing stars, the Milky Way, the Magellanic Clouds and beyond. By promoting astrotourism it encourages visitors to learn about light pollution and to help decrease it when they return home. Imbewe also provides tourism activities to those looking for an authentic Kalahari experience.

Outreach. Community and youth programmes at Imbewe are run by local elders who transfer traditional ‡Khomani San knowledge to younger generations. This knowledge includes all aspects of traditional life such as ethnobotanical knowledge, cultural practices and exposure to their world view relating to the geographical features of their environment. The night sky and the visible celestial bodies have an important role in these cultural practices.

Lessons learnt highlights

- Ensuring that visitor facilities strictly observe dark sky protection standards
- Bringing traditional cultural knowledge to the forefront of the visitor experience
- Maintaining dark skies as part of protecting cultural heritage and sustainable astrotourism as an economic benefit to the local economy

Old Man on His Back Ranch Nocturnal Preserve
Canada

DSAG class 2c, Dark Sky Park: rural area, area of outstanding landscape beauty, recreation compatible with conservation. Old Man on His Back Conservation Area. IUCN Category not reported.

Contributed by Robert Dick, Royal Astronomical Society of Canada

Recognition. In the late 1980s the Old Man on His Back Ranch (OMB) was donated to the Nature Conservancy of Canada (NCC), an organization that works to protect natural areas and their native species. The NCC recognises that light pollution is a threat to conservation. OMB was successfully nominated by the NCC in 2015 to become an RASC Nocturnal Preserve. The RASC developed the Nocturnal Preserve designation for areas that conform to the lighting restrictions of RASC Dark-Sky Preserves (DSPr), but do not or are unable to provide an astronomy outreach programme that is required for their other certifications. Nevertheless, the Nocturnal Preserve designation requires that OMB must honour the other DSPr requirements. A memorandum of understanding with the RASC clarifies these responsibilities.

Description. The ranch encompasses 53 km^2 in the southwest corner of the province of Saskatchewan, 16.5 km from the Canada-US border. It is 400 km and 360 km respectively from Calgary and Regina, 5 and 6 hour drives. The area typifies the prairie landscape (Figure 3.10) and is protected from oil and gas development. It was once the range of bison, which are now being re-introduced. Until recently it was a working ranch, operated as open range [visitcypresshills.ca/attractions/old-man-on-his-back-ranch].

Oil and gas extraction beyond the OMB boundary is a particular problem because it is absolved from responsibility for its environmental disruption of the night. Although there are strong environmental protection regulations, these do not yet apply to the night environment. As a safety measure, oil wells, and occasionally gas wells, flare off gas by burning it in the air. These fires can be seen for tens to a hundred kilometres across the prairie, and are prominent in satellite images of the night. The RASC is attempting to have the nocturnal environment recognised in the Canadian environmental assessment process.

Achievements. In the OMB there are only four outdoor lights. Three are fully shielded 50W halogen lamps at the visitor centre building and are used only occasionally. The fourth is an unshielded 150W HID lamp which is controlled by a switch and rarely used. The large expanse of the property is wild rangeland with no power. With no additional lights on the property it was easy to comply with the RASC Guidelines for Outdoor Lighting.

Figures 3.10. Day and night at the Old Man on His Back Ranch, Canada. Daytime (top) and night (bottom) panoramas show the typical flat landscape of the Canadian prairies. In the night view the Milky Way arches over the Aurora Borealis. Source: Alan Dyer

Activities. The OMB Visitor Centre provides a focus point for the visitors. However, astronomy programming is limited to periods when RASC members come to the area to observe and provide public astronomy interpretation.

Outreach. There is also a Municipal Outreach Plan to increase awareness in neighbouring communities that artificial outdoor light should be treated as a pollutant to be minimised, rather than increased as a symbol of prosperity.

Lessons learnt highlights

- Cooperation with the RASC to provide astronomy programmes for visitors
- Outreach plan to encourage neighbouring communities to minimise light pollution

Chaco Culture International Dark Sky Park
United States

DSAG class 3, Dark Sky Heritage Site: protected heritage physical works of mankind.
Chaco Culture National Historic Park, IUCN category V.

Contributed by David Welch, Dark Skies Advisory Group, IUCN

Recognition. The IDA certified Chaco Culture in 2013. It became a World Heritage Site in 1987.

Description. From the 9th to 13th Centuries Chaco Canyon was the centre of a civilization of social, political and architectural sophistication. An engineered system of roads and evidence of a vast trading network are indicators of its former inhabitants' relationships with other peoples over a wide area. The characteristic building of the Chacoan civilization is the great house, a multistoried, multi-roomed structure (Figure 3.11). The park's 13,749 ha contain 4,000 recorded archeological sites that combine many elements of planned architectural designs, astronomical alignments, geometry, landscaping and engineering. Together they created an urban centre of spectacular public architecture, one that still awes and inspires a thousand years later, and which is sometimes referred to as the Stonehenge of America (Fagan, 2008, 134).

The park, located in the US state of New Mexico, encompasses the alluvial valley floor of Chaco Canyon, side canyons and expansive sandstone mesas and gently rolling hills. The

Figure 3.11. Pueblo Bonita Great House, US. Source: IDA

vegetation is mainly grassland and desert scrub. Cottonwood and willow groves are abundant along the canyon floor and around seeps and springs. Scrub and wildflower communities occur on the sandstone bluffs. Pinyon-juniper woodland is well developed on higher elevations.

Achievements. For more than a decade before IDA recognition the park conducted a night sky quality programme. Zenith luminance measurements are now collected on a five-year cycle to monitor changes in sky quality conditions. Should light pollution threats require more frequent monitoring, Chaco will work to expedite its monitoring schedule accordingly. A generous donation led to the building of the Chaco Observatory in 1988, which is the only astronomical observatory operated by the US National Park Service.

Activities. Since 1988 the Park has partnered with the astronomy community to add astronomy to its public programmes. In 1991 a partnership was forged with the Albuquerque Astronomical Society to host annual star parties. The night sky is a substantial recreation interest and a way for the public to connect with, and better understand, the ancient culture that once thrived in the canyon. The enthusiastic response from the public became an incentive to improve the park's exterior lightscape in the early 1990s.

Three nights each week from March to October staff and volunteers guide visitors to spectacular views of the night sky. The programmes typically begin with a presentation either on archaeoastronomy or the significance of dark skies, then segue to a naked-eye tour of the constellations and other features, and conclude with a chance for park visitors to view distant objects through telescopes. After-dark programmes include the archaeoastronomy of Chaco Culture, focussing on architectural/celestial alignments, Sun watching traditions, viewing with public telescopes, night walks at full Moon featuring oral traditions and patterns of the Moon, and campfire astronomy led by volunteers. Special events are also organised to view eclipses and meteor showers.

Outreach. The Albuquerque Astronomical Society remains a strong partner, contributing to the construction and operation of the Chaco Observatory, as well as helping to conduct outreach and education activities. Other nearby astronomy groups such as the Rio Rancho Astronomical Society and the New Mexico Institute of Mining and Technology astronomy club also contribute. School groups of all ages visit the park to take part in its observatory programmes, and staff utilise the park's portable telescopes to take its astronomy programmes to schools, scout camps and other organizations. Park staff also travel to nearby communities to give astronomy programmes and facilitate star parties.

Lessons learnt highlights

- Taking action in response to organizational and sub-national (State of New Mexico) policies and legislation to protect the night sky
- Ongoing monitoring of night sky conditions
- Diverse interpretation programmes for visitors
- Taking astronomy programmes to local schools and communities

Irving Urban Star Park
Canada

DSAG class 4a, Dark Sky Outreach Site: urban or suburban outreach site.
Irving Nature Park, Saint John, New Brunswick, Canada. IUCN Category not reported.

Contributed by Robert Dick, Royal Astronomical Society of Canada

Recognition. Irving Nature Park was certified by the RASC in 2011 as Canada's first urban star park.

Description. Only a ten minute drive from the centre of Saint John, New Brunswick, the park is ideal for public access even in winter (Figure 3.12). It serves a regional population of 130,000. Its primary quality as a nature park is the absence of outdoor lighting. Despite its proximity to Saint John its woodland buffer zone provides physical isolation from the city core, resulting in a skyglow level of 20.3 mag/arcsec2, which is good to excellent for areas this close to a city. The property is privately owned but open to the public year-round. Snow is not cleared in winter so vehicle access is limited during that time.

Over the last four decades the population of the Saint John has decreased from 90,000 to 70,000, thereby limiting urban light pollution. Furthermore, the Irving Nature Park management has no interest in investing in built facilities on the property.

Achievements. The three concerns when designating this site were light pollution, continued access and visitor engagement. In response to these issues the City of Saint John supported the designation. The Ministry of Tourism for New Brunswick and J.D. Irving Ltd, the private company that owns the Park, also submitted supporting letters.

Activities. This is a suburban location noted for its dark sky programming and viewing opportunities. Park staff provide for visitor engagement during the day from the beginning of May to the end of October, i.e. the northern summer and autumn. During the main tourist season the staff provide walking tours of the property and give talks on the park's geology, wildlife and ecology. The local branch of the RASC schedules public presentations and star parties

Lessons learned highlights

- Active cooperation between local astronomers, the city of Saint John and J.D. Irving Ltd forest products company to obtain RASC certification
- Astronomy interpretation delivered by volunteers

Figure 3.12. Irving Nature Park and Urban Star Park, Canada. A wooded upland peninsula and tidal flats. The City of Saint John, Canada, is in the background. Source: Google Earth

Yeongyang Firefly International Dark Sky Park
Republic of Korea

DSAG class 4b, Dark Sky Outreach Site: rural outreach site. Includes: Yeongyang Firefly Eco Park; Yeongyang Firefly Eco Forest; Yeongyang Firefly Special Zone; Wangpicheon Ecosystem and Landscape Conservation Area. The Eco Park is within the Wangpi River Basin Ecological Landscape Protected Zone, IUCN category IV.

Contributed by Adam Dalton, formerly of the International Dark-Sky Association

Recognition. Because of the potential economic benefits of astrotourism for Yeongyang County, one of the least economically advantaged in the Republic of Korea, in 2013 it contacted the IDA regarding a potential designation for Firefly Eco Park. In 2015 the park became the first International Dark Sky Park (IDSP) in Asia. It is significant for the conservation of fireflies which are known to benefit from conditions of natural darkness. Of sites designated within the IDSP programme, the park's multifaceted emphasis on sustainable rural community development, combined with ecological protection, serves as an outstanding example of the unique benefits which stem from dark sky protection and designation.

Description. Yeongyang Firefly Eco Park lies within the mountainous and remote Yeongyang County. With 16,540 residents it is the third least populous of the Republic of Korea's 81 counties snd it is one of the darkest areas in thecountry (Figure 3.13). Managed by the county, it has been under legal protection since 2005.

Achievements. In recognition of the need to maintain its firefly population, the park developed a management plan to protect natural darkness. Owing to these progressive outdoor lighting policies, its outdoor lighting already largely complied with IDA Dark Sky Park guidelines. This facilitated a simpler IDSP application process for the Firefly Eco Park, as lighting retrofits were less extensive than in the case of most other IDSP applicants.

Since 2015 the park has made considerable progress towards restoring and maintaining the natural night environment for the benefit of its signature organism, the firefly. In 2019 funds were secured to cover the long-term cost of breeding and to maintain the fireflies' access to the natural nocturnal environment.

Since designation, the Yeongyang Firefly Eco Park has seen a dramatic increase in the number of people who visited its observatory and dark sky programmes, from 5,137 in 2015 to 9,903 in 2019. The busiest month, August 2019, saw 4,625 persons attend a night sky programme.

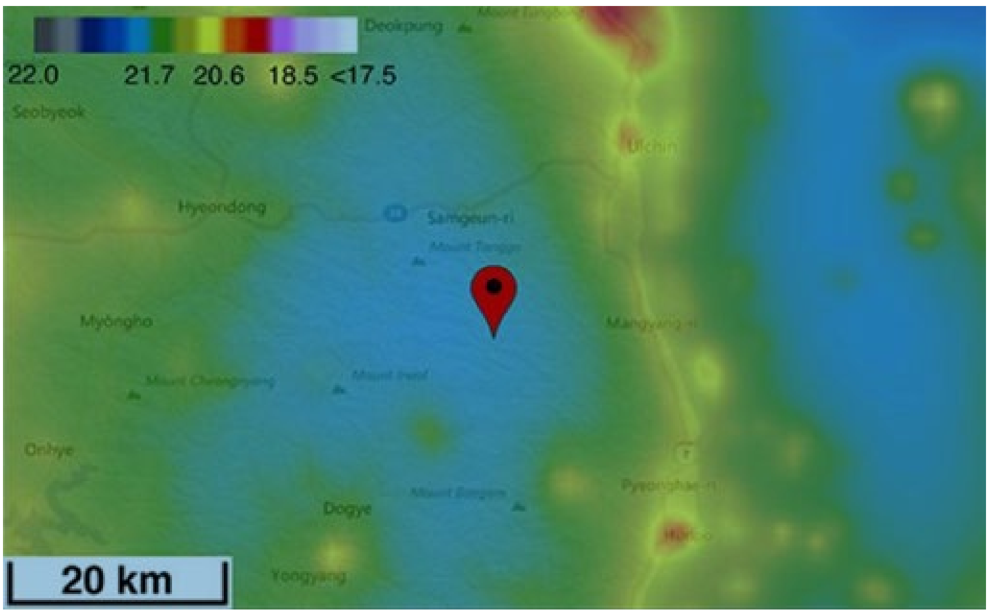


Figure 3.13. Yeongyang zenith sky brightness map, Republic of Korea.The red marker locates the park. The map's false colours indicate predicted zenith night sky brightness based on the New World Atlas of Artificial Night Sky Brightness (Falchi *et al.*, 2016). The colour bar shows zenith luminance in units of magnitudes per square arcsecond. Source: IDA

Activities. The park's history of astronomy and outreach related to dark skies positioned the site to meet many designation criteria pertaining to public outreach and education. Shortly after firefly protections came into effect, Korean amateur astronomers began to take note of the site and flocked there with increasing frequency to experience dark skies without having to travel especially far from home, as the Firefly Eco Park is located within a five hour drive of Seoul. Each year there are numerous events related to firefly ecology with respect to dark sky preservation. Such actions highlight the potential for other sites interested in dark sky conservation to designate a charismatic species as a compelling reason for dark sky preservation.

Outreach. Owing to the Park's status as the first IDSP in Asia, other potential places in the region have reached out to Yeongyang in order to learn from the its experiences, including most recently a delegation from Taiwan which chaired the successful HeHuan Mountain IDSP designation effort.

Lessons learnt highlights

- Prior recognition of the need for light pollution abatement to protect a signature species
- Assisting other protected areas in their search for dark sky place certification

River Murray International Dark Sky Reserve
Australia

DSAG class 5, Dark Sky Outreach Site: core protected area and a sustainable development buffer zone of cooperating community, rural and natural area jurisdictions. Includes the following. Conservation parks: Swan Reach, IUCN Category 1a; and Ngaut Ngaut Park, IUCN Category III. Reserves under municipal jurisdiction: Brookfield, Ridley, Marne Valley, and Towitta Park. Private protected areas: Moorunde Wildlife Reserve and Yookamurra Wildlife Sanctuary.

Contributed by David Welch, Dark Skies Advisory Group, IUCN

Recognition. 2019 by the International Dark-Sky Association

Description. Approximately 100 km northeast of Adelaide, South Australia, the reserve covers more than 320,000 ha, 20,000 ha of which are public and private protected areas such as wildlife reserves and wetlands. Separated from the lights of Adelaide by a range of hills, these lands provide ideal dark sky observation locations and ensure long term protection of dark skies. Swan Reach Conservation Park is 2,023 ha of almost untouched bushland protected by state government legislation since 1970. Australia's largest river, the River Murray, flows through the Reserve for 80 km. It is already a major tourist attraction, with more than 250,000 overnight visitors a year. The river is an excellent place from which to view the night sky.

The region's economy is dominated by the River Murray as it provides water for the city of Adelaide and for irrigation for a diverse range of agriculture, viticulture, horticulture, tourism and recreation. The majority of the sixteen towns and villages in the reserve are along the River Murray, and are separated by large areas of farmland and parks. The population density of approximately one person per square kilometre means the impact of human settlements on the night sky is minimal.

The 49 ha Ngaut Ngaut Park is an ancient Indigenous campsite, meeting place, burial ground and sacred site. It protects extensive carvings tied to the creation of the River Murray, cultural practices, hunting, local wildlife and observations of the stars. Culture is passed on through stories, carvings and abandoned objects. Carvings in cliffs represent phases of the Moon and other ancient astronomical observations. Stories about the Sun, the Moon and constellations like Orion and the Pleiades are also carved into its cliffs. There are also constellations unique to Australia's Indigenous people, such as the 'emu in the sky,' known to Europeans as the Milky Way, that use the dark spaces between the stars to create the entire image.

Achievements. This community-initiated project received strong support from local businesses, community groups, individual residents and the scientific community including the Chief Scientist of South Australia. The potential for the reserve to increase the region's visitor numbers has given the local community a huge motivation to assist in achieving and maintaining dark sky status. To do this, residents have attended events in large numbers and volunteered to measure darkness.

Activities. Community events leading to IDA recognition include dark sky and light pollution information nights, a Lunar Eclipse Breakfast, telescope access, and a darkness measuring competition. This reserve will also host an education and research centre in the town of Meldanda presenting educational events for schools and the community. It will focus on astronomy and the impact of light pollution on Australian native animals. A demonstration site on the main street of the town of Cambrai will showcase new types of luminaires and outdoor lighting and practical ways to reduce light pollution.

Outreach. The River Murray Dark Sky Reserve Committee is a collaboration between local residents, scientists and local government. Its role is to establish, manage and promote the reserve with a range of public events. It collaborates with state and local authorities to build awareness of light pollution and ways it can be addressed in the region and across South Australia. There are also many newspaper, radio and TV interviews to raise local and national awareness of the reserve and of light pollution. Outreach materials include posters and fact sheets.

One of the most important aspects that the reserve offers is the opportunity for the local Indigenous community to work with the South Australian Museum and the Adelaide Planetarium to study Indigenous constellations and to reconnect with lost elements of their culture.

Lessons learnt highlights

- Strong and widespread community and stakeholder collaboration to help establish and manage the dark sky reserve
- Engagement with local Indigenous communities to help preserve and communicate traditional cultural heritage
- Frequent public dark sky events

Westhavelland International Dark Sky Reserve

Germany

DSAG class 5, Dark Sky Outreach Site: core protected area and a sustainable development buffer zone of cooperating community, rural and natural area jurisdictions. Part of Westhavelland Nature Park, IUCN Category V.

Contributed by David Welch, Dark Skies Advisory Group, IUCN, with inputs from Andreas Hänael, Planetarium Osnabrück, Germany

Recognition. In 2014 the IDA recognised 78,660 ha of the Nature Park as an International Dark Sky Reserve (Figure 3.14).

Description. Westhavelland Nature Park, about 70 km west of Berlin, is one of 101 nature parks that cover 26% of Germany. Nature parks are large-scale protected landscapes and nature conservation areas intended for recreational purposes and sustainable tourism. Through sustainable land use they also protect cultural landscapes with diverse species and habitats. Westhavelland Nature Park covers 131,500 ha of extensive glacial deposits, wetlands and water bodies (Meier, 2015). It is an important resting place for thousands of geese, swans, cranes, ducks and sandpipers on their long migrations. Beavers, otters, amphibians and fish are abundant. In 1978 large areas were declared Ramsar wetlands of international importance. About 70,000 people live in the nature park, of whom about half are in two towns. It offers very dark skies not far from the bright metropolitan region of Berlin with its 4.4 million people.

Rathenow, the principal town in Westhavelland, has a long tradition in the optical industry. Lenses for microscopes, eyeglasses and magnifying glasses have been produced there since the early 1800s. The production of photographic cameras and more optical firms followed. After World War II Rathenow was the only producer of eyeglasses in the German Democratic Republic, and after the reunification of East and West Germany several optical firms stayed in Rathenow. In 2007 Optikpark Rathenow was created to commemorate this tradition. Several optical experiments are exhibited in the Optikpark, most notably a large brachymedial telescope, meaning that it combines mirrors and lenses (Figure 3.15). At the administrative centre, mounting posts for telescopes have been installed with the help of private donations. Several large telescopes were donated by the Potsdam Planetarium and by a private citizen.

Achievements. The management plan aims to preserve dark landscapes to protect nocturnal animals and a dark sky for visitor enjoyment. The plan also includes a development concept for sustainable tourism, in which the night sky and education about nature at night play an important role. Lighting retrofits continue in many communities within the reserve. High pressure mercury and sodium vapour lamps are being replaced with shielded LED lights that have lower colour temperatures.

Like biosphere reserves, Westhavelland shows the value of bringing together many communities and protected areas to preserve and appreciate a natural night sky. Continuing efforts by dedicated volunteers result in significant astrotourism benefits, frequent star parties, and ongoing outreach to neighbouring communities.

Activities. An extensive education and communications programme includes the annual WestHavelländer AstroTreff star party, dark sky interpretive programming, a European Day of Parks event and the Kunst und Kultur (Art and Culture) programme.

It is difficult to estimate the number of visitors to the nature park and to the reserve. This is because it is a mix of protected, private and public lands and there are many ways to enter the area. Nevertheless, in some years 1,500 to 2,000 individuals have attended organised events. Many people come for special astronomical events, such as a lunar eclipse or the annual Perseid meteor shower.

Outreach. Founded in 2014, a nonprofit association maintains a website that publishes information about the reserve and its outreach programme. Some communities outside the reserve have expressed an intent to start implementing the same guidelines for outdoor lighting. Partnerships have been also established with private enterprises to develop astrotourism.

Lessons learnt highlights

- Adopting a biosphere reserve model to preserve nature, the night sky and public access
- Outreach to stakeholders within and outside the reserve to encourage responsible outdoor lighting and to foster the appreciation of naturally dark night skies
- Active night sky programming and the provision of public access to high quality telescopes

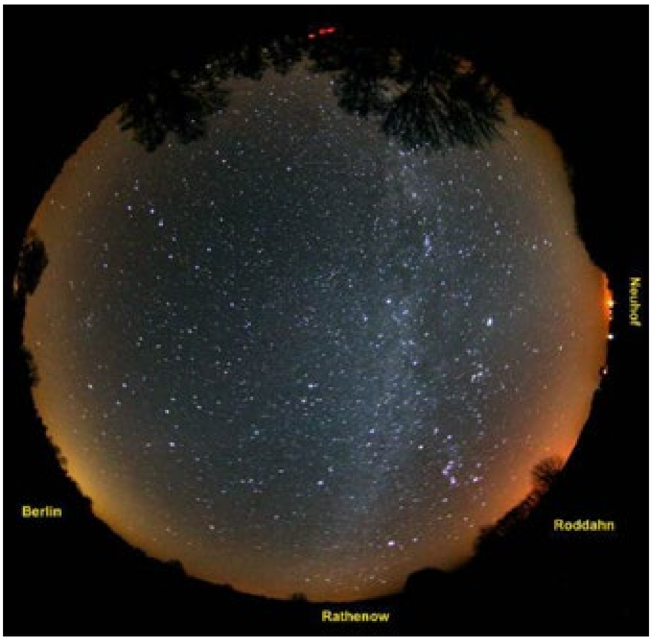


Figure 3.14. The night sky over Westhavelland, Germany. In this image from 22 February 2011, the zodiacal band can be followed across the Milky Way. Source: IDA

Figure 3.15. The brachymedial telescope in Optikpark Rathenow, Germany. Source: IDA

Flagstaff International Dark Sky Community
United States

DSAG class 6a, Dark Sky Community: city, town or village.

Contributed by David Welch, Dark Skies Advisory Group, IUCN.

Recognition. In 2001 Flagstaff was recognised as the world's first International Dark Sky Community for its pioneering work that balances preservation of the natural night sky with concerns about public safety and economic security.

Description. Flagstaff, Arizona (population 76,000; metropolitan area 145,000) has long been a centre for astronomy research. The US Naval Observatory, located 8 km west of Flagstaff, is a site for optical and near-infrared astronomy. The Lowell Observatory (Figure 3.16) operates two sites in the area. Both sites suffer increasing light pollution from regional and even statewide development. Other facilities include the Navy Prototype Optical Interferometer, the National Undergraduate Research Observatory, the Geological Survey Astrogeology Centre, and the Discovery Channel Telescope.

Achievements. Flagstaff has achieved worldwide recognition for leadership in the protection of dark skies. Beginning with an ordinance in 1958 that addressed searchlights, over fifty years of policy decisions and implementations have fostered an astronomy industry that now includes the many facilities mentioned above. Public support for protection of the night sky for both general enjoyment and professional deep space research has become an established element of community and regional identity.

Zoning that restricts the amount of outdoor light per acre was approved in 1989 by both the City and its surrounding County. Since then the codes have been periodically updated and strengthened. One major change was to replace mercury vapour street lights with dark sky compliant low pressure sodium (LPS) lights.

Activities. To remain one of the world's premier astronomy sites, to preserve naturally dark night skies as an expression of community values, and to better utilise a valuable economic and tourism attractor, Flagstaff continues to implement evolving standards that address problems associated with increased artificial light, air pollution, illuminated signage and development. One element is enforcement of compliance with lighting codes. The City conducts annual audits to identify non-compliant properties, investigates all violations, approximately forty in 2018, and works with non-conforming properties to bring them into compliance. Most street lighting

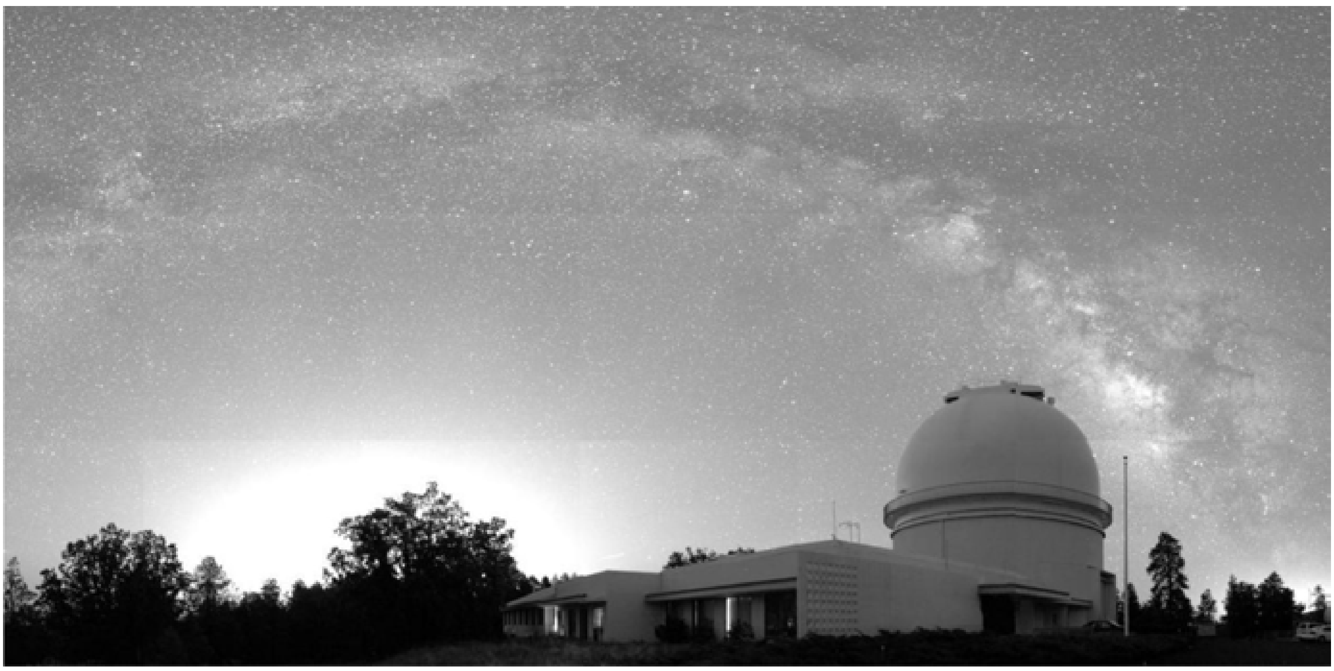


Figure 3.16. Lowell Observatory, Flagstaff, US. Source: IDA

around the world is being replaced by bright white LEDs which can dramatically degrade night skies. If there is a brightening of Flagstaff's dark skies of just 10% over current conditions, then critical astronomy missions cannot be maintained. However, Flagstaff's low pressure sodium (LPS) street lights now need replacing. They are increasingly expensive to purchase and replacement parts are becoming more difficult to acquire. The LPS lights are also prone to structural failures of the pole/arm connection due to the size and weight of the fixtures, especially in wind prone areas. Flagstaff has entered into a project with the State of Arizona to find and fund replacement solutions. The project seeks the best LED luminaire technology that both achieves municipal objectives for safety and cost effectiveness, and astronomical objectives for maintaining dark skies.

Outreach. Flagstaff provides a good example of how dark sky policies need continual action, to enforce standards and bylaws and to maintain and replace equipment as it ages and as new technologies appear. Underlying this is the importance of maintaining public support, both of citizens and municipal staff.

Lessons learnt highlights

- Continuing outreach to citizens to support dark sky compliant policies and practices
- Active promotion and protection of astronomy as a principal economic base of the city
- Collaboration with other levels of government to find optimal lighting solutions

Moffat International Dark Sky Community
United Kingdom

DSAG class 6a, Dark Sky Community: city, town or village.

Contributed by David Welch, Dark Skies Advisory Group, IUCN

Recognition. By the International Dark-Sky Association in 2012

Description. Moffat is located along the River Annan in southern Scotland, and is home to about 2,500 residents. It is a spa town which has attracted visitors since 1685 when the spa waters were discovered. People came to Moffat from across the country to bathe in or to drink the sulphurous water piped from three wells in the hills above the town. It was once favoured by the Scottish national poet Robert Burns. A small but growing tourism base is now a main part of the local economy. Much of Moffat's architecture was built around this tourist industry. Nestled amid the rolling hills of the Southern Scottish Uplands, Moffat offers spectacular views of the night sky. To the east lies Galloway Forest International Dark Sky Park (IDSP).

Achievements. Because of the preparations for Galloway's IDSP certification, the Dumfries and Galloway Council recognised the value of dark sky compliant street lighting. In 2013 it announced a £7.4m investment in street lighting across its entire area. The vast majority of the almost 600 street lights have been replaced with full cut-off, 3200K LED fixtures. The effect is striking (Figure 3.17). In the past one had to go out of town to see the Milky Way. One can now stand in the town centre and see the arc of the galaxy. Note that as of 2021, the Guidelines for Outdoor Lighting recommend a limit of 2200K (RASC, 2020).

Moffat began the process of applying for IDA recognition in 2012 and only completed the project in 2016. The was due to the governance structure of towns in Scotland, in which legal jurisdiction is vested in a series of council areas. While towns like Moffat were once largely self-governing, they lost their status as autonomous corporate entities upon the adoption of the Local Government (Scotland) Act of 1973. It states that "all local government areas existing immediately before that date ... shall cease to exist, and the council of every such area shall also cease to exist." However, to qualify as an International Dark Sky Community, outdoor lighting policy must be established at the council level.

The applicants lobbied the Dumfries and Galloway Council to make the changes, and Moffat's application was submitted to the IDA in September 2013. It was then withdrawn at the request of the applicants because the IDA programme guidelines had by then been amended to a lower

Figure 3.17. Views from The Holm, Moffat, UK, before and after refit. Source: IDA

threshold of 3000 lumens. This resulted in a need to return to the Council for more changes to the lighting policy. The resulting lighting plan goes above and beyond IDA minima and results in better protection of the entire Dumfries and Galloway Council area, which includes Galloway Forest Park IDSP. Moffat provides a good example of the benefit of working constructively with a higher level of government.

Activities. The village hosts an annual series of public astronomy lectures, conducts ongoing sky brightness monitoring and has constructed several telescope mounting piers near the village centre. It has secured funding to further retrofit outdoor lighting to be dark sky compliant.

Outreach is illustrated by the joint efforts of village residents and local astronomers to lobby the Council of Dumfries and Galloway to endorse the lighting plan.

Lessons learnt highlights

- Lobbying of, and collaboration with, higher levels of government to achieve dark sky goals
- Hosting public astronomy events and providing public telescope mounting sites

North Frontenac Township Dark Sky Preserve
Canada

DSAG class 6b, Dark Sky Community: rural area without a formal protected area.

Contributed by Robert Dick, Royal Astronomical Society of Canada

Recognition. The Dark Sky Preserve was certified in 2013 by the Royal Astronomical Society of Canada.

Description. North Frontenac Township, of about 1,900 people, encompasses 1,165 km^2. During the summer this swells to about 7,000 as people go to their seasonal cottages or cabins. The Preserve is located in Eastern Ontario, a two-hour drive west of Ottawa, Canada's capital, which has a metropolitan population of 1.5 million. It is also less than four hours drive from each of the two largest cities in Canada, Toronto and Montreal.

The township is situated in a region where limestone rocks of the Saint Lawrence River Valley overlap granite rocks of the Canadian Shield. This produces an ecotone where boreal and temperate ecologies mingle. The region was scraped clear of soil during the ice ages, making agriculture very difficult. As a result, colonization in the 1800s was not very successful so there was little economic development. Ecotourism now benefits from this lack of development. The preserve encompasses small towns and villages but is dominantly a rural area of woodlands, lakes and cottage country. Its hilly nature and low population result in a very low skyglow with a zenith value of 21.4 mag/sec2.

Achievements. The municipality believed that becoming a dark sky preserve would bolster ecotourism, and the local RASC chapter wished to promote astronomy to the public. It

Figure 3.18. North Frontenac Township Dark-Sky Preserve Astronomy Observing Site, Canada. The illumination is used to help highlight the social aspects of a star party. Normally no lights are permitted. Source: Tim Trentadue

believed that careful use of the Guidelines for Outdoor Lighting (RASC, 2020) would create a better balance between semi-urban and wilderness areas. These guidelines are based on the sensitivity of wildlife to artificial light at night. Mixed success has been achieved. The core of the preserve is centred on a prepared observing site with a 12 m square concrete pad next to an observatory housing a 0.4 m telescope. This observing site has become popular among citizens and visitors alike. However, municipal policies reflect the aspirations of citizens, most of whom have little interest in the outdoor environment at night. Although low-impact luminaires are available, most citizens prefer more typical urban lighting and municipal staff still prefer to purchase from local suppliers that do not know about, or don't carry, low-impact luminaires.

Activities. The preserve encompasses the entire township but astronomy activity is mostly at the dedicated observing site four km southwest of the township offices (Figure 3.18). A 100 m^2 concrete pad provides for stable telescope tripod installation and has year-round access with a parking area and toilet facilities. It is adjacent to a rarely used emergency medivac helipad. No camping is permitted at this site since there are several commercial camping sites elsewhere in the township.

Outreach. The dark sky designation has raised the popular profile of the township. It is able to differentiate itself from neighbouring townships. Although astrotourism here is not lucrative, anecdotal reports suggest a symbolic value for the preserve as it raises the township's profile in the ecotourism market. In practical terms, the preserve has raised funds to build an observatory for a 41 cm telescope beside their observing pad.

Lessons learnt highlights

- Providing a facility for amateur astronomers and the general public to view the night sky
- Adopting dark sky guidelines for lighting, although this has been offset by the difficulty of getting suppliers in small communities to carry, order and install such lighting.

CHAPTER 4.

Lessons learnt from the case studies

This chapter combines the lessons of the case studies and observations from the discussion of impacts and opportunities outlined in Chapter 1. They are presented as recommendations that may evolve into a report on good practices and guidelines to mitigate light pollution.

Governance and management

- Have management policies and practices in place to protect or restore natural darkness.
- Adopt a UNESCO biosphere reserve model to preserve nature, the night sky and public access. To learn about biosphere reserves, see [en.unesco.org/biosphere].
- Particularly for dark sky reserves with multiple partners, acquire tax-free status to help make many activities financially feasible.
- Work with non-profit partners for funding and volunteer support.
- Learn from other dark sky places with similar situations to develop practical solutions and activities. To find existing dark sky places, go to [darkskyparks.org/dsag], select "the world list of dark sky places" and then search the web for matching names. Places seeking dark sky status should go to the website of at least one of the certification organizations listed in Chapter 2. The choice of which one should depend primarily on the ability to establish a good working relationship with a representative of that organization. Application documents and annual reports for places certified by the International Dark-Sky Association can be seen at [darksky.org/our-work/conservation/idsp]. For Fundación Starlight see [fundacionstarlight.org/index.php].
- Ensure that the site has adequate financial and staff capacity, combined with deliberate and targeted planning, to obtain a successful dark sky place certification, especially when there is substantial existing outdoor lighting.
- Implement the Guidelines for Outdoor Lighting given in Chapter 5 of this report and in the source documents from which they are derived. This will facilitate recognition as a dark sky place either by an authoritative, arm's length body or by legislation, regulation or policy of the appropriate national, territorial, state or provincial jurisdiction.
- Establish a system to provide regular updates to staff, stakeholders and the public on progress toward protecting night skies and night ecology. This is particularly important to helpunderstand delays in implementation and to ensure that staff are fully aware of their obligations.
- Ensure that visitor facilities strictly observe dark sky protection standards.
- Respond to international guidance and to national, sub-national and organizational policies and legislation to protect the night sky.
- Lobby and collaborate with higher levels of government to help achieve dark sky goals.

Astrotourism

- Actively promote astrotourism, including giving public access to available telescopes.
- Incorporate dark sky tourism into the management plan of a protected area. Refer to Leung et al. (2018) for IUCN guidelines on tourism and visitor management.
- Develop and deliver a broad range of night sky programming for visitors.
- Host public astronomy events and provide public telescope mounting sites and unlit parking lots.
- Use park and partner visitor centres as foci for night sky programmes.
- Integrate astrotourism with sustainable development activities.
- Where applicable, monitor and publish the economic benefits of a dark sky place.
- Allow reasonably frequent public access at night to night sky viewing locations.

Cooperation and outreach

- Seek IDA, RASC, Fundación Starlight or other certification. Engagement with those organizations brings a wealth of detailed advice on how to restore, maintain and interpret natural night skies.
- Link to other levels of government to find optimal lighting solutions.
- Reach out to local suppliers and encourage them to stock or catalogue dark sky compliant hardware.
- Work with businesses to provide a wide range of visitor opportunities.
- Partner with astronomy organizations and their volunteers to provide programmes for visitors.

Figure 4.1. Aurora on the shores of French Lake, Quetico Provincial Park, Canada. Source: Darksky

- Maintain regular contact with partner organizations to ensure that the cooperative activities remain relevant, resolve emerging problems and respond to new opportunities. One way to achieve this is to distribute the progress reports required by certifying agencies.
- Reach out to local stakeholders and communities to promote night sky compliant lighting and appreciation of naturally dark night skies.
- Take astronomy programmes to local schools and communities.
- Assist other protected areas in their quest for light pollution abatement and potential dark sky place certification.

Ecological connections

- Understand the impacts of light pollution on species and their ecological relationships. This requires a mix of site-specific and species-specific research coupled with tracking of the broader literature on ecological impacts. Depending on the resources of the protected area this may need cooperative agreements with universities or research institutions.
- Recognise the need for light pollution abatement to protect vulnerable species.
- Monitor night sky conditions to track progress toward achieving natural dark skies, maintaining them and providing early warning of emerging threats. In many existing dark sky places this is conducted in partnership with a local astronomy society, often the same one that worked with the protected area to obtain dark sky certification.
- Conduct ongoing monitoring of light-sensitive and light pollution indicator species and interspecies relationships. As with research above, this is often best achieved through invitations to appropriate agencies to do research and monitoring in the protected area.
- Promote research on the ecology of the dark sky place. Research centres and local universities can involve students in research on the effects of artificial light. For a protected area it would help to recruit expertise related to its species and ecosystems.

Cultural connections

- Partner with local Indigenous peoples and historians to document local and regional heritage related to the night sky.
- Maintain dark skies as part of protecting cultural heritage.
- Partner with local Indigenous peoples to bring their traditional cultural knowledge to the forefront of the visitor experience.

CHAPTER 5.

Guidelines for outdoor lighting

There is no easy separation of outdoor lighting situations into mutually exclusive categories. Natural areas can be managed as parks or reserves. Unmanaged areas could be true wilderness or undeveloped lands within urban areas. Heritage sites and areas may be cultural or natural, or both as in the case of archaeological sites within an extensive protected natural area. Urban areas may contain play parks, landscaped green spaces such as street medians with trees, and heritage waterways. In this report the guidelines are divided into two sections for natural areas and built areas, understanding that there will be overlap of situations.

Policies that protect natural areas from human development have been in place in many countries for many decades. However, they usually contain the caveat that the park be accessible to the general public. Historically, this was not seen as a limitation because the impact of human activity was not well documented and was assumed to be minor. More recently, increasing visitor needs and services have resulted in built amenities in otherwise natural areas, and these facilities are having a profound impact on the ecological integrity of natural areas. Artificial Light at Night (ALAN) is used to improve visitors' peace of mind, and to aid in navigation in vehicles and on foot. However, the increasing and unrestrained use of artificial light affects more than the just the immediate area around the facilities.

In 1980s the International Dark-Sky Association (IDA), the Royal Astronomical Society of Canada (RASC) and other astronomy groups began to focus public attention on the impact of ALAN on astronomy and the enjoyment of the night sky. Both the IDA and RASC promote fully shielded luminaires and limited brightness of the emitted light. The key messages are to illuminate only the area of interest and use as little light as practical and only when needed. Both organizations leveraged their efforts with the media, but their relatively small membership limited the weight of their messages for governments and the general public. In the early 2000s, realizing that most of the public was interested in, or had an opinion about, the environment, the RASC modified its programme to also focus on protecting the ecology of the night, not just astronomy. The IDA also now considers ecological protection and interpretation in its dark sky certifications. In both Canada and the US, these astronomy/dark sky organizations started working with their respective national park organizations to protect night skies and the ecology of the night in protected areas.

Throughout the 20th century there was an accumulation of information on the impact of light on the behaviour of animals. Although generally considered to be beneficial for humans, there was mounting evidence that light can adversely affect ecosystems. Indeed, it was found there are biological benefits to periods of darkness. More research and awareness of the biological impact of ALAN in the early 2000s resulted in the development in 2008 of the Guidelines for Outdoor Lighting (GOL) for Parks Canada. At the same time the RASC adopted the GOL for its Dark Sky Preserves, adding to astronomy the impacts of ALAN on the environment and human health. In parallel, the US National Park Service started working with the IDA to obtain dark sky status for its parks. The IDA has since developed lighting guidelines for reserves, parks and communities, and recommends the GOL as a guidance document for applicants to achieve IDA certification. Subsequently, Fundación Starlight has developed similar guidance for UNESCO sites.

In recognition of these initiatives, this report builds its outdoor lighting guidelines for natural areas on the following three principal sources:

- The Guidelines for Outdoor Lighting, RASC (2020). These were originally developed by Robert Dick of the Royal Astronomical Society of Canada for that country's national parks and historic sites. They have subsequently evolved to cover more situations, such as urban star parks. The guidelines include detailed prescriptions for many lighting situations in protected areas. They are often referred to in applications for dark sky certification under the IDA's Dark Sky Places Program. They are also available through the IDA website [darksky.org].
- Guidelines for the five IDA dark sky place categories, namely parks, reserves, sanctuaries, communities and urban night sky places. These are also available on the IDA website. See also the IDA recommendations for residential and business lighting at [darksky.org/our-work/lighting/lighting-for-citizens/residentialbusiness-lighting].
- Alternative Ways of Lighting the UNESCO Sites, a booklet published by Fundación Starlight in association with UNESCO's man and the biosphere programme (Marin, 2015).

Several other organizations have outdoor lighting guidelines in preparation. Some of this material is used here but cannot yet be cited. Since the drafting of this report the Australian Government has issued light pollution guidelines to protect marine wildlife (Australian Government, 2020).

These documents continue to evolve as new situations and lighting technologies emerge. While originally developed for protected areas, they apply to all natural areas where light pollution is and should be a concern. They address the different types of facility often found in parks and reserves, and a range of pedestrian and vehicle traffic needs. However, the priority is to respect and protect nature. The following guidelines are presented first as general principles, then specifically for built facilities in protected areas, and finally for a range of other situations such as urban communities.

Principles of good outdoor lighting

These principles can be expressed succinctly as follows. More details follow.

- **Need:** use light only if it is needed. Before installing or replacing a light, determine if light is needed. Consider how the use of light will impact the area, including wildlife and their habitat. Consider using reflective paint or self-luminous markers for signs, curbs and steps to reduce the need for permanently installed outdoor lighting. Lighting should not be used just for aesthetic purposes.
- **Brightness:** use the least amount of light needed. The amount of light produced (lumens) is the most important consideration to ensure an area is not excessively lit. It should be appropriate for the activity taking place. Be mindful of surface conditions as some surfaces may reflect more light into the sky than intended.
- **Spectrum:** minimise the blue component and seek zero violet. Use amber lights such those having a colour temperature no more than 2700K. This aids night vision by all animals, including people. However, 2700K light contains up to 10% blue light, so it is better to use either 2200K lights or phosphor-converted amber lights which have 1% or less of their light in the blue part of the spectrum, usually defined as less than 500 nm wavelength.
- **Extent:** shield light so that it falls only where it is needed. Use shielding and optical shaping methods to target the direction of the light beam so that it does not spill beyond where it is needed. To reduce skyglow, do not use lights that project any part of their beam into the sky. To reduce glare, use lights that restrict their beam to downward cones. This improves the ability of drivers and pedestrians to see into shadows and dimmer areas.
- **Timing:** use light only when it is needed. Use active controls such as timers or motion detectors to ensure that light is available when it is needed but turned off or dimmed when it is not needed. Examples include curfews for arena lighting, and motion sensing and dimming for pedestrian areas.
- **Collaboration:** Encourage neighbours to reduce their light pollution, particularly glare and trespass into your domain.
- **Energy efficiency:** Use energy efficient lights, provided that they do not conflict with the other principles.

Need

Before determining what type of lighting should be installed or retrofitted, ask if the light is even necessary. If there is no need for artificial lighting, it should be removed rather than replaced, even with better technology. Do not simply assume that there is a valid reason for a currently installed light. Where outdoor lighting is deemed to be necessary for public safety and navigation, in the broadest sense, e.g. including walking at night on footpaths in campgrounds, the following principles must be taken into consideration:

- Illumination should not exceed the minimum required levels.
- The affected area of illumination should be as small as practical.
- The duration of the illumination should be as short as practical.
- Light fixtures should emit a minimum of blue spectrum components, i.e. avoid the use of white light.

These are elaborated in Chapter 7 on laws and policies.

Brightness

Artificial lighting is typically based on daytime vision that uses cone vision cells in the retina that typically require more than 10 lux to distinguish between blue, green-yellow and orange-red light. These cone cells require at least 1 lux, ten times the illumination of the full Moon, to see anything. Therefore, under a natural night sky they are effectively blind. At light levels characteristic of twilight and night, perceived colour becomes desaturated as the cone cells struggle to work below 10 lux and the rod cells begin to take over for night vision. This explains why lighting for good colour rendering in typical rural outdoor environments is not practical, especially in protected areas. Refer to Appendix 2 and the Glossary entry for lux to see other typical values.

Humans' night vision is between 100x and 1000x more sensitive than day vision, but is easily bleached by the illumination typical of urban areas. As illumination slowly increases through twilight between 1 and 10 lux, there is a smooth transition between the roles of rods and cones. However, when moving from bright to dim areas it can take the rod cells several minutes to fully adapt. This is why rapid transitions from bright to dark areas temporarily blind us to many of the objects in the shadowed area. This delay for the rod cells to recover from exposure to bright light makes the transition from cone vision to rod vision problematic.

Target surfaces should be illuminated with the least amount of light necessary. Tables 5.1 through 5.7 later in this chapter list low-impact illumination levels for a range of applications. The lumens needed for an application can easily be determined from the area times the lux. In an ideal hypothetical example of uniform luminance, a small street light that delivers a uniform 3 lux over a 10 x 20 m area requires about 600 lumens of light. This would be expected from a 6 watt LED luminaire. In practice, however, street light LEDs range from 30W to 60W and typically have non-uniform illumination.

Spectrum

Our biology responds to the spectrum of light, though our brain perceives colour based just by the cone cells. Because animals have adapted to the blue-light circadian rhythm, artificial light at night should not emit blue and violet spectral components. The resulting spectrum should look yellow to amber in colour. This corresponds to a coordinated colour temperature no higher than 2700K, the so-called warm white, and preferably 2200K, i.e. amber. In the past it was difficult to provide light without these blue spectral components, but in the last few years PC-Amber lights have come on the market that emit light down to 1800K. In spectral terms, the bulbs should emit no more than 2% of their radiance below 500 nm, and their median wavelength should be above 585 nm. In ecological settings it is preferable to use phosphor converted amber lights which emit less than 1% of their illumination in the blue part of the spectrum. However, in urban settings with the much higher illumination levels that allow better colour recognition, the public perception of lighting for safety, security and aesthetics may justify keeping to the higher 2700K threshold.

Typical white-appearing incandescent lamps emit about 14% blue light. Common high-pressure sodium lamps appear amber but emit about 10% blue light. LED lights that appear white emit 10-40% blue light, depending on the manufacturer and colour temperature. See Appendix 3 for more information on the spectrum of common lamp types.

There are three practical ways to achieve this amber spectrum:

- Filter existing lights to cut out the blue light.
- Replace the existing light bulbs with amber lights, typically sold to reduce the attraction of flying insects.
- Replace the light fixtures with ones that emit the compliant spectrum.

A smoothly varying spectrum provides better colour rendering by emitting a wide range of colours. Phosphor converted amber LEDs provide this type of spectrum with no blue components. They are the currently preferred emitters for low-impact lighting.

The spectrum of light reflected from a surface depends on both the colour of the surface and the colour of light that illuminates it. For example, when illuminated with white light, a yellow or red surface will reflect very little blue light. Similarly, illuminating a white surface with light with no blue components will also minimise the impact of the reflected light. White surfaces should not be illuminated with white light.

Extent

The emitted light should not be visible beyond the target area. This requires a fully shielded fixture that emits no light upwards and, ideally, restricts the light emitted between the horizontal and 10° below the horizontal to a small fraction of the total emitted light.

These requirements can be achieved in these four ways:

- Mount an external shield to the luminaire housing.
- Mount the luminaire low enough so that it does not shine beyond the target area.
- Replace the offending luminaire with one that includes the appropriate shielding.
- Install or plant an opaque perimeter fence or hedge that extends higher than the luminaires.

Figure 5.1. Acceptable and unacceptable light fixtures. Source: International Dark-Sky Association

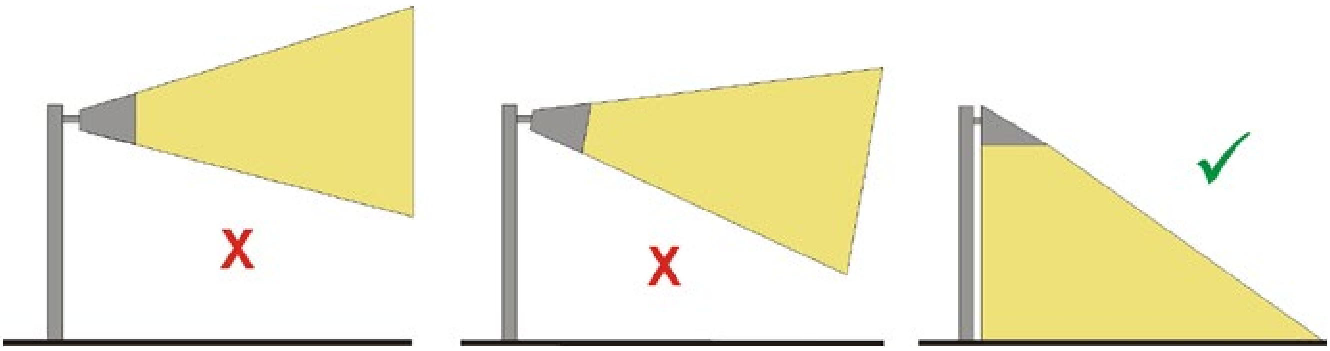


Figure 5.2. Floodlights with good and bad angles of mounting. Source: Modified from IDA

Some examples of acceptable and unacceptable fixtures and mounting are shown in Figures 5.1 and 5.2. More information on recommended luminaire types is in Appendix 4.

Where there is a desire to illuminate a valued site for cultural or interpretive reasons, yet avoid any stray light falling off the target, it is possible to construct an assembly of LEDs and shielding to shine light only at the target, with no direct illumination of the surroundings. An example is for a church in Steinbach, Austria, part of the Naturpark Attersee-Traunsee International Dark Sky Park [www.darksky.org/our-work/conservation/idsp/parks/naturpark-attersee-traunsee-austria]. As yet there is no specific agreed recommendation for this utilization ratio. Lighting managers are simply urged to keep the stray light proportion as low as possible.

Timing

If illumination is required after sunset, then it should be used only while people are present. After activities have ended, ground illumination should be reduced to less than one lux. This is sufficient to safely indicate pathways, to provide a sense of place, and to allow reading instructions on a map for late night navigation. Scheduling can be as simple as turning off the luminaires when visitors are not expected, such as after business hours or during dark time curfews. However, manual dimming is not reliable. Preferably, use automatic timers and motion detectors.

Collaboration

Encourage neighbours to also reduce their light pollution, particularly glare and trespass beyond their property. They may not even realise that their lighting is bothersome. Suggest alternatives to their current fixtures. Ask them or help them to move the light, to shield it, or to add a motion sensor so it activates only when needed. Do not dismiss the need for lighting for safety, but explain that light trespass is a form of pollution. For conservation managers, collaboration will often involve outreach to neighbouring municipalities and landowners to develop cooperative agreements. One of the best ways for a protected area to meet its conservation goals, be they related to light pollution or to any other ecological matter, is to seek a dark sky or biosphere reserve style of agreement.

Energy efficiency

Use energy efficient lights, provided that they do not conflict with the other low impact lighting principles. A serious, emerging light pollution problem worldwide is the switch to bright white LED lighting, especially for streets and highways. The lower energy use of LEDs is used to rationalise increasing the amount of emitted light. This should be resisted. This energy efficiency difference is less than a few percent, and is overwhelmed by the increase in perceived glare and biological impacts, factors not priced into the cost of electricity. As noted above, LEDs with minimal blue spectrum are available. Alternatively, white LEDs can have amber filters added.

Guidelines for built facilities in natural areas

What is practical depends upon what is needed and how you can achieve it. Most luminaires are designed for urban areas. However, for ecological reasons the illumination levels specified in this document are lower. This restricts the type of light sources that may be used. Although high intensity discharge and compact fluorescent lamps are very efficient, they may emit more light than is recommended in these guidelines. To address this, incandescent lights may be used for short periods of time or more advanced yellow or amber LEDs may be installed.

While managers have the discretion to decide what lighting levels are most appropriate in their situation, they are encouraged to stay within the limits suggested here. Lighting should provide only what is required for people to move around when adjacent to built facilities. It should be restricted to those areas and for the normal periods of human activity related to them. 'Dark time' is a term used in some parks to identify the end of significant activity within an area. It is used here to identify when the use of outdoor light should be discouraged. To aid in the automatic scheduling of outdoor lighting, dark time should be defined as beginning two hours after sunset.

The following tenets have been used in developing these guidelines:

- Buildings require illumination only when open or available to the public. After a building is closed for the day, either to the public or staff, lights visible from the outside should be turned off.
- Lighting curfews should also apply. The operating hours of a facility should be managed to limit the need for artificial outdoor light at night.
- To limit the duration of light exposure on the ecosystem and to save energy, light activated timing circuits should be used to turn off outdoor lighting on or before the beginning of dark time or at the end of scheduled activity.
- Pathways should be illuminated only when pedestrians are in transit. All reasonable efforts should be made to turn off lighting when pedestrian traffic is low or is no longer expected.
- There should only be enough artificial light needed for finding direction and aiding safe movement between lit structures and the surrounding unlit area. This applies to both the brightness and extent of the illumination.
- Full cut-off (FCO) or sharp cut-off (ShCO) luminaires (Figure 5.3) should be used to prevent light scattering beyond the immediate area of the light fixture.
- Where vehicle and pedestrian traffic is at a low speed or infrequent, retroreflective signage should be used instead of installed lighting fixtures.

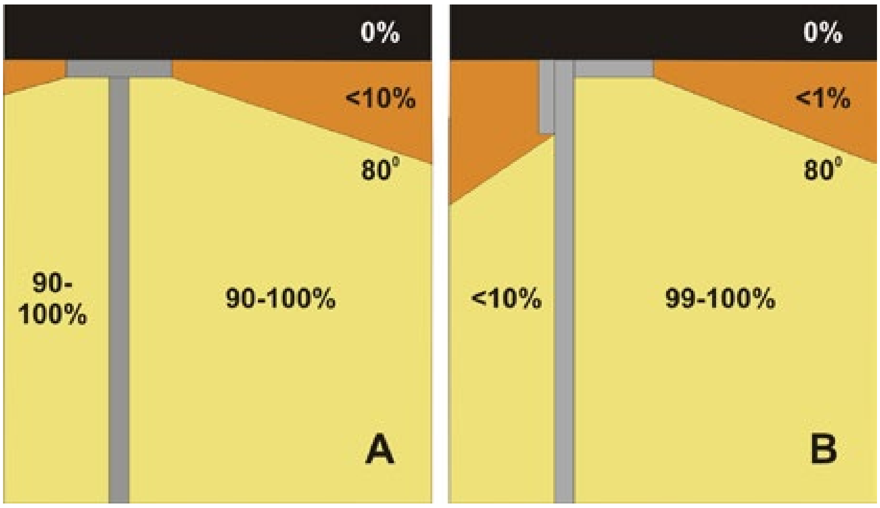


Figure 5.3. Full cut-off and sharp cut-off luminaires. A. Full cut-off: no up-light and less than 10% emitted above 80° from the vertical. B. Sharp cut-off: no up-light and less than 1% emitted above 80°. B also shows back shielding so that less than 10% of emitted light passes behind the fixture. Source: Modified from Jägerbrand & Bouroussis, 2021

Table 5.1. Building illumination guidelines

Situation	Type	Light*	Level (lux)	Height	Curfew
Administration buildings Public buildings Retail Stores Vending machines	FCO** ShCO (Figure 5.3)	Amber incandescent, compact fluorescent or LED, filtered	~2 lux	2.5 m	Yes
Toilets Washrooms Shower facilities	Marker FCO	Amber incandescent, compact fluorescent or LED, filtered	~2 lux	2 m	No
* Wattages for individual lamp types are not specified due to differences in efficacy. ** FCO: Full cut-off. ShCO: Sharp cut-off.					

- The colour of light should have minimal blue (short wavelength) content. This can be achieved with amber light, i.e. with a colour temperature no more than 2200K, either as emitted by the source or achieved through filters. Where more than 2200K is required, no more than 1% of the total emitted light should be in the zone between 80° to 90° degrees from the nadir, i.e. the sharp cut-off requirement. The illumination level from white light should be less than 40% of the maximum levels specified in this chapter. This will help preserve night vision and limit the extent of the ecological impact.

Buildings

Lighting at the entrance to buildings is generally justified for navigation and safety. Some perimeter lighting is also generally installed for security. However, light does not provide security unless it is actively monitored. Illumination along a wall that does not provide access may reduce security and attract vandals. Recommended illumination levels and luminaire types for entrances are shown in Table 5.1.

Administration buildings are those with private offices and will generally be closed after dark. Illumination of the main doorway and steps leading to the main door may be required for a short period after sunset. After hours, either all interior lighting should be turned off, or window coverings should be used to prevent interior light from shining outside. Timing circuits should turn off all outdoor lighting within 30 minutes of the office being closed. For late-working staff, manual reset switches or motion detectors may be programmed to extend this period, but typically for less than one hour.

Public buildings are those which are open to the public during business hours and may also contain private offices. Because these buildings have potentially high levels of pedestrian traffic, exterior illumination may be higher than for administration buildings. After hours, either all interior lighting should be turned off, or window and door coverings should be used to prevent interior light from shining outside. All outdoor lighting should be turned off within 30 minutes of the building being closed. Exterior lighting should be limited to the main door area and steps. Subject to the building's use, light-activated or timing circuits should be used to turn the lighting on after sunset and off after the building is closed for the public, or following a reasonable period, typically no more than an hour.

Retail stores such as souvenir and grocery shops generally have more pedestrian traffic than most other areas and illumination may be required while they remain open for business after dark. Window coverings should be used so that interior lighting will not shine outside 30 minutes after sunset. Exterior light should be permitted but restricted to FCO or ShCO fixtures illuminating the ground around the public entrance. Exterior lighting should be turned off within 30 minutes after business hours.

Vending machines should be located in an enclosed space and their lights should not shine directly outside through doorways or windows. Where practical, these machines should be enclosed in existing public buildings. Figure 5.4 shows a plan for a dedicated vending machine enclosure, such that the machines are not directly visible from outside. Only FCO or ShCO fixtures should be used to illuminate the area outside the entrances. Illumination of the outside ground area should not go beyond five metres from the entrance. Lamps for vending machines tend to be fluorescent tubes behind a translucent display, and may emit significant amounts of white and blue light, undermining night vision. Unless the machines are dimmed or filtered, illumination levels outside these enclosures may be higher than for other buildings in order to ease the transition for visitors from the bright interior to the dark surroundings. Doorway lighting should be turned off or dimmed within two hours after sunset. Interior lighting may remain on at the owner's discretion.

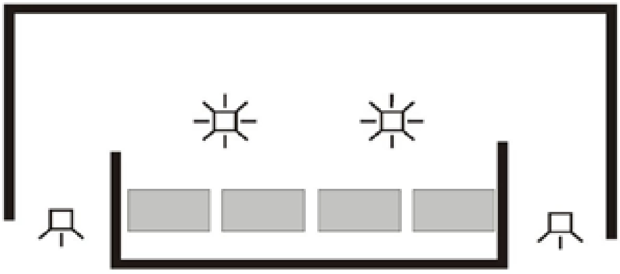


Figure 5.4. Sample vending machine enclosure. (Source: Robert Dick)

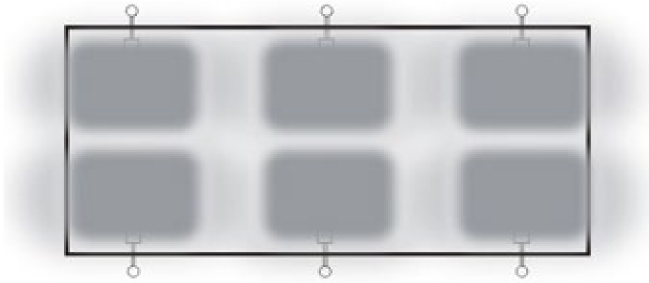


Figure 5.5. Parking lot lighting pattern. Source: Robert Dick

Washroom, shower and toilet facilities. If these facilities are open throughout the night, FCO or ShCO fixtures should be used to illuminate the entrance and any steps. An illuminated door may be used as the marker light. Interior lighting in these facilities must also be considered. Excessive interior lighting levels can produce serious glare through the windows that will impair visibility outside the building. After sunset, interior lighting should use amber lamps, red lamps or amber filters. Lighting levels, measured horizontally at the floor, should not exceed 10 lux. If more light is required, windows should be screened so that no light escapes to the outside.

Parking, roads and paths

Parking areas usually have less traffic at night than during the day, but they may require lighting due to activities scheduled after dusk. This lighting may be necessary until gate closure or dark time, whichever occurs first. Where required, pole mounted FCO or ShCO luminaires should be placed one pole height from the extreme corners of the parking lot and distributed evenly along the perimeter with an approximate pole spacing of no less than four times the luminaire height. Their light distribution pattern should be confined to the parking area, as shown symbolically in Figure 5.5. If necessary for larger parking lots, poles may be located within the parking area.

Administrative personnel generally leave when offices close. Luminaires in their parking areas should be turned off within 30 minutes of the office closure. A timing circuit or motion sensor should control the lights.

Small visitor parking areas, e.g. for less than ten cars, experience little traffic and should not be illuminated. Larger lots may require better visibility than smaller lots due to their higher pedestrian and vehicle traffic. These lots may be illuminated at the discretion of management, but illumination levels should not exceed the limits listed in Table 5.2.

Roads and intersections. Ideally, lighting should not be used on roads in or near the vicinity of the protected area. Self-luminous markers and retro-reflective signs and surfaces should be the standard. Cars have their own illumination, providing photopic vision to drivers. In practice, however, roads and highways are typically subject to standards laid down by regional or national highway authorities due to their inherent dangers for both drivers and pedestrians. When drivers approach an intersection, they require up to three seconds to react and apply brakes. Therefore, intersections should be marked with luminaires, retro-reflective signage or both. Illumination of adjacent areas should be minimised to avoid distracting drivers and to limit ecological impacts. Where main highways run through protected areas, lighting needs should be evaluated in consideration of the foregoing principles. If lighting is judged to affect the quality of the protected area, then its manager should request the highway agency to use light fixtures that will most closely comply with these guidelines. FCO and ShCO shielding should be used. As a minimum, the manager should form an agreement with the highway agency so that they have input to the selection of lighting attributes and the luminaires.

On highways subject to fast and high volume traffic, marker lighting may be required to alert drivers well in advance of the intersection. To ensure that they do not unduly affect the environment but are visible to approaching traffic, these marker lights may be shielded and oriented to minimise illumination beyond the side of the road. Depending on the height and spacing of existing street poles and the height of shielding hedges, the luminaires should be mounted no higher than six metres and the light emitted should be no greater than 2000 lumens, using amber LEDs to minimise blue light exposure to the environment (Table 5.3). Unfortunately many luminaires are set on ten metre poles and further apart to save costs, so additional care should be taken with shielding to control extent. A marker light should appear no brighter than Venus on a clear twilight evening, about 1 lumen. Retro-reflective signage should be used for all other intersections. Illuminated signage should not be permitted (Table 5.6). Where government highway standards take precedence, use the minimum allowable illumination.

Table 5.2. Parking lot illumination guidelines, maximum values

Parking area	Type	Light*	Level (lux)	Height	Curfew
For less than 10 cars	N/A	None	N/A	N/A	N/A
For 10 or more cars	FCO, ShCo	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	Yes
* LPS: Low Pressure Sodium. HPS: High Pressure Sodium. CFL: Compact Fluorescent Light. LED: Light Emitting Diode.					

Table 5.3. Roadway illumination guidelines

Situation	Type	Light	Level (lux)	Height	Curfew
Major roads	None	None	None	N/A	N/A
Major roads and intersections	Semi cut-off, marker	LPS, HPS or amber CFL or LED, filtered	~3	6m	No
Minor roads and intersections	Signage only	None	None	N/A	N/A

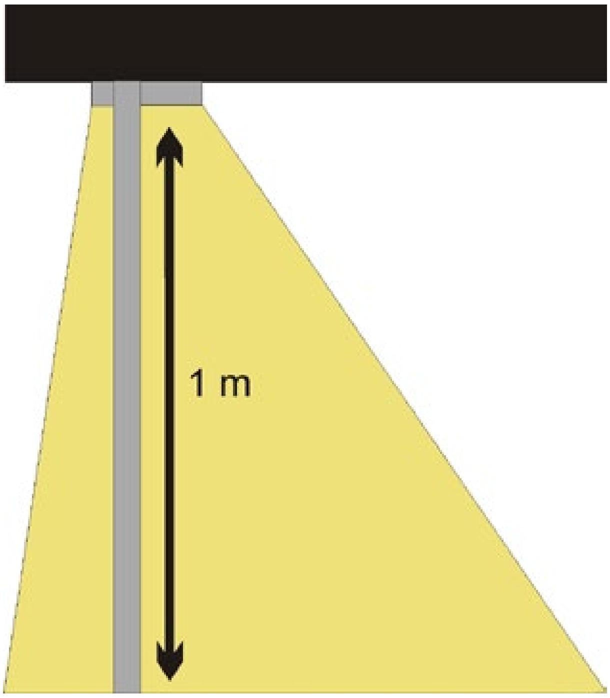


Figure 5.6. Bollard luminaire.. Source: Modified from Robert Dick

Figure 5.7. Path with reflective crushed stone. Source: Robert Dick

Lesser roads may provide access to large parts of a natural area and typically have low traffic volumes. They may also provide for local traffic. These roads and their intersections see infrequent use after hours. Retro-reflective signs should be used instead of lighting.

Paths and sidewalks provide a relatively level surface for pedestrians and aid in site navigation. Visibility is necessary but excessive illumination prevents people seeing the sides of the path for situation awareness. Although visitors might use flashlights, additional pathway lighting may be required to guide visitors to public events and facilities.

Paths are also used by wildlife. Therefore, pathway lighting should be restricted to paths near buildings, parking lots and campgrounds. Since overhead FCO and ShCO luminaires will illuminate areas much wider than the path, low wattage bollard lighting (Figure 5.6) or railing mounted lighting should be used such that the light is directed down and along the path, and not in all directions from the fixture. Fixtures should be shielded or lensed so that illumination is limited to the path width. The closeness of the luminaires to the ground necessitates very low intensity lights. This limits the current available products to low wattage incandescent bulbs and amber or filtered LEDs. Low-brightness CFL lamps are not available at the time of writing. Rather than asphalt, pathways could use white or light-coloured crushed stone, such as limestone, to be visible even in low levels of ambient light (Figure 5.7). Another option is to embed fluorescent markers at the edges of the path or mounted on bollards or railings (Figure a5.2).

Table 5.4. Pathway illumination guidelines

Situation	Type	Light	Level (lux)	Height	Curfew
Minor paths	None	None	N/A	N/A	N/A
Illuminated paths	FCO ShCO	Amber incandescent, CFL or LED, filtered	~1 lux	1 m	Yes
Main paths	FCO ShCO	Amber incandescent, CFL or LED, filtered	~1 lux	1 m	No

Table 5.5. Shoreline illumination guidelines

Situation	Type	Light	Level (lux)	Height	Curfew
General areas	None	None	N/A	N/A	N/A
Dock bollards	FCO ShCO	Amber or red incandescent, CFL or LED, filtered	~1 lux	1m	No
Lock facilities	FCO ShCO	Amber or red incandescent, CFL or LED, filtered	~3 lux	6 m	Yes

Table 5.6. Signage illumination guidelines

Situation	Type	Light	Level (lux)	Height	Curfew
Buildings	Reflective, light colour	Amber LED* filtered	~3 lux	1–2 m	Yes
Navigation	Reflective, light colour	Amber LED* filtered	~3 lux	<1 m	No
Information	Retro-reflective, light colour	Amber LED* filtered	~3 lux	1–2 m	Yes
* Select for about 3 lumen/m2 (0.3 lumen/ft2)					

Table 5.7. Developed property and community enclaves illumination guidelines

Situation	Type	Light	Level (lux)	Height	Curfew
Door lights	FCO, ShCO	Amber incandescent, CFL or LED, filtered	<3	1.5 m	Yes
Yard lights	FCO, ShCO	LPS, HPS, amber CFL or LED, filtered	<3	6 m	Yes
Municipal lights	FCO, ShCO	LPS, HPS, amber CFL or LED, filtered	<3	Situation dependent	No

Unless remaining for an activity, individuals walking along a path will usually have left the area after one or two minutes. To minimise unnecessary light exposure, motion detectors with a timer should be used to turn the lights on and then off after a few minutes. Detectors may be installed at the entrances to pathways or at the ends of the illuminated portion of the path. Main pathways leading to all-night facilities, such as toilets, may be illuminated throughout the night, but should still respect the criteria shown in Table 5.4.

Shorelines

Conservation managers typically have limited authority over navigation laws and regulations, so the following guidelines are general. Nevertheless, to the extent allowed, lighting should only be considered for docks, jetties, lock facilities, boat launching areas and public beaches. Homes and cottages may have outdoor lighting but it should conform to the building guidelines noted above, and light fixtures should not be within 10 metres of the shoreline.

Conservation managers should inform the owners and users of shoreline property of the impact that artificial light has on the ecology of the water and adjacent lands.

- Property owners should be advised to shield all outdoor lighting to prevent emitting light toward the water. This practice goes beyond simply installing FCO or ShCO luminaires, as their downward cone of light can still spill beyond a shoreline. Furthermore, any such lighting should be turned off when people are not outdoors on the property.
- Shoreline lighting should be amber or red (Table 5.5). Blue and white lights should not be permitted.

- Except for essential safe navigation purposes, light fixtures should be prohibited within ten metres of a shoreline. Overhead luminaires that shine into the water should not be permitted.
- High traffic areas and areas near machinery, such as lock facilities, may require higher levels of illumination when machinery is being used.

Scheduling

Wayfinding requires very little light (0.1 to 1 lux), but unshielded fixtures undermine this because glare prevents seeing trail-side features, landmarks and trip hazards. Some protected areas may have a defined dark time during which unnecessary lighting should be turned off. Light may be used during peak activity during twilight and early evening but should be turned off or significantly dimmed at dark time, typically beginning two hours after sunset. The manager may also identify lighting critical to safety that should remain on but at a significantly dimmed level. Virtually all visitors to a park use flashlights or headlamps, so they have light when necessary. Retroreflective signage will complement the use of these personal lights.

Signage

Signs are essential for safe and efficient navigation, giving directions along roadways or pathways and their intersections, and displaying names for sites or buildings. They are usually located adjacent to buildings or other structures at the side of roadways and pathways. It is strongly recommended that illuminated signs be prohibited in conservation areas. Such undesirable signs include, but are not limited to, back illuminated signs, electronic billboards, and signs illuminated from below, above and/or in front. To provide for visibility of signs after dark, their location, colour scheme and material should permit reading the sign with flashlights or vehicle headlights, or with existing compliant pathway or roadway lighting. When otherwise deemed necessary, signs may be illuminated to the levels shown in Table 5.6.

Retro-reflective paints may be used so that signs are visible only when necessary. Signs may be mounted on or near buildings such that exterior building lighting may provide some illumination. The signs should use colours consistent with retro-reflective materials and illumination by flashlights. Pathway and information signs should be located less than one metre above the grade of the path so they may be found and read after dark by pedestrians with flashlights. All bollards and railings should be marked with retroreflective material so that they are visible to pedestrians during dark time. Roadway signs should be mounted in accordance with standard roadway practice. Refer also to Appendix 5, Signage, and Figures 3.1 and A5.1.

Tower navigation avoidance beacons

Towers for radio and television broadcasting, microwave transmission, mobile phone networks and wind turbines proliferate in natural and rural areas. Conservation managers must be aware of the options available for tower navigation beacons that are regulated by transportation authorities, since aircraft navigation rules typically supersede other regulations. Nevertheless, towers in natural areas should not be fitted with night navigation beacons unless strictly required by such regulations.

Where they are necessary, navigation beacons should be of the minimum luminance and should use red flashing lights. There are several types of navigation avoidance beacons that may be used on towers. A low impact example is a beacon with a collimated rotating beam. Its luminous intensity can be lower than other types of beacons and emit less total light, resulting in less light scattered into the environment while maintaining its visibility to pilots. Birds are less attracted to red light than to white light, and appear to be less able to orient themselves to flashing beacons compared to non-flashing types.

Visitors to protected areas

Subject only to ensuring visitor safety and responding to emergency situations, managers should encourage visitors to avoid the introduction of unnecessary artificial light at night. This should include suggesting reasonable limits on lighting camp sites and recreational vehicles, as well as a general prohibition of searchlights.

High power flashlights (>300 lumens) should be discouraged, whereas low power red or amber flashlights are acceptable but should also be used sparingly. Users may hold their fingers over the lens of their flashlight as an improvised amber filter. Such techniques will reduce glare and help maintain dark adaptation. Installation and extended use of portable outdoor lighting should be strictly prohibited.

Table 5.7 offers guidelines for residents and property managers within park enclaves.

Lighting management plan

A lighting management plan (LMP) is a written policy adopted and published by the managing agency. It sets forth conditions under which areas may or may not be lighted. A satisfactory plan is mandatory for certification as a dark sky place under the various programmes described above, but is also recommended for all protected areas that have built facilities. An LMP should identify the different situations that are contemplated. It should prescribe the manner in which certain areas may be lit in terms of maximum illumination levels, lamp type, spectrum, appropriate shielding and timing. An LMP must embrace all the principles listed at the start of this chapter. Exceptions should be clearly stated and justified. These may include lighting required by law. In most cases a substantial part of an LMP will be an inventory of existing lighting, notes as to each fixture's or site's compliance with dark sky guidelines, and a schedule for conversion to achieve compliance.

Appendix 7 presents a synthesis of recommended lighting solutions for low ecological impact. See also Jägerbrand & Bouroussis (2021, 9) for a synthesis of the foregoing recommendations.

Guidelines for other situations

Villages, towns and cities host a great amount of ecological diversity. The reasons for protecting nature in urban areas are described in an IUCN Best Practice Guidelines publication (Trzyna, 2014). Here the focus is on approaches to minimise light pollution in built areas. Urban ecology, be it in gardens, parks and other landscaped areas, should be protected against light pollution along the same lines as described for the natural areas guidelines described above. However, there are three additional reasons to control light pollution in the built environment: energy efficiency, crime and safety, and human health. See Chapter 1 for explanations of these. Urban lighting also pollutes the region well beyond city limits. This light should be contained within the built area. The following material presents guidelines to address light pollution in urban areas. It is based largely upon the principles and technical guidelines offered by the International Dark-Sky Association, including its Model Lighting Ordinance which will be addressed in Chapter 7.

Developed enclaves within natural areas

These may include owner-occupied and rented private properties within a protected area, whether isolated or within communities. Inform owners of such properties about the impact of artificial lighting on wildlife. Encourage them to remove lights that stay on all night, and to replace unshielded yard lights with FCO or ShCO luminaires. Ask them to replace white LED and metal halide bulbs with either high pressure sodium, low pressure sodium, amber LED or filtered LED fixtures. Encourage them to turn off all exterior lighting when all occupants are indoors.

Historic and cultural sites

These guidelines give priority to nature conservation, but some direction is given for historic and other culturally important sites. They may be located within urban areas where light pollution is at a level in which the foregoing standards do not result in a significant overall improvement. The philosophy of not over-lighting an area is prudent for better visibility, which leads directly to greater safety, better aesthetics and a reduction of operating costs. Outdoor lighting at these sites should use FCO or ShCO fixtures and should illuminate the facilities only to the minimum levels of standards and guidelines of the surrounding area. If lighting fixtures of a historic style are to be installed on the site, then the FCO or ShCO varieties should be used where possible. Prior to the late 19th century, historic lighting was restricted to the power of candles and oil burning lamps. Since historic lighting rarely included white light, low power amber light should be used.

Municipalities

Municipal lighting should be FCO or ShCO, as illustrated in Figure 5.1. Illumination levels should be no greater than 5 lux, and, where regulations permit, no more than 3 lux. White light should not be permitted. Colour temperatures should ideally be around 2200K and no higher than 2700K, although 3000K LED luminaires may be used in certain circumstances. In Québec, Canada, the guideline for dark sky protected areas is an upper limit of 2200K, and ideally 1800K. There is an upper limit of 3000K for more urban areas, again with 1800K preferred (Rémi Boucher, personal communication).

Area lighting fixtures, such as yard lights and dusk to dawn fixtures or similar luminaires should not be permitted. White LED, metal halide or mercury vapour lamps should not be allowed. These products produce excessive glare and light trespass, and emit short wavelength light (blue spectrum) that affects wildlife and night vision. Outdoor lighting should be turned off when people are indoors or are no longer on the property.

Use just enough outdoor light for the intended use. As an example, commercial and public concourse lighting fixtures should have less than 1500 initial lumens lamp output. If properly shielded as described below, this will provide approximately 5 lux, or 50 times the illuminance of a full Moon, depending on the mounting height, type of light distribution and area covered.

Municipal officials often rely on distributors to select appropriate luminaires but are rarely aware of the adverse impacts of light. This leads to the purchase and installation of polluting light fixtures. Further guidance on this can be obtained by consulting the IDA Fixture Seal of Approval at [darksky.org/our-work/lighting/lighting-for-industry/fsa/].

Residential areas

In these areas, outdoor lighting is often shielded by trees, and fixtures are typically well spaced. LED lights along roadways are, however, particularly troublesome. Well-engineered luminaires are too expensive for small municipal governments with a limited tax base. The poor shielding and high colour temperature of inexpensive luminaires often produce considerable glare. This creates shadow hazards, so the public may demand even more and brighter lights, resulting in even more glare. Careful observance of the principles already noted will mitigate these situations. This is especially so with a good lighting plan that calls for moderate to low brightness and colour temperatures, and properly spaced and shielded fixtures.

There must be continuous communication and awareness-raising throughout the population. Hardware stores should be able to help homeowners comply with the guidelines by carrying compliant luminaires or being receptive to ordering such lights. As noted above, the IDA Fixture Seal of Approval site provides guidance [darksky.org/our-work/lighting/lighting-for-industry/fsa].

Turnover in municipal staff leaves gaps in awareness. A light pollution abatement policy should be constantly discussed so that it does not become forgotten. Citizen groups can remind staff of the need to comply with the lighting guidelines.

There are situations where unshielded fixtures may be appropriate, for example, using low intensity marker lights or bollards for pathways, or to maintain a heritage lighting style. In such cases lamps should emit less than 100 lumens. Nevertheless, there should be restrictions on the total amount of unshielded lighting, such as a limit on lumens per hectare or total site lumens. Ideally, there should be a policy to address excess lighting, such as a maximum allowed lumens/hectare or maximum illuminance specification. Another common situation is unshielded strings of festival or holiday lighting. Such use should be strictly limited to holiday periods according to the prevailing belief system of the local society, and no more than 30 days in total during a year. They should be turned off after 23:00 hours until sunrise, emit not more than 150 lumens per metre and not more than 6000 lumens in total for a residential or commercial property, and emit light with a colour temperature less than 2700K.

For more information about addressing lighting in commercial and residential areas, refer to the IDA web site [darksky.org/our-work/lighting/lighting-for-citizens/residentialbusiness-lighting].

For homes, see the IDA Dark Sky Friendly Home Lighting Program [idsw.darksky.org/activities/dark-sky-friendly-home]. Figure 5.8 is an example of the preferred way to light the front of a house. As well as spectrum, brightness and extent, such lighting should be controlled by a curfew timer and motion sensor.

Figure 5.8. Dark sky friendly house lights. Left: incorrect. Right: correct. Source: IDA

Illuminated signs should be regulated. Externally lit billboards and signs should be subject to the other recommendations contained herein. Self-illuminated signs should not exceed a luminance after sunset of 100 nits (100 candelas/m^2). Better, their use should be restricted to pedestrian and traffic control and navigation.

Where possible, rather than having illuminated signs, use non-illuminated signs of bright letters on a dark background, ideally white on black or at least of contrasting colours; see Figures 3.1 and A3-1. Black letters on white signs are harder to resolve after dark.

Roads and highways

Urban practices for roads and highways have evolved over more than half a century as technology and vision science have improved. These practices were based on traffic studies and accident statistics and did not consider the impact of the light on other than the art of driving. Although street lighting can improve visibility, this is only when precautions are used to limit glare and roadside distractions. Current practices refer to the amount of light that illuminates the ground and the brightness of the illuminated surface. They do not refer to the shielding of the light or its spectrum. However by specifying FCO or ShCO shielding, appropriate uniform illumination and amber light, impacts not related to driving can be significantly reduced. Many municipal standards and bylaws set minimum light levels. What is important from a light pollution perspective is try to keep to minimal light levels and not add more brightness without good reason.

For example, residential areas, which may include over half the total area of a city, have relatively low volume and low speed traffic that may not need more than 5 lux illumination. Shielding the luminaires and using amber light further improves visibility. Typical street lighting goes up to 2500 lumens per lamp set up to 10 m high. A major complaint from homeowners is the glare of street lights seen from their windows. This is mostly solved with shielding, but closer, lower and dimmer lights are preferable. This will also enhance uniformity, reducing the bright patches at nadir that make the areas between lamps appear dim. The use of amber light further reduces the perception of glare. With these considerations, a lower illumination level will be perceived as bright enough. 500 lumens per lamp will suffice in dark sky parks when shielding, amber lights and lower mounting heights are used.

Care should also be taken during retrofits not to increase the amount of blue spectrum in the new lamps compared to the old ones. To save energy, high pressure sodium lights are often replaced by LED lamps. Unfortunately this means a change of the light from amber, 2100K to 2500K, to white, 3000K to 4000K, thus adding a blue spectrum component. The blue portion reflects well off road and sidewalk surfaces and can result in excessive glare from wet surfaces. The extra reflectance can increase in sky brightness, as described in Hung et al. (2021) which reports that “typical one-for-one HPS to 3000K LED replacements are likely to increase light pollution.”

Safety along highways is generally provided by proper road design for the allowable speeds, and, of course, car headlights. In rural areas, highway traffic density is much lower than on major urban roads. It is impractical to continuously illuminate highways but marker lighting and reflectors can be used to increase the awareness of motorists. Marker lighting will draw attention to intersections and hazardous turns. To prevent glare and increase visibility further along the road, the luminance of the marker should be as low as practical.

Research and monitoring

Assessing and monitoring light sensitive resources

Much remains to be discovered about the relationships between light levels, spectral content, directionality, timing and ecological impact (Jägerbrand & Bouroussis, 2021). Nevertheless, current knowledge on the impact of artificial light demonstrates a high risk of adverse ecological impact, especially for light sensitive or nocturnal species and sensitive habitats (Dick, 2020 to 2021). Conservation managers should identify the features and processes in their area that may be sensitive to light pollution. For newly established parks and reserves, this entails identifying values sensitive to light pollution and including them in a basic resource inventory and analysis. This will not normally involve field research. Rather, it can be achieved through a review of published science.

As noted previously in the section on ecological impacts, it would be persuasive to argue for less light pollution if its contribution to an aspect of environmental degradation, such as wildlife population levels or a biodiversity index, could be given a statistical or quantitative weighting.

Similarly, there is also scope for more research into the effects of artificial light in a variety of habitats.

Once particular values are identified as being potentially sensitive to light pollution, managers should encourage independent researchers to conduct field studies to learn more. In cases where the impacted value has a critical ecological role the manager should sponsor appropriate research. The results should then inform the resource management and lighting management plans of the protected area. This could include a programme to monitor key ecological resources for their response to artificial light, and their adjustment once ecologically polluting light is removed.

Monitoring sky quality

Protected areas that offer night sky programmes to visitors should establish a sky quality monitoring programme. Positive or negative trends can be detected and included as part of visitor engagement. Those trends can also inform partners and neighbours in the greater ecosystem as to emerging threats or pollution control success stories. In many cases a local astronomy society will volunteer to do this, and all the park or reserve will have to do is

1. agree to provide secure monitoring sites.
2. allow night access even if only for a few nights a year
3. help to present the results to the public, and
4. archive data.

There are several approaches to monitoring night sky quality. The simplest is typically done by amateur astronomers who record the dimmest star visible at a given time. However, this is sensitive to the eyesight and experience of the observer, and is also a subjective assessment of air quality. The Bortle Sky Quality Scale shown in Figure 1.2 still results in a qualitative approach but does not require an observer to know particular stars and their magnitudes. The Unihedron Sky Quality Meter is an inexpensive hand-held photometer that makes it easy to take accurate measurements of the brightness of the night sky. The Globe at Night Project [globeatnight.org] is a more quantitative approach that benefits from interested people counting the visible stars in a defined area of sky. It does not require any instrumentation and benefits from a large number of contributors. Finally, all-sky cameras provide calibrated images of the entire night sky dome. The system developed for the US National Park Service stitches several images into one mosaic. Other versions capture the whole sky in a single panorama. Various data sets are now combined with satellite data to produce global skyglow assessments (Falchi et al., 2016; [lightpollutionmap.info]).

Appendix 6 describes scales and units for measuring light pollution. Appendix 8 describes measuring equipment and protocols.

CHAPTER 6.

Guidelines for public engagement

Visitor engagement

Multimedia facilities

Some dark sky places offer exemplary facilities for night sky viewing and understanding. They include Montsec Starlight Reserve in Spain where Parc Astronòmic Montsec showcases a planetarium with a projection dome that opens to reveal the real sky at the end of a presentation (Figure 3.2). In Canada, the Astrolab at Mont-Mégantic Dark Sky Preserve hosts a night sky museum and multimedia theatre. Aoraki MacKenzie International Dark Sky Reserve in New Zealand has its Astro Cafe on Mount John (Figure 6.1). These and several other dark sky places also include research grade telescopes with public access. If your park includes such facilities, you probably do not need to read this chapter. At least make sure that access hours and special events are well promoted. The rest of this chapter is aimed at protected areas that do not already have an investment in dark sky activities.

The value of interpreting the night sky

People who visit protected areas do so to see nature through outdoor activities away from urban environments. The experiences of the dark sky protected areas described in Chapter 3 show that when given the opportunity to learn about and see the night sky and the ecology of the night, visitors are eager to see a naturally dark night sky and its many celestial treasures. They are also eager to learn about and see how wildlife is more nocturnal than diurnal (Figure 1.8). They enjoy presentations and displays about these values. They may not come for the night sky and wildlife, but they are an audience willing to learn and share this knowledge back home. Interpretation of the night should therefore be one of the core features of protected area interpretation.

Equally important is the role that protected areas can play in demonstrating the principles and practices of sustainable development. Visitors to protected areas tend to be sympathetic to concerns about conservation and environmental protection, and so are, again, a willing audience for such messages. Accounts of the history of outdoor lighting (see Chapter 1), explanations of light pollution and what can be done about it, and demonstrations of what certain parks have done about it (Chapter 3) all provide key messages for the public to take back to their home environment.

One of these key messages is that it is never too late to do something about light pollution. With increasing scientific research and media articles, public awareness of light pollution is increasing. There are simple and effective solutions for reducing light pollution, some as simple as changing a light bulb or installing a motion sensor. Equipped with awareness, education and

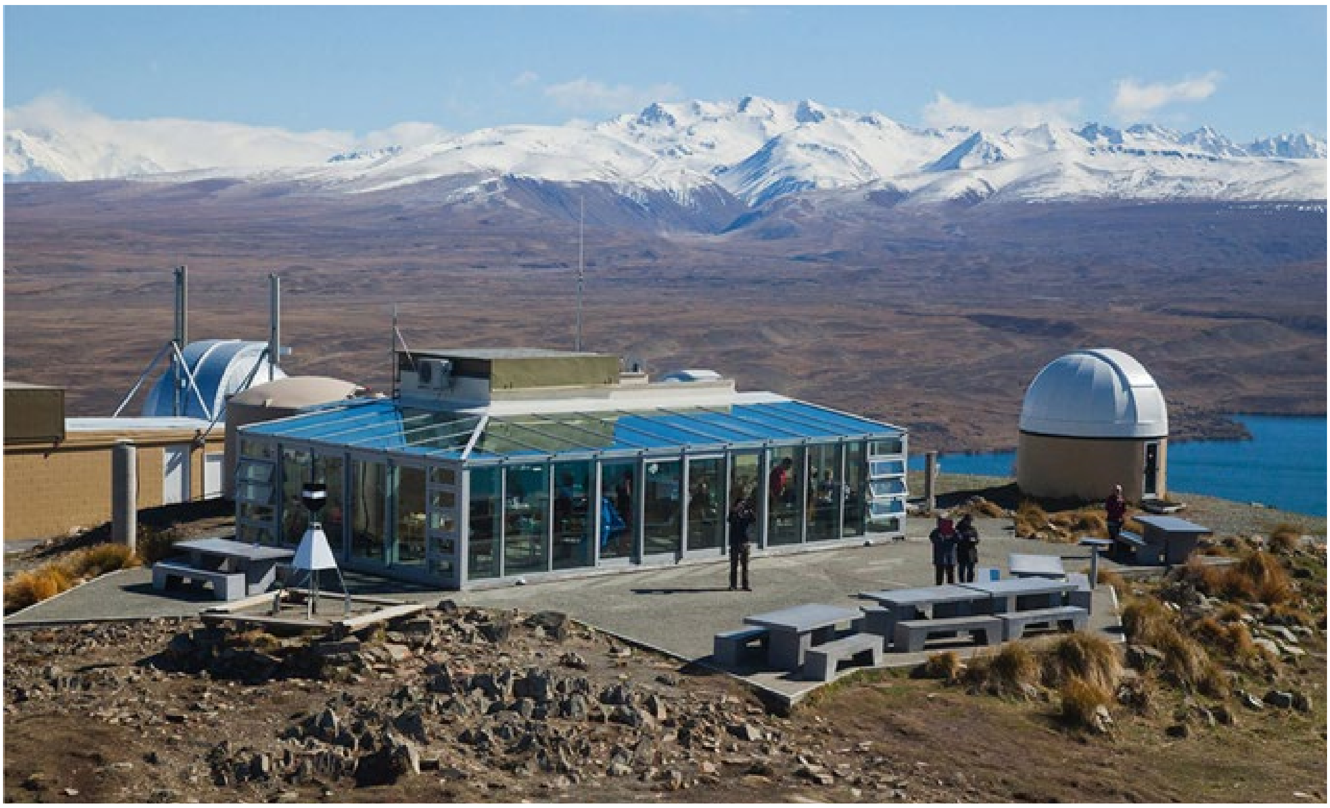


Figure 6.1. The Astro Cafe on Mount John, Aoraki MacKenzie, New Zealand. Source: Maki Yanagimachi

determination, one might see a gradual reduction in light pollution, and in some areas even a restoration of the natural night sky. As urban dwellers lose opportunities to see the night sky, park interpretive activities are a great way to connect visitors to the wonders and values of nocturnal environments. Personal connections bring motivation and understanding of ways to protect the night sky and the ecology of the night. Providing this context will help encourage park visitors to become night sky stewards and develop a sense of pride for night skies and ecology 24/7, not just in conservation areas but throughout urban, rural and wild areas.

Interpretation of the night sky and nighttime ecosystems is fascinating and almost boundless. Universal topics of survival, time, heritage, progress and discovery open many paths to explore. Of course, looking up into the night sky begs the question, are we alone in the Universe? Questions can also be explored about mankind's role and influence on the planet, a topic of wide appeal and one to which everyone can relate a personal experience.

With the majority of people now living in cities, protected areas often provide the best opportunity for seeing starry skies. Naked eye views of the Milky Way and the thrill of dancing auroras can be transformative and an experience equal to seeing iconic panoramas or charismatic megafauna. Even urban parks can connect visitors to the nighttime environment. Though these parks might not offer high quality night sky views, they are still a respite from the city's incessant glare, providing relatively dark areas that serve as important natural preserves, and the best available nearby night sky conditions for large numbers of people. Visitors can be encouraged to contrast what they see of the night sky from the rural fringe of their city to what they see in an inner suburb, as illustrated by Bortle classes 7 and 3 shown in Figure 1.2.

Park interpreters can help stargazers make sense of the night sky and enhance their experience with connections between their lives and the world around them. Interpreting the natural dark can engage visitors about the night sky's role in shaping civilizations, its critical function in nocturnal environments and ecosystems, and the work done by conservation agencies in protecting the natural world and inspiring visitors to be voices for night sky preservation in their own communities. Night sky activities also attract many visitors and benefit local communities.

There are many ways that interpreters can engage park visitors with the night sky, including activities, stories and associated themes. The first steps are to acquaint visitors with the night's charismatic qualities and help people feel at ease in low light settings. Gaining an appreciation for the qualities of the natural world at night can lead not only to a curiosity about the cosmos, but a desire to protect and preserve the ability to see it in as natural a state as possible. This paves the way to understanding the night sky in relation to other aspects such as geology, biology, ecological relationships, archaeology (Figures 1.18, 1.19 and 1.20), cultural practices and folklore. It may also bring a deeper comprehension of universal themes such as time, space, connectivity, beauty and wilderness (see back cover photo).

As noted at the end of Chapter 1, there is a lot more to the night sky than stargazing. The night is full of things to discover, whether a star-filled sky in the darkest regions of the Kalahari Desert in southern Africa, a park's nocturnal environment in Australia when small marsupials become active, or a lunar alignment at cultural historic sites like Stonehenge in the United Kingdom. There is a whole world operating under the night sky that has always been an integral part of the human experience. In thinking about your approach to the subject, embrace all night topics, not just astronomy. Many parks and park interpreters already offer a range of night activities. There is usually no need to start from nothing. Seek out and share information from and with staff and members of nearby parks, local astronomy societies and Internet portals such as those of the International Dark-Sky Association, the Royal Astronomical Society of Canada and Fundación Starlight.

The night outside

Whether at star parties or when attending night talks, guide visitors to become familiar with prominent clusters of stars like the Pleiades (Figure 1.21), learn their stories, revel in their histories, ponder their science, and simply gaze at their beauty. Telling the stories of the constellations provides valuable insights into cultural histories. Not only is this true of the classical Greco-Roman mythologies common in western culture, but also of the storytelling of traditional peoples around the world. Bringing these night sky stories to park visitors is a wonderful way to integrate local cultural traditions into the understanding of the history and ecology of a protected area. The night sky is a timeless muse that has inspired creativity and inquiry for generations.

Table 6.1 presents some ideas for interpretive stories that can be witnessed with the naked eye. More can be identified and developed through consulting and cooperating with local astronomers and their organizations. The night skies are ripe for exploring universal topics of survival, exploration and mankind's place in the world and Universe. The night and the stars evoke a myriad of feelings from fear to awe and help humans delve into essential questions about who we are, the importance of stories and what we value. The ecology of the night presents many examples of how the natural environment does not sleep. On the contrary, it depends on darkness for many ecological functions.

Astronomy

The Milky Way is a barred spiral galaxy composed of vast numbers of stars and planets, including the Sun and the Earth. It appears as a band of stars and light arcing across the night sky (Figures 3.16, 6.2, A7-4, A7-5 and the back cover photo). Its position and orientation in the sky varies with one's location on Earth, with the seasons and with the nightly motion of the sky. It owes its milky glow to the light blended from numerous stars residing in the plane of the Milky Way. Scientists estimate the Milky Way to be between 100,000 and 180,000 light-years in diameter. It is shaped in the form of a flattened spiral that contains more than 100 billion stars. The Solar System lies halfway from the galactic centre on the Orion Arm of the disk. Its central black hole, Sagittarius A, is thought to have a mass over four million times greater than the Sun. On clear nights one can contrast the brighter from the darker parts of the spiral arms where the view of stars is obscured by interstellar dust. In the Southern Hemisphere one can also easily see two nearby galaxies, the Large and Small Magellanic Clouds.

Story telling can cover the science, discovery and physics of the Milky Way and the rest of the Universe. Finding and naming constellations and asterisms gives insight into many cultural traditions, especially when coupled with the appearance and movement of planets across them.

Constellation stories go a long way in creating memories and wonder and connecting to other cultures. You do not have to memorise every constellation. Presenting an evening of star lore is a great way to explore the night sky and to share information, history and values through story-telling. If your park has a connection to a local cultural heritage, explore its Indigenous stories. Just like amateur astronomers, Indigenous elders in your area may be willing to share their cultural tales. If your park is coastal or marine, explain celestial navigation prior to GPS. Ask how else people have used stars to navigate.

Encourage audiences to point out constellations and share stories from their own cultures. Stories from Peru or Greece will be different than those from China or Iceland. Many of the same constellations can be seen, although the night sky looks different from North America versus southern Africa. Multicultural stories emphasise what is unique about a place and peoples' experience of it, but also what different cultures have in common.

Comets are like giant snowballs of frozen gases, rock and dust roughly the size of a small town. As comets orbit near the Sun, their mass heats up, spewing dust and gas that is blown away from the Sun by the solar wind. This process creates a tail that can stretch for millions of kilometres. Scientists believe that comets may have brought water and organic compounds, the building blocks of life, to the early Earth and other parts of the solar system. Astrophotography of Halley's Comet, visible from Earth every 75 to 76 years, reveal its nucleus and other new data about this and other comets' compositions. When they near the Earth,

Table 6.1. Themes for interpreting the night

Theme	Sub-theme	Some topics
Astronomy	Deep space	Galaxies, constellations, asterisms, nebulae, specific stars.
	Near space	Planets, comets, the Moon, the Sun, eclipses, zodiacal light, gegenschein, satellites and the International Space Station.
Atmosphere	Earth's shield	Meteor showers, meteorites, auroras.
	Weather	Noctilucent clouds, lightning, sprites.
Earth	Species	Bioluminescence, nocturnal mammals, bats, birds, insects.
	Relationships	Predator-prey dynamics, phenology affected by light.
Society	Built heritage	Antas, henges, historic observatories, modern observatories.
	Culture	Mythology, traditions, wayfaring, agricultural calendars.

many other comets are visible to the naked eye, for example Hale-Bopp, Neowise and Leonard in recent years. Once spotted by telescopes their path is predictable for weeks to months. When a comet becomes visible, interpreters should integrate them into night sky talks and star parties.

The Moon is the brightest and largest object in the night sky. It was formed from debris left over after a Mars-sized body collided with Earth. It is the fifth largest moon in the Solar System, and the only place beyond Earth where humans have set foot. Earth's climate is relatively stable because the Moon moderates our planet's wobble on its axis. It also causes tides, creating a rhythm that has guided humans for thousands of years and the development of life for over three billion years.

The Moon is visible because sunlight reflects back to Earth from its surface. As it circles Earth, the amount of light seen on its surface changes throughout the days and weeks of the month. These lunar phases repeat each month. The New Moon is not seen because its unlit side faces Earth. The Waxing Moon seems to grow larger due to the increasing amount of light from the Sun on the surface facing Earth. The maximum illumination is the Full Moon. The Waning Moon grows dimmer as it completes its circuit and again approaches the New Moon phase.

As well as the Moon's phases and tides, story telling can focus on the mythologies and traditions of local cultures. Lunar phases also link to the ecology of the night. Many predator-prey relationships are governed by the presence or absence of moonlight, and many predators have evolved eyes capable of seeing far more in the dark than can humans.

Eclipses

Both the Sun and the Moon are subject to total and partial eclipses. A total solar eclipse occurs when the New Moon comes between Earth and the Sun, temporarily and fully blocking the Sun's light except for its corona, a thin ring of light passing around the Moon. This exact alignment is referred to as *syzygy*, a Greek word that means paired together. In a partial solar eclipse, the Earth, Sun and Moon do not perfectly align, and so the Moon only partly obscures the view of the Sun. During a total lunar eclipse, which occurs during the full Moon phase,

Figure 6.2. The structure of the Milky Way over Mt John Observatory, New Zealand. 6.2. Foreground: the dome of the 1.8 m microlensing observations telescope, New Zealand's largest optical telescope, used mainly to search for exoplanets. Source: Fraser Gunn

the Earth blocks the sunlight from reaching the Moon and casts its umbra, the darkest part of its shadow, on the Moon's surface. Similarly, in a partial lunar eclipse, the Earth moves partly between the Sun and the Moon, and only part of its shadow is observed on the Moon's surface.

Explanations of these phenomena are easily demonstrated through diagrams or hand-held models. Like planetary movements and meteor showers, eclipses are well predicted and viewing events can be planned. Lunar eclipses lend themselves to nighttime events. Do not, however, expect a lunar eclipse to integrate with a normal star party because the brightness of the Moon before or after the eclipse reduces the ability to see into deep space. Solar eclipses, of course, appear during daytime. Interpreters should communicate the well-known dangers of looking directly at the Sun, even through some home-made filters. For liability reasons, rather than organizing viewing events, interpretation may be better aimed at messages about the danger of viewing eclipses directly.

Meteors are chunks of ice or rock in space, ranging in size from a grain of sand to hundreds of metres in diameter. Smaller ones, less than 10 m in diameter, are sometimes called meteoroids. When a meteor enters the Earth's atmosphere, its high speed causes it to burn up and vaporise in a streak of light. If enough remaining mass reaches the Earth's surface it becomes a rock known as a meteorite. Single meteors occur in the night sky all the time, but the best times to see them are during meteor showers. These occur when swarms of meteors enter the atmosphere over a few days, producing brilliant trails that illuminate the night sky. These showers are predictable and intensify when the Earth's orbit passes through streams of debris left behind from comets. Famous ones include the Perseids Shower, not to be confused with the Pleiades star cluster (Figure 1.21), which peaks around the 12th of August each year, and the Leonids which peak around the 17th of November. Because of their predictability, star parties can be timed to coincide with these showers.

The atmosphere at night

Auroras are caused by energetically charged particles that escape the Sun, interact with plasma in solar winds and then reach Earth's atmosphere. Collisions with Earth's magnetic field produce electric currents that appear as shifting curtains or arcs of blue, green, red and orange. In the Northern Hemisphere they create the Aurora Borealis, or Northern Lights, and in the Southern Hemisphere the Aurora Australis. As they are associated with the magnetic poles they are best seen at middle to high latitudes.

Story telling can highlight these ghostly apparitions and their role in mythologies. Explanations can also refer to the connections between sunspots, solar flares and the solar wind to disturbances to telecommunications and electricity distribution grids. There is also the ongoing science of the hissing, crackling or muffled banging sounds sometimes heard during auroras.

Clouds can add to a night experience, as when noctilucent clouds are visible. These are high clouds that remain illuminated long after the Sun has set. Partly cloudy skies can also be used as a simple gauge of whether or not there is substantial light pollution. During a partly clouded night, in an area free from light pollution, one should see fields of stars amid the black patches of the undersides of clouds. In light-polluted areas one sees the opposite, grey clouds reflecting artificial light from the ground and separated by darker patches with only a few faint stars visible. Encourage visitors to observe this when they return to the city.

The Earth and nature at night

Most living things need the night for survival, and many animals are nocturnal (Figure 1.8). Some animals come out at night to escape the heat of the day. Others need the night to hunt, mate or avoid predators while foraging. Animals such as cats, owls and rodents have developed dark-adapted vision, keen hearing and sensitive smell to help navigate at night. Once sea turtles start laying eggs on beaches they can be approached and witnessed without any impact. In some North American and Eurasian parks, motion-triggered cameras and barbed wire hair traps reveal the night movements of large cats and bears. Parks with natural sounds programmes can also introduce visitors to the night calls of birds and wolves. Seeing such creatures and activities is, of course, difficult for humans. However, some sightings are possible when assisted by a knowledgeable guide. In Australia, for example, small marsupials can be seen in the right areas by keeping still, waiting, then turning on flashlights. Such practices should be done with amber flashlights, or by providing visitors with amber filter paper for their personal flashlights. Fingers over the lens also provide an effective orange filter. Conservation managers must also balance the benefits of increasing public appreciation, learning and support against what may be considered a disruptive practice. A middle course would be to restrict the frequency, duration and location of such viewing.

Hosting night sky events

Protected areas are natural locations for astronomy enthusiasts to converge for nights of stargazing and community connections. There is always a night sky to ponder, whether at the coast, in a desert, on a mountain or in an urban setting. For a growing number of parks around the world, visitor numbers increase when astrotourism experiences are offered. This is particularly true for small cultural places like rural historic sites. Just as visitors return to natural areas for hiking and landscape appreciation, so too night sky viewing attracts repeat visitors to cultural sites that normally do not experience such returns. Even without an on-site planetarium, simple outdoor sky rings and telescope mounting pads can be built to help host night sky interpretive events (Figure 3.7).

Star parties

Star parties (Figure 1.6) are events where enthusiasts bring their telescopes to share with visitors. Advanced amateur telescopes are too big to carry far, so the ideal places for star parties are at or adjacent to unlit parking lots where there is solid, stable ground and where there are no lights to inflict glare upon stargazers (Figure 3.7). Flashlights may be needed to assist walking around and between other viewers with safety. These should be filtered to red or amber to preserve eyes' adaptation to scotopic vision. Amateur astronomers often provide star finders, hand-held devices that can be programmed to identify a star through its viewfinder, or vice-versa, provide directions (left, right, up, down) to help the viewer locate a specific celestial object.

Hosting night sky events involves another level of interpretive planning. They are also a lot of fun, and can create lasting memories for park visitors. Some parks can host large festivals with telescope viewing opportunities for visitors. If your park is not among these but is interested in building a programme, reach out to these other parks for advice. But you do not need telescopes to provide enjoyable experiences. Start small and you will grow your park's reputation over time. With a little research, mentoring and planning, you'll be on your way to organizing an event. Table 6.2 summarises the tools and techniques that are useful when interpreting the night. More details are offered in the text that follows.

Table 6.2. Aids for interpreting the night

	Approach	Some basic needs
Active seeing	Star parties	Cooperating local astronomers who provide telescopes. Vehicle access at night. No lights. Rock or paved ground for mounting telescopes. Cell phone astronomy apps. Green laser pointers, but only if not near an airfield.
	Observatories	Where present, public access times.
	Naked eye	Aided by binoculars.
	Scale models	Markers or signs that are spaced to scale to represent the Solar System. They can range from 10s of metres across to 10s of kilometres.
	Walks	Smooth front-country paths. Reflective path surfaces between access and viewing areas (Figure 5.7). Dim amber or red flashlights to preserve night vision. Regular flashlights may be used if filtered, even through closed fingers. Parabolic microphones to experience night sounds.
Passive learning	Talks	Slides and projectors. Diagrams. Planisphere. Orrery. Almanacs. Guidebooks.
	Audio-visual presentations	Movies, automated slide shows.
	Travelling planetaria	Indoor tent domes for several people plus planetarium projector. May be purchased, or loaned by astronomy societies or schools.
	Printed material	Static displays at visitor centres or along paths. Hand-out pamphlets. Posters for purchase.

Telescopes

Many parks host night sky festivals and star programmes with telescopes for people to experience dark, starry night skies throughout the year. Most parks do not own telescopes, but plenty of amateur astronomers do, and many are happy to share their equipment and knowledge of the night with staff and visitors. Staff can work with these astronomers to better understand the night sky and build their astronomy knowledge. With training, equipment and support, these local experts can empower staff to share the awe-inspiring scenery of the night, and to craft and deliver messages for its protection. Observing the night sky with telescopes alongside amateur astronomers or professional scientists provides a platform for discussing science and humanities concepts. These range from constellation myths and cultural stories to astronomical advancements and the concepts of deep time and deep space.

Many countries have astronomy societies with local branches and members. Find out how they can help you plan your stargazing programme. University astronomy departments and high school science clubs are also resources for connecting with astronomers and other educators who can provide scientific information about the environment beyond Earth.

Binoculars

Do not dismiss the power of binoculars for exploring bright star clusters, the Moon, planets and other celestial bodies. Though they do not provide the same level of magnification or the stability of a telescope mounted on a tripod, they still give excellent views and the ability to see more of the night. Hand-held green laser pointers, typically of 4 to 5 milliwatts power, use a beam of light that reflects off natural aerosols to help point out stars and other sky features. However, note that lasers should not be used near airports so as not to confuse or blind pilots.

Almanacs and cell phone apps

Almanacs and cell phone apps such as Globe at Night described below, are available to help find planets and other astronomical events on any given night. Examples include meteor showers, moonrise and moonset times, and passes of the International Space Station.

Stargazing with the naked eye

Telescopes are wonderful instruments for peering deeply into the night sky, but you do not need one to experience the beauty of the night. If your location provides reasonable views of the night, then plan an evening of stargazing in a comfortable outdoor setting, such as an amphitheatre or open lawn. Have visitors bring chairs or blankets. Advise them in advance to wear warm clothing for sitting or standing still while the night temperature drops, especially in dry climates where the best sky viewing is to be found. Incorporating a few stargazing tips and activities into a standard night hike or talk can pique the interest of visitors and doesn't require a lot of expertise. Guide visitors to find common asterisms like the Winter Hexagon, the Big Dipper, the Southern Cross, Orion's Belt or the Pleiades.

Night walks

Natural features take on a unique and compelling glow under the powerful light of a full Moon or the gentle sparkle of starlight. There is a natural fascination for creatures that are awake and moving about when most people are asleep. Engaging park visitors after hours can yield rewarding opportunities to observe nocturnal wildlife in their natural habitat. Dawn and dusk are other good times to observe animals, as anyone can attest who has been on a desert safari. Those who experience nature at night may be treated to dramatic scenes quite different from views by day.

First, determine what animals in your area come out after dark, why they might be nocturnal, and where they would likely be found such as on the ground, in a tree, near water, on rocks or on a prairie. Also consider the loading capacity of the local ecosystem in terms of numbers of visitors at one time or cumulatively, and the sensitivity of the sites to visitor numbers and flashlights. Guidance on carrying capacity in protected areas may be found in Manning (2007).

Find a location without obstacles, assess potential hazards, and have a plan for what to do if something unwanted happens. If possible, meet or lead visitors to an appropriate habitat to investigate, or simply to watch and wait in a convenient location removed from artificial noise.

Full Moon hikes and night walks are great opportunities for visitors to tune their senses to their surroundings. Before beginning, let their eyes adjust to the dark and encourage them to use all of their senses. The cone cells in our eyes are activated during the day and the rods at night. While only a few minutes of darkness is enough to significantly improve night vision, it takes at least 45 minutes for our eyes to adjust fully to the dark. Even a quick peek at a cell phone screen will interfere with this process. Encourage park visitors to allow their eyes to adjust in order to fully appreciate the ambience of the night. This can be a useful exercise even when just stepping outside a lecture theatre. The temptation to use a flashlight is great, but once the eyes adjust it is amazing what can be seen that was not previously possible.

Animals are sensitive to sounds. Remind visitors to be as quiet as possible, thereby increasing the chance of sightings. Encourage visitors to guess the nature of wildlife sounds, such as socializing, warning, mating or foraging. Prompt participants to consider whether there are sounds or lights that might impair their ability to see or hear animals.

Parabolic microphones (Figure 6.3) are an inexpensive way to amplify and show the acoustic activity of bats and birds, even during the day. Good quality ones can be purchased for as little as US$50. They can even be bought for less at some toy stores yet still be effective. Find out if your park has or could obtain one, especially if you are also presenting a natural sounds programme. These instruments help curious kids and adults of all ages to understand how bats hunt and create an opportunity to explore the unique contributions these creatures make to the ecosystem. Even more basic, they help to illustrate just how many birds are around even in the daytime when they are not visible to the untrained eye because of tree foliage.

Ask visitors to engage all their senses and consider the following questions. What sounds do they hear? Do they recognise the smells of certain trees and plants? Do they see any animals? Is there a glow of urban light on the horizon or glare from a nearby light? If so, does this disturb the experience? How might it disturb wildlife? How does the terrain look different at night? How does cloud cover or the Moon's phase shape the experience? Encourage a few moments of silence to immerse your audience even further in their nighttime experience.

Figure 6.3. Ty.pical parabolic microphone Source: Wikimedia commons

The night inside

Bring the sky indoors

If you cannot get outside under the sky due to rain, terrain or other reasons, there are still ways to connect visitors to the concepts and wonders of the night sky. Indoor activities during sunset and twilight can be used to prepare the visitor to what they might see and experience when they go into the night. Talks and group sessions can be integrated into a park's lecture programme. Several presentations are worth having on hand in the event that a star party or night walk is curtailed by bad weather or clouds. Useful teaching aids may include a star chart or star wheel, sometimes known as a planisphere. A portable planetarium provides a great discovery tool for small groups, especially children.

Create a presentation that orients visitors to key stars, planets, asterisms, constellations or other astronomic and atmospheric phenomena. Visitors can apply this information the next time they are under a night sky. Introduce the concept of deep time. All the natural light seen at night was emitted from as little as eight minutes to billions of years ago. Connect the age of light seen in the night sky to what was going on in your area during the time when the light started its journey. Link the travel time of light from galaxies to famous events in the Earth's history, such as the comet that killed the dinosaurs. Link travel time of light from nearby stars to the ages of audience members. The Internet has many useful resources to help you develop such themes.

Bring the ecology of the night indoors

If you are unable to lead park visitors to wildlife, perhaps you can bring wildlife to visitors. If your park has webcams with infrared or low light settings, install them in an area likely to have nocturnal activity. Visitor centre auditoriums and display rooms are good venues for viewing webcam footage. If scientists or resource managers use camera traps in your park, these motion-triggered tools will capture a range of wildlife at night. Slide and video presentations are great tools to introduce the importance of the night in nature. Static displays of photo essays of in-park night sky photographs can by coordinated with star parties, dark sky certification ceremonies and the like. Such events are also opportunities to discuss the different impacts of light pollution on various taxa.

Light pollution

A simple indoor exercise about light pollution can be done after a presentation, be it on cultural traditions of the night, nocturnal animals or constellations. It reinforces an understanding of artificial light at night and the impact that small amounts of light can have on dark environments. Assemble an audience in an interior room, shut the doors and turn off the lights. While you talk for a few minutes, the audience's eyes will adjust to the dark. Before turning the lights back on, invite the audience to express what they can see. Unexpected patterns and images will emerge. Beams of light from outside may filter in through cracks in the door. Objects in the room will be distinguished from the surrounding darkness. Equipment status lights will be evident. Even some shadows within the darkness may be visible. Subtle variations in shades of darkness may appear, ranging from light gray to deep black. Have visitors share observations. If needed, introduce your own. Explain how this exercise will shape observations of their own night surroundings.

Presentations specifically on light pollution should illustrate how much the view of the sky is hampered by light pollution, as shown by Figure 1.2. Colours will also become desaturated. Bright colours will appear light gray and darker colours will appear a darker shade of gray. This and other graphics, many of them included in this publication, are available online to help build an illustrated talk. Examples include the impact of glare on what can be seen nearby (Figures 1.17 and A4.2), and the good an bad ways to illuminate the outside of a home (Figure 5.8). Numerous slide and video shows may be downloaded directly from organizations such as the International Dark-Sky Association, the Royal Astronomical Society of Canada and Fundación Starlight. Just follow the links previously noted. Static materials such as posters and pamphlets are also available form the IDA and the RASC.

As humans learn more about the benefits of natural darkness, they fear the dark less and love the night more. However, the benefits of natural darkness must be balanced with the needs of other members of the night community. The guidelines presented in Chapter 5 present the arguments and solutions. The bottom line for audiences is to understand the need for just enough light of the right colour, in the right places and at the right time. Hopefully your audiences will absorb these messages and make their own contributions to reducing light pollution in their home cities, towns and villages.

The cultural heritage of the night sky

Chapter 1 gives several examples of archaeological and cultural values related to the night sky, such as antas, henges, temples and Polynesian navigation skills. Good resources for these stories can be found in Aveni (2008) and Krupp (1991). Chapter 3 gives examples of specific protected areas with dark sky values, such as Hortobágy, Hungary, and Chaco Culture, US. Your park may also be close to or within the traditional territory of an Indigenous people. In any of these situations, research these cultural links and incorporate them into engagement with visitors. As well as telling of alternate naming systems for constellations, talk about celestial calendar events of the Sun, Moon, planets and stars. In some cases, elders from traditional communities may be willing to help create presentations and static displays, and perhaps even participate in story-telling presentations.

In modern times, Global Positioning Systems have replaced the sextants, chronometers and charts of the previous millennium. Earlier still, ancient but reliable star-finding methods provided knowledge for wayfaring and navigation. For example, African American cultural history tells how fleeing slaves found their way north to freedom by following the Drinking Gourd. This is a grouping of stars within the Ursa Major constellation named after the gourd that slaves commonly used for dipping and drinking water. Coded directions in the form of songs helped slaves identify the star patterns. In the Northern Hemisphere most people know the Drinking Gourd as the Big Dipper, whose stars in the bowl point to the North Star, a helpful guide for those without maps.

Challenge your audience to think how they might navigate a long distance, on land or at sea, with just celestial and solar observations by the naked eye. Suggest what other clues there might be as to nearby locations, such as marine navigation aided by observing birds and floating vegetation, or estimating latitude from the time of the year and day and the position of the Sun. Could you find your way across unknown bodies of land or water guided only by the stars?

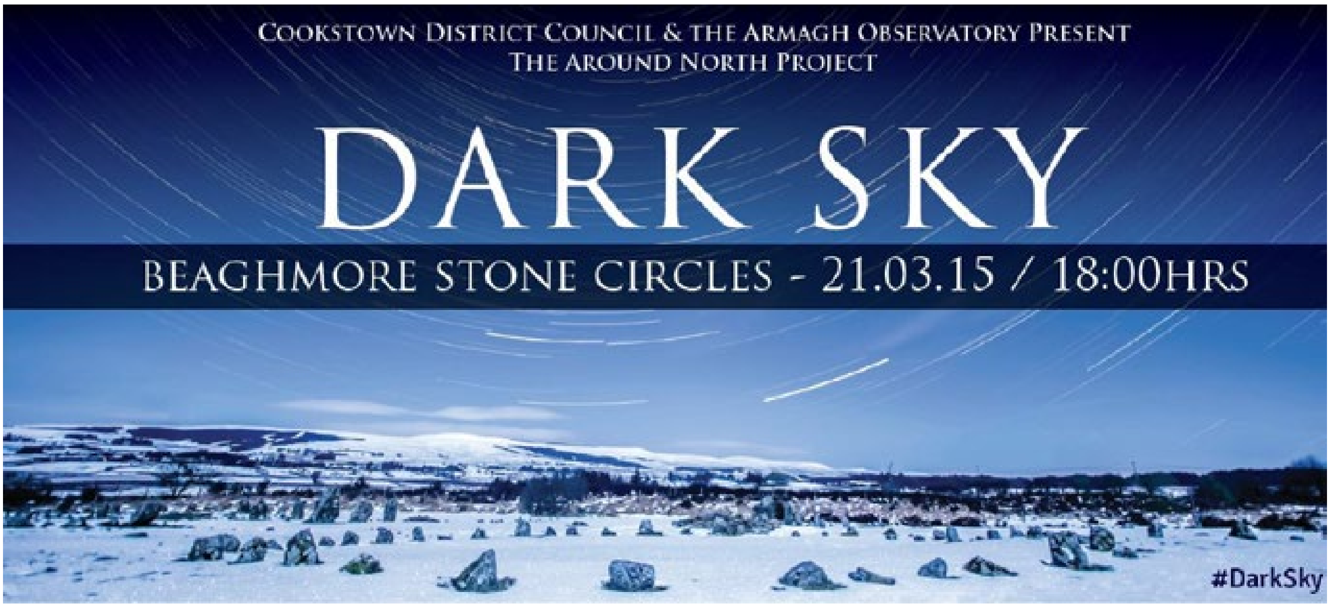


Figure 6.4. Advert for a Davagh Forest dark sky event, Ireland. Source: DarkSky

Outreach

Conservation managers should seek to build public understanding and political support for all aspects of ecological and cultural protection, and light pollution abatement and naturally dark nights are no exception. Just as ecological corridors, home ranges and watersheds often go well beyond park boundaries, so do night skies. Widespread public support is needed to maintain their integrity. Reducing or eliminating glare, skyglow and light domes beyond the boundaries requires public engagement. There are several approaches to achieving this. Depending on the specific local situation and staff resources, not all may be practical. Nevertheless, consider outreach actions from the suggestions that follow:

School programmes

Encourage local schools to incorporate dark sky messages into their curricula. Beyond simply expanding the scope of subject matter, seek out joint activities such as inviting classes to star parties, lectures and demonstrations. Equipment can be loaned and borrowed. Park staff who have developed presentations should seek to take similar presentations to schools, adapted to the age and education level of the students.

Citizen engagement

Consider direct advocacy to local residents, such as through dark sky awareness events that may be organised through a local astronomy club, municipality or school. Dark sky awareness documents and other information documents may be distributed to residents and visitors. Pamphlets and web materials can educate visitors and the interested non-visiting public, encourage them to consider their own actions, and support local public officials who endorse reduction of light pollution.

Encourage visitors and local people to join the Globe at Night initiative. This is an international campaign to track light pollution changes affecting the night sky. It also raises public awareness of the impact of light pollution by inviting citizen-scientists to measure and submit night sky brightness observations. All that is needed is a computer or smart phone. On Globe at Night campaign dates, participants go outside more than an hour after sunset, typically between 20:00 to 22:00 local time, and when the Moon has not risen. Using a star chart, participants select the faintest star visible in a constellation of their choice and estimate per cent cloud cover. The app then sends the data to Globe at Night to build global trend data. See globeatnight.org.

Commercial and institutional support

Many dark sky places see an increase in visitor numbers once certification is promoted, either by the park or by the certifying agency. Sometimes this is a short-term boost, but it often results in a modest but ongoing increase in visitors. This can be of particular help at rural cultural heritage sites. Many people only visit such sites once, whereas recurring events like star parties can bring repeat attendance, especially from within the region. With this in mind it is worth investigating the potential for financial and in-kind support from local businesses and chambers of commerce to link hotel accommodations and local excursions to astrotourism and night sky events.

Some dark sky places have been able to garner financial support for equipment and built facilities, such as displays, night sky shows, viewing platforms, public telescopes and theatres. Some of these may involve the granting of naming rights. As well as private companies, this form of support is sometimes available through partnerships with universities and observatories. Local astronomy and friends of park societies may be able to provide in-kind support by asking amateur enthusiasts to lead star parties, give presentations and lead night walks.

Political support

Whether a natural area is protected or not, advocates of light pollution abatement should seek commitments to quality lighting through municipal policies. Such policies should embody the principles of outdoor lighting presented in Chapter 4 on lessons learnt from case studies and Chapter 5 on guidelines for outdoor lighting, and illustrated in Chapter 7 on laws and policies. Encourage local governments to upgrade public installations and encourage improved private lighting, e.g. by funding retrofits for better shielding and light sources, or by introducing bylaws even if they allow exemptions for existing installations until a scheduled replacement. Encourage municipalities to develop and distribute communications that support night sky viewing and good lighting, such as publications, flyers and public service announcements. As well as direct advocacy to municipal authorities, consider seeking support from other community organizations such as chambers of commerce, local electrical utilities, lighting retailers and residential community associations.

Media relations

Consider advertising public talks and star parties. Issue and distribute press releases for dark sky events, especially for dark sky place certification. Either through press releases or direct interviews, explain the issues of light pollution and why it is important to mitigate it, both for the public's appreciation of the night sky but also to help restore and maintain the ecological integrity of a natural area. Even more, explain how the local taxa have different reactions to light pollution. This will help raise public awareness of the impacts of artificial light at night.

CHAPTER 7.

Laws and policies

Policies around the world

Many jurisdictions, from national to local, have environmental, nuisance, habitat and species protection laws, regulations and policies that can be interpreted to include control of light pollution. However, few such legal instruments specifically address artificial light at night. Bringing about meaningful control of light pollution on local to regional scales is a multivariate problem that involves aspects of science, technology, politics and law. The scale of the problem varies along jurisdictions from national to local, and solutions proceed according to the legal customs of each jurisdiction. France, Czechia, Slovenia, Croatia and substantial parts of Italy and Chile have comprehensive national or regional laws governing outdoor lighting for the purpose of reducing light pollution. In Spain the Law of the Sky for the Canary Islands, in Spanish *el Ley del Cielo*, was passed by the Spanish government in 1988. Its purpose is to protect world class astronomy observatories from light pollution. Its implementation led to significant reductions in outdoor lighting on the island of La Palma and consequently less energy consumption. It also bans all commercial and private aircraft from flying over the observatories at El Teide on Tenerife and at El Roque de los Muchachos on La Palma.

Some laws are binding. Others are advisory and simply establish norms or recommendations without giving enforcement authority to officials. For instance, in some countries that follow the United Kingdom's town and country planning system, such as Australia and New Zealand, non-binding guidance related to outdoor lighting exists that is considered an obligatory element of the planning permission process. Further, in some jurisdictions the prevailing standard is not comprehensive and applies only to, for example, roadway lighting. Other types of environmental laws may have meaningful provisions related to outdoor lighting and the reduction of light pollution, even if these are not their primary purposes. Lastly, laws governing outdoor lighting are sometimes found in building and energy codes, such as the California Building Energy Efficiency Standards. See Table 7.1 for notes on links for these laws and policies.

While statutory laws are the primary approach to controlling light pollution, some jurisdictions affect change through regulatory or rule-making processes. These executive actions often take the form of implementing legislation, but in other cases they serve as stopgap measures to address problems in the absence of enabling legislation. For instance, in many countries the environmental impact assessment process requires applicants for development permits to show that adequate steps have been taken to mitigate the impacts of artificial light at night, even if no particular statute requires this.

Throughout the world such national and sub-national laws, regulations and advisory policies are the exception rather than the rule. However, many towns and cities have introduced outdoor lighting polices that curtail light pollution, albeit principally concerned with energy efficiency. As well, protected area agencies like the United States National Park Service and Parks Canada have internal policies that address light pollution. Finally, all the sites that have been certified as dark sky sites, as described in Chapters 2 and 3, have lighting management plans that commit them to a series of practical measures such as those described in Chapter 5.

Outdoor lighting policies around the world suffer from a number of deficiencies, chief among these being an overall lack of consistent enforcement. With this in mind, policies can be written in ways so as to be more readily enforceable. The ultimate success of this approach relies on broad public support.

Principles for policy

The ideas embodied by most legislation or regulation to control light pollution assume that artificial light exists specifically to meet human needs. These ideas are designed to be translated into both the literal and legal language of the jurisdiction, and adapted in consideration of local norms and traditions. First, lighting should be warranted according to the desired outcome, and, where possible, non-lighting alternatives such as reflective paints and self-luminous navigation guides should be used instead. Policy should assist in determining whether lighting is necessary, and guide its use once necessity is established.

Notwithstanding the preference for no artificial outdoor lighting in natural areas, if lighting is needed, or existing lighting to be modified, it should adhere to the following additional principles:

- Light should be directed only where it is needed, illuminating an object or task performance area, and should not spill beyond the target.

Table 7.1. Citations for laws and policies

Country	Citation
Australia and New Zealand	AZ/NZS 4282:2019, Control of the obtrusive effects of outdoor lighting. [infostore.saiglobal.com/en-us/Standards/AS-NZS-4282-2019-1141358_SAIG_AS_AS_2703687/] AS/NZS 1158.3.1:2005, Lighting for roads and public spaces, Pedestrian area (Category P) lighting - performance and design requirements. [infostore.saiglobal.com/en-us/Standards/AS-NZS-1158-3-1-2005-117844_SAIG_AS_AS_246746/]
Chile	Norma de Emisión para la Regulación de la Contaminación Lumínica (Emission Standard for the Regulation of Light Pollution), Decreto Supremo N°043/2012 MMA, 2012. [opcc.cl/wp-content/uploads/2019/04/DS_43_2012_MMA.pdf]
Canada	Mont-Mégantic International Dark Sky Reserve regulations apply to 34 municipalities. They require a maximum of 2200K for most usages, no uplight, limits on illumination or lumens/area, and rules for timing of operation (Rémi Boucher, personal communication).
Croatia	Zakon o zaštiti od svjetlosnog onečišćenja (Protection Against Light Pollution Law) Public Gazette 14/2019. [zakon.hr/z/496/Zakon-o-za%C5%A1titi-od-svjetlosnog-one%C4%8Di%C5%A1%C4%87enja]
Czech Republic	Act No 86 of 14 February 2002, O ochraně ovzduší a o změně některých dalších zákonů (On Air Protection and on Amendments to Some Other Acts) in Collection of Laws of the Czech Republic. 2002, Vol. 38, pp.1786-1840, ISSN 1211-1244.
France	Arrêté du 27 décembre 2018 relatif à la prévention, à la réduction et à la limitation des nuisances lumineuses (Order of 27 December 2018 on the prevention, reduction and limitation of light pollution); NOR: TREP1831126A [legifrance.gouv.fr/eli/arrete/2018/12/27/TREP1831126A/jo/texte].
Italy	No national law but many regional ones. For a summary of regional Italian laws, see P. Cinzano, Light Pollution in Italy [lightpollution.it/cinzano/en/page95en.html].
Slovenia	Uredba o mejnih vrednostih svetlobnega onesnaževanja okolja (Regulation on the Limit Values of Light Pollution of the Environment), Official Gazette of the Republic of Slovenia, no. 81/2007, 7 September 2007 [uradni-list.si/glasilo-uradni-list-rs/vsebina?urlid=200781&stevilka=4162].
Spain	La Ley del Cielo (The law of the sky) [boe.es/buscar/pdf/1988/BOE-A-1988-25332-consolidado.pdf]. For an English update, see [iac.es/en/outreach/news/30-years-protecting-canary-sky].
United Kingdom	England: BS EN 13201:2015, Road lighting [landingpage.bsigroup.com/LandingPage/Series?UPI=BS%20EN%2013201].
United States	California: California: Energy Code. (www.energy.ca.gov) This code specifies mandatory, performance and prescriptive standards for both indoor and outdoor lighting in residential and commercial settings throughout California. The standards are implemented at the design and construction stage, and all buildings permitted for construction must adhere at least to the mandatory standards. Michigan: The Dark Sky Coast Bill of 2013 legislates six dark sky preserves. Hawai'i: The state has a law that requires the state Department of Transportation to comply with county outdoor lighting ordinances that are more stringent than state regulations when installing new outdoor lighting at airports, harbours and along highways. The purpose of the law is to preserve the dark skies over Haleakala and Mauna Kea Observatories. Hawai'i and Maui counties have lighting ordinances that address shielding and spectrum (John Barentine, personal communication).

- Light should be used only when it is useful, and actively reduced or extinguished during times when humans are not present.
- Light should be no brighter than necessary to perform the intended task, and deployed in such a way as to reduce glare.
- Light should include the least fraction of short-wavelength (blue spectrum) emissions possible in order to minimise impacts to the visibility of the night sky and to biological systems.

Outdoor lighting design should take into account all of these factors. For more guidance by the International Dark-Sky Association (IDA) and the Illuminating Engineering Society (IES), refer to [darksky.org/our-work/lighting/lighting-principles].

With respect to protected areas, planning will benefit from knowing which light-sensitive species inhabit landscapes and what lighting aspects have the most bearing in them. Such planning should identify zones according to the following (Jägerbrand & Bouroussis, 2021, 17):

- Current level of light pollution
- Potential for growth of artificial lighting within the viewshed and species' home ranges
- Ecological dead zones that cannot be used by some species because of over-illumination

- Barrier effects and fragmented zones isolated by, for example, continuous light barrier.
- Attraction or repulsion of species to or from artificial lights
- Conservation of dark areas
- Buffer zones to protect sensitive environments
- Water environments that may reflect light and have higher luminance

A model lighting ordinance

The IDA- IES initiative

Model policies have been developed to aid decision makers with legally appropriate language that encompasses good lighting practices. End users of these models may choose either to enact them in their entirety, or select only particular features for enactment, or adapt the language to meet particular needs. The models serve to ground discussions around writing and implementing policies initially. They are also useful references for refinement of existing policies, given feedback from the implementation process.

Early attempts by the International Dark-Sky Association (IDA) to craft a model outdoor lighting policy involved no input from the lighting industry. They referred to quantities such as watts of power consumed by luminaires rather than the luminous flux they emitted, as is now preferred. After an initially poor reaction to the IDA model and the related concerns of the astronomy community, the Illuminating Engineering Society (IES) chose to reach out to these stakeholders with the goal of producing an improved model that did not represent an existential threat to the outdoor lighting manufacturing industry.

In 2005 a joint IDA-IES task force was established to create a comprehensive lighting policy for North America incorporating the latest lighting engineering knowledge and design guidance. The resulting Model Lighting Ordinance (MLO) was released for two rounds of public review in 2009 and 2010, and published in June 2011 with an attached user's guide. The MLO addresses the need for strong and consistent outdoor lighting regulation (IES, 2011).

Summary of MLO features

The MLO introduced two major innovations to outdoor lighting policy. One is the notion of lighting zones (Table 7.2). This approach builds on the tradition of land use codes that allow or prohibit various activities on properties according to cartographic zones defined according to common land-use characteristics. Such zones typically distinguish land parcels on which residential dwellings are built from parcels used for commercial or industrial activities. Zoning based on land use simplifies the process of managing activities and evaluating planning permission applications. The MLO capitalises on this by embedding outdoor lighting

Table 7.2. Summary of IDA-IES Model Lighting Ordinance lighting zones

Zone	Label	Description
0	No ambient lighting	Areas where the natural environment will be seriously and adversely affected by lighting. Impacts include disturbing the biological cycles of flora and fauna and/or detracting from human enjoyment and appreciation of the natural environment. Human activity is subordinate in importance to nature. The vision of human residents and users is adapted to the darkness, and they expect to see little or no lighting. When not needed, lighting should be extinguished.
1	Low Ambient Lighting	Areas where lighting might adversely affect flora and fauna or disturb the character of the area. The vision of human residents and users is adapted to low light levels. Lighting may be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, most lighting should be extinguished or reduced as activity levels decline.
2	Moderate Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to moderate light levels. Lighting may typically be used for safety and convenience but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.
3	Moderately High Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting is generally desired for safety, security and/or convenience and it is often uniform and/or continuous. After curfew, lighting may be extinguished or reduced in most areas as activity levels decline.
4	High Ambient Lighting	Areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security and/or convenience and it is mostly uniform and/or continuous. After curfew, lighting may be extinguished or reduced in some areas as activity levels decline.

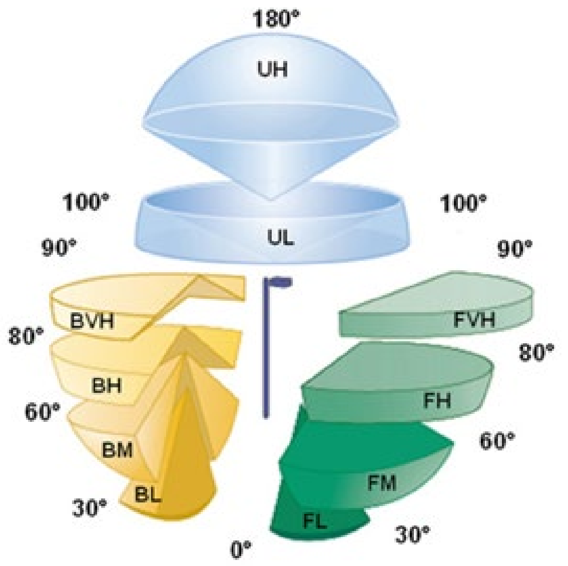


Figure 7.1. Graphical depiction of the IES BUG rating system. Source: International Dark-Sky Association

prescriptions into a system whose broad uses are already well understood. For cities that adopt lighting zones, each land parcel is assigned a zone number for which the outdoor lighting policy allows or prohibits certain lighting practices. Exceptions are handled in the policy through a system that separately judges petitions for use of non-conforming installations.

The MLO also implements the Backlight-Uplight-Glare (BUG) rating system introduced by IES in 2007 and amended in 2011 (Figure 7.1). This scheme assigns allowable light emissions in three broad volumes of space around the luminaire and replaces the earlier IES cut-off rule describing the emission pattern of luminaires. The BUG scheme has the advantage of describing uplight in terms of absolute lumens instead of per cent of total lumens. This means that luminaires are judged by the real amount they will emit upwards. Note, however, that the cut-off principle is still widely used in many places, and is also followed in these guidelines.

The system consists of back light (B), up light (U) and front (F) light emission zones in which acceptable values are given. Each emission zone is further subdivided into regions defined according to the indicated angular ranges with respect to the local nadir (0º): very high (VH), high (H), mid (M), low (L).

Further features and innovations of the MLO include the following:

- Lighting controls are required for all lighting, including both timers and dimming capabilities
- Curfews for all lighting that involves lowering light levels at the curfew hour by at least 30%
- Total light emission restrictions for non-residential land parcels that can be determined using one of two methods
- Full shielding of all lighting and appropriate lumen limits for residential land parcels
- Guidance for lighting types only allowed by special permission, such as high-intensity sources, lasers, searchlights, outdoor athletic facilities and parking structures
- An amortization schedule for existing, non-conforming lighting
- Street and roadway lighting is not addressed in the main body of the document, but rather in an annex that gives specific prescriptions for this type of lighting.

Criticism and future of the MLO

Despite its ambitions, the MLO has had comparatively little impact in the US and Canada. It has seen almost no use in other countries. While its contents have no doubt influenced municipal codes in a number of US municipalities, very few cities or towns have adopted its text in any substantial way. Users have registered a number of complaints about the MLO to which they attribute its lack of widespread adoption. Its language is strongly oriented toward conventions of American law, which deter potential users elsewhere. Many users say that the MLO is too technical, and its provisions too complex, to be comprehensible by either elected officials or municipal staff when they consider writing local outdoor lighting policies. For instance, the performance method requires complex, computer-based calculations that pose a practical challenge. On the other hand, the MLO did not address spectrum/colour.

Some users complain that the MLO considers situations that are inappropriate or highly uncommon in very small municipalities, and therefore the MLO comes across as overkill. Others bristle at the highly prescriptive nature of the site limits for non-residential properties, asking instead for much simpler provisions. Lastly, the substance of the MLO in terms of limiting off-site impacts involves reliance on the BUG rating system. While well intended it has never enjoyed widespread public understanding or support.

An effort is underway to substantially revise or replace the MLO upon the mutual agreement of IDA and the IES. The issue will be studied to identify the shortcomings of the existing model policy and a set of recommendations produced to inform the revision or replacement process. Based on the lack of uptake even in North America, the conclusion is that there cannot be a truly universal model outdoor lighting policy. The details of legal requirements vary too much among countless individual jurisdictions worldwide. The success of any attempt to capture the underlying principles will depend strongly on the suitability of suggested language to the legal requirements of the jurisdiction in which it is applied. As a result, the best approach may be to start with a limited set of principles, such as those listed earlier in this chapter and in Chapter 5 on guidelines for outdoor lighting, and adapt them carefully to the needs of the local language, in both literal and legal senses.

Figure 7.2. Aurora display, Wood Buffalo National Park, Canada. Source: DarkSky

CHAPTER 8.

Closing remarks

The sea-bird wheeling round it, with the din
of wings and winds and solitary cries,
Blinded and maddened by the light within,
Dashes himself against the glare, and dies.

— The Lighthouse by Henry Wadsworth Longfellow, 1850

Beyond its immediate impacts, light pollution is a major signature of humanity's presence on the face of Planet Earth. The familiar satellite images of the Earth at night illustrate the scope of human activities, not just spatially but also in a temporal sense. It is worth reflecting on this when seeing such a picture, not just as something striking and dramatic, but sad and disturbing. If nothing else, consider that when looking down, whether from space, a plane or even a tall building, every point of light that you see represents a waste of energy. Unshielded, over-bright and continuous lighting adds up to at least one-sixth of all electricity use worldwide.

Environmental issues like climate change, acid rain, species extinction and habitat destruction generally require significant top-down, multilateral actions. These include treaties, laws and regulations to control large-scale pollution, to set emission standards, to curtail the international traffic of endangered species, or to develop pricing mechanisms to influence public behaviour and consumer choices. Light pollution is very different. Once the ecological consequences, energy waste and threats to human health are recognised, meaningful action can be taken from the bottom up. Much can be achieved in the long term by actions in our own homes and neighbourhoods, by managers of natural areas and by outreach and learning in schools and parks. Steady and sustained local actions will add up to significant regional, national and continental success. Changing light bulbs or luminaires to reduce blue spectrum, removing excess brightness, ensuring that artificial light goes only where is needed, adding timed or motion-detecting switches, and removing unnecessary light fixtures are all low-hanging fruit that are easy to grasp.

Like much else in the field of nature conservation, mitigating light pollution benefits from inexpensive collaboration. Conservation managers, amateur astronomers, educators, park visitors and environmental activists can, and often do, work together to restore and protect natural darkness, at minimal cost but with great social and environmental benefits. Organizations like the International Dark-Sky Association (IDA), Fundación Starlight and the Royal Astronomical Society of Canada (RASC) can provide practical guidance, especially through their dark sky place certification programmes. There are also many other groups and resources available through the Internet to guide those wishing to abate light pollution, especially the RASC/IDA Guidelines for Outdoor Lighting.

Appendices

The appendices give detailed technical information and guidance beyond the main body of this report. In each case, the reader is encouraged to consult additional online resources, especially since the science and technology of lighting and light pollution management continues to evolve. Citations are also included in the relevant chapters of this report.

1. IUCN Resolutions and Recommendations
2. Illumination levels and night vision
3. The spectra of common lamp types
4. Recommended luminaire types and mounting heights
5. Signage
6. Scales and units for measuring light pollution
7. Lighting recommendations for low ecological impact
8. Measuring equipment and protocols
9. Aspirational skyglow values for dark sky places

Appendix 1: IUCN Resolutions and Recommendations

IUCN's role

The International Union for Conservation of Nature (IUCN), founded in 1948, is composed of both governmental and non-governmental organizations and thus is in a unique position to reflect and promote the priorities of the global conservation community. With over 1,400 Member organizations, seven specialised Commissions composed of some 15,000 experts, and a Secretariat of a thousand staff posted in many countries, IUCN is a global authority on the status of the natural world and the measures need to safeguard it.

IUCN describes its role as "the only institution that brings governments and civil society together with one purpose: to advance sustainable development and create a just world that values and conserves nature. The Union's diversity, depth and reach give its decisions a powerful mandate and its actions profound impact."

IUCN's Member organizations, from over 160 countries, include States, governmental agencies at the national and subnational levels, NGOs large and small, Indigenous peoples' organizations, scientific and academic institutions and business associations.

Resolutions and Recommendations form the body of IUCN's general policy. These are formulated through an open consultative process involving the full IUCN membership with input from IUCN's seven commissions. They are considered and acted upon by the Members' Assembly, IUCN's highest decision-making body, which meets every four years as part of the IUCN World Conservation Congress. "Resolutions" are aimed primarily at IUCN itself; "Recommendations" are directed to other agencies, third parties or the world at large.

Light pollution

Until 2012, light pollution had not been the subject of IUCN Resolutions or Recommendations, or even mentioned in them.

For the Members' Assembly held that year during IUCN's World Conservation Congress in Jeju, Republic of Korea, a motion to adopt a Recommendation titled "Dark skies and nature conservation" was introduced by InterEnvironment Institute, a US-based IUCN Member, along with several cosponsors. The motion was based on the work of the IUCN Dark Skies Advisory Group, part of the Urban Conservation Strategies Specialist Group of the IUCN World Commission on Protected Areas. Below is the Recommendation that was adopted.

In 2020-21, the Members' Assembly held at the World Conservation Congress in Marseille, France, adopted a strong Resolution, "Taking action to reduce light pollution." Its lead sponsor was the French Foreign Ministry. See below for the text.

(For English, French and Spanish versions of IUCN Resolutions and Recommendations, visit the Resolutions Search page: https://portals.iucn.org/library/resrec/search)

Dark skies and nature conservation (2012)

IUCN Recommendation WCC 2012 Rec 183. The lead sponsor was InterEnvironment Institute on behalf of the IUCN WCPA Urban Conservation Strategies Specialist Group.

GIVEN that species and ecosystems function night and day, and that artificial light can interfere with organism and ecosystem functions;

UNDERSTANDING that the appreciation of cultural heritage sites in their authentic state, the enjoyment of landscape aesthetics, and a true wilderness experience may be diminished by outdoor artificial light, glare and sky glow;

RECOGNIZING that astronomy, both scientific and amateur, and night sky viewing by the general public are essential contributions to understanding and enjoying our natural world;

BEING aware that cultural traditions, mythology and ceremony throughout the world bear a close relationship to night sky phenomena; and

NOTING that energy efficiency, human health and personal safety are all enhanced by the use of proper lighting and diminished by excess lighting;

The World Conservation Congress, at its session in Jeju, Republic of Korea, 6–15 September 2012:

1. CALLS UPON environmental and natural resource management agencies to recognize that outdoor artificial light should be subject to effective standards in order to help restore and/or maintain the ecological integrity of natural areas and the commemorative integrity of cultural sites, to respect traditional beliefs related to the night sky, and to protect species and ecosystems everywhere;

2. SUGGESTS that urban and non-urban infrastructure management authorities regulate and control outdoor lighting in the areas under their jurisdiction so as to achieve just the right amount, spectrum and timing of outdoor lighting necessary for public use and safety;

3. ENCOURAGES natural area managers and non-governmental organizations to promote awareness of dark sky values and the need for and methods of reducing outdoor artificial light;

4. RECOMMENDS that universities, science-funding agencies, and scientific institutions foster and support research into the nocturnal aspects of biological and ecological function;

5. URGES protected area management authorities to develop visitor activities that lead to public appreciation and understanding of nocturnal ecology and the night sky; and

6. RECOMMENDS that protected area and other conservation agencies seek out opportunities to cooperate with scientific and amateur astronomy organizations and aboriginal peoples on optimum outdoor lighting design, darkness monitoring, delivery of visitor activities, and outreach related to the night sky, the nocturnal aspects of ecosystems and the importance of the night sky to traditional cultures.

Taking action to reduce light pollution (2020)

IUCN Resolution WCC 2020 Res 124. The lead sponsor was the Ministère des Affaires étrangères et du Développement international (Ministry of Foreign Affairs and International Development) of France.

NOTING that artificial night lighting has expanded considerably worldwide generating light pollution that continues to increase by an estimated 2 to 6 % per year, and reducing darkness everywhere including in protected areas;

NOTING that the impacts of artificial light at night affect many biological groups, both flora and fauna, vertebrate and non-vertebrate, and affect the functioning of ecosystems and the free services that they provide to human societies, including pollination;

RECALLING that a large proportion of animals live partially or exclusively at night and a daily period of darkness is essential for all living organisms to alternate periods of rest and activity;

RECOGNISING that the outdoor lighting alters the chronobiology of living organisms and their synchronisation with their environment, in animals and plants, for example for trees by delaying the fall of leaves;

RECOGNISING that artificial lighting disrupts the orientation of many animal species with severe adverse effects (marine turtles, migrating birds, etc.) and reduces the quality of habitats and connectivity within landscapes, with consequences for the viability of populations;

RECOGNISING that artificial lighting affects trophic relationships between species, increasing foraging time available for diurnal species while diminishing it for nocturnal ones and reducing the cover of darkness for both predators and prey;

NOTING that artificial light obscures the anti-predator, luring and courtship signals of diverse bio-luminescent organisms including fireflies and glow-worms;

RECOGNISING that the impacts of light wavelengths on biological groups are very diverse (e.g. orientation, growth, phototaxis, circadian clock, activity modification) and that a biological group can be affected by several types of impact;

RECOGNISING that some wavelengths have more impact on biological groups than others;

NOTING that the outdoor lighting fleet is now either gradually being replaced or newly installed using light-emitting diode (LED) technologies that can lead to an increase in lamp intensity and a significant proportion of blue in their light spectrum that presents a risk for living organisms and increases sky glows, and that finally often results in an increase in the intensity of light together with the energy savings they provide;

RECOGNISING that awareness of light pollution is still low among most states, local authorities and private actors;

ACKNOWLEDGING that the purpose of some lighting is to protect human life, as well as property;

NOTING the importance of urban development and the number of places lit at night with no purpose and their contribution to energy waste and then to climate change; and

NOTING that a volume on dark skies and nature conservation in the IUCN Best Practice Protected Area Guidelines Series is being prepared by the Dark Skies Advisory Group of the Urban Conservation Strategies Specialist Group of the World Commission on Protected Areas;

The IUCN World Conservation Congress 2020, at its session in Marseille, France:

1. CALLS ON the Director General to assist efforts of Members and Commissions to reduce light pollution;

2. RECALLS that it is everyone's duty to ensure the protection of the nocturnal environment;

3. CALLS ON all IUCN Members and agencies that manage land and water areas to develop, disseminate and implement engagement, education and outreach programmes to explain the harmful impacts of light pollution, the benefits of preserving natural darkness, and methods to reduce light pollution, with such programmes being directed at all appropriate stakeholders, including but not limited to, visitors, users, private and corporate residents;

4. ENCOURAGES authorities in charge of the planning and management of outdoor lighting to examine the utility of existing lighting and then i) to remove the unnecessary light points (i.e. those not necessary to ensure the safety of humans or property) and ii) to adapt the remaining lighting as closely as possible to the needs, incorporating several options:

> **a.** defining the useful illumination level, so as not to risk over-lightning, which may cause biodiversity perturbations;
>
> **b.** reducing the lighting time at night, in particular by switching off in the middle of the night;
>
> **c.** avoiding upward lighting by choosing a fixture with the light fully shielded and ground-level downward-directed;
>
> **d.** avoiding any illumination of a natural environment (unless safety is at stake);
>
> **e.** limiting the risk of glare for nocturnal species avoiding outdoor lights that exceed international agreed standards; and
>
> **f.** choosing wavelengths that have the least impact on terrestrial species according to the knowledge, which indicates to this day to favour amber lights with little blue;

5. RECOMMENDS that natural environments should not be illuminated in order to reduce or avoid pollution, unless safety is at stake;

6. RECOMMENDS that authorities identify, preserve and restore naturally dark infrastructure (i.e. ecological networks formed by cores linked by corridors which are both characterised by a natural level and periodicity of night-time darkness) to facilitate the functioning of healthy, species-rich nocturnal environments;

7. RECOMMENDS that agencies funding research support research and evidence synthesis on the effects of artificial night lighting on species and that research organizations and universities set up corresponding research programmes; and

8. RECOMMENDS that agencies raise awareness by collaborating with states, local authorities and private actors on educational programmes that address the effects of artificial night lighting and measures to reduce light pollution.

Note: The volume referred to in the preamble became the present publication.

Appendix 2: Illumination levels and night vision

There are two aspects to brightness, namely luminance and illuminance. Luminance is the amount of human-sensed light that is either emitted by a light source or scattered off a surface. It allows seeing a light source or lit surface. Illuminance is that portion of light that falls onto a given surface. However, if the luminance is excessive, it can produce enough glare to make it difficult to see the illuminated surface. The natural night environment is subjected to the light of the Moon on a monthly cycle. Seen from space its luminance is 6,000 cd/m^2 and illuminance 0.267 lux. From the ground through the Earth's atmosphere it has a maximum luminance of about 4500 cd/m^2, and its illuminance on level ground is only 0.1 lux (Table A2-1). This is enough to see while walking, but it is only one tenth of what is needed to read a map or instructions, hence the need for at least some artificial light at night.

Colour recognition is poor at less than three lux, but arguably unnecessary since colour is not required for most late-night activities. Human eyes do not perceive colours equally. Light with short wavelengths appears brighter than light of longer wavelengths. Comparisons show that blue light appears up to ten times more glaring than the comparable luminance of yellow or amber light. Therefore the light spectrum must be considered when assessing allowable brightness. If blue spectral components are present then the illumination should be lowered to minimise the debilitating effects of glare and its ecological impacts.

Table A2-1. The brightness range of human vision

Rod cells only, night		Mesopic, rods and cones		Cone cells only, day	
New Moon	0.001 lux	Reading limit	1–3 lux	Cloudy day	10 lux
Crescent Moon	0.01 lux	Reasonable colour vision	10 lux	Home	100 lux
Full Moon	0.1 lux				

Appendix 3: The spectra of common lamp types

The content of short wavelength light at night must be minimised to reduce its ecological and health impacts. Since technologies exist that emit no blue light, a lower limit of 500 nm should be required for the emitted spectrum of a light fixture, resulting in amber lights.

Incandescent lamps

These are thermal light sources in that they depend on the heating of a filament and a surrounding gas in a glass ampoule. Their colour temperature ranges from 2500K for a basic tungsten filament to about 3500K for halogen cycle lamps. Most of their emissions are in the long wavelength infrared with very little emitted in the blue part of the spectrum (Figure A3.1). This smooth emission band helps produce a yellow to amber colour, but our brains adapt to this, giving the naked eye the illusion of white light, but which is revealed to be yellow when taking photographs uncompensated for this spectrum, i.e. using daylight camera settings.

High intensity discharge lamps

A gas is excited to glow by an electric current. The mixture of gases determines the apparent colour of the light. Four common types are high-pressure sodium, low-pressure sodium, metal halide and fluorescent (Figure A3.2). These lamps generally show a spiky spectrum with varying amounts of blue light. This may range from zero for the low-pressure sodium lamps, to 10% for high-pressure sodium, to over 20% for metal halide.

Light emitting diodes

The light emitted by LEDs depends on their design. The most basic LEDs emit narrow spectral bands about 20 nm wide. This is so narrow that only a single type of cone cell in our retina can detect them, such as the light from narrow band red LEDs. A more common LED uses blue light to excite a phosphor which converts some of the blue light to longer (amber) wavelengths. More blue produces a higher apparent colour temperature. Spectrum A in Figure

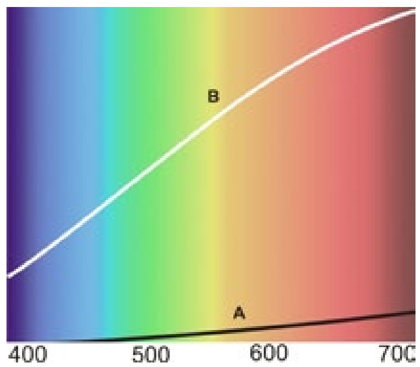


Figure A3.1. Incandescent lamp spectrum. Horizontal scale in nanometres. Vertical scale: relative luminance. A: 2500K for tungsten filament. B: 3500K for halogen cycle lamps. Source: Robert Dick

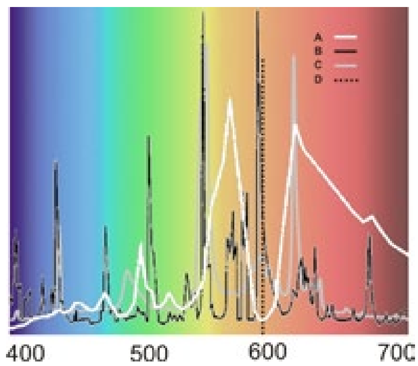


Figure A3.2. High intensity discharge lamp spectra. A high pressure sodium, B metal halide, C white compact fluorescent, D low pressure sodium. Source: Robert Dick

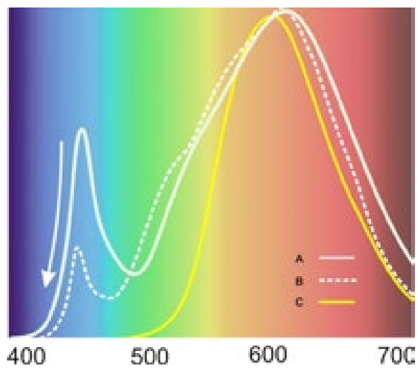


Figure A3.3. Light emitting diode spectra. Colour temperature represented by A is 4000 K, B 2700 K and C 2000 K. Source: Robert Dick

A3.3 corresponds to a colour temperature of 4000K. Varying the amount and type of phosphor produces a spectrum with different colours based on the ratio of blue to amber. Lowering the blue content reduces ecological impact, with no blue emission having the least impact.

Appendix 4: Recommended luminaire types and mounting heights

Luminaire distributors offer options and combinations to serve a wide range of applications. Many people find this confusing when trying to buy a light and therefore tend to accept the recommendations of the salespersons. However, the sales staff may not fully appreciate what type of luminaire will be appropriate for the application, or what is needed to minimise disruption to the natural environment. The customer often ends up buying a light that is too bright or that impacts a much wider area than needs to be illuminated.

The term luminaire refers to the whole light fixture, including the bulb, optics, power supply, internal electronics and physical support. Luminaires are designed to be seen. During the day they can be passive architectural components. At night they actively create a lightscape that transforms the natural night into an artificial display with a very different aesthetic. Most urban luminaires are designed to have maximum impact on the night environment by illuminating to the brightness suitable for daytime vision, thereby undermining the ecology of the night and blinding night vision. It is impractical to discuss all the different luminaires, so this appendix highlights their main features that have low ecological impact and that minimise the disruption to the aesthetics of the night.

There are many different designs of luminaires, and it is difficult to select one that suits a specific use. Here the focus is on elements of light fixtures that provide sufficient illumination and that reduce the use of electricity. How different luminaire components affect visibility and the impact of artificial light at night is explored. Each component affects night vision in different ways. In the context of minimizing the impact of artificial light on the environment, the range of options becomes much more focussed. The process begins by knowing the application, such as for pedestrian activity or vehicle movement. As well, the illumination level and power used can range over a factor of ten. Therefore there is a significant financial and ecological impact resulting from this decision.

Enclosure

The enclosure is engineered to protect the other components from the weather while allowing access to the interior for cleaning and maintenance. The enclosure affects the luminaire’s shielding characteristics but it is also designed for its daytime appearance. As discussed elsewhere in this report, shielding limits the extent of light trespass beyond the target area and the corresponding glare visible at a distance. It is critical that the luminaire is mounted so that the lens or flat window is horizontal, otherwise any shielding provided by the enclosure will be compromised. Unfortunately this principle is often ignored by the technicians who install lights, often tilting them to aim the light cone to the centre of a lit area, resulting in significant light shining above the horizontal.

There are two primary shielding classifications of which only fully shielded designs offer low-ecological impact. The Illumination Engineering Society (IES) refers to the fully shielded attribute as Full Cut-Off (FCO), with less than 10% of the total light emitted within 10° below the horizontal plane that passes through the bottom of the luminaire. While not an IES standard, an even more stringent shielding is called Sharp Cut-Off (ShCO) which reduces this down to less than 1%. Figure A4.1 illustrates unshielded and shielded examples. The left pane shows a typical example of a non-shielded enclosure. The light-dispersing lens extends below the opaque metal of the enclosure. This allows scattered light to be emitted above the horizon. This also creates glare at a distance, and light trespass. The middle pane shows a recessed lamp, but the structure of the enclosure reflects some of the emitted light in all directions. The right pane shows two FCO luminaires. They are characterised by a flat horizontal window at the bottom of the luminaire. When mounted correctly there is no up-light and glare is minimised.

Although meant to provide safety, bright isolated lighting can actually reduce safety and security by reducing visibility into the less illuminated periphery (Figure A4.2). Shielding would help in this situation, but even brightly illuminated ground can cause enough glare to blind our more sensitive night vision from seeing beyond the pool of light. A high brightness contrast reduces the ability to see into the dimmer areas.

Optical components

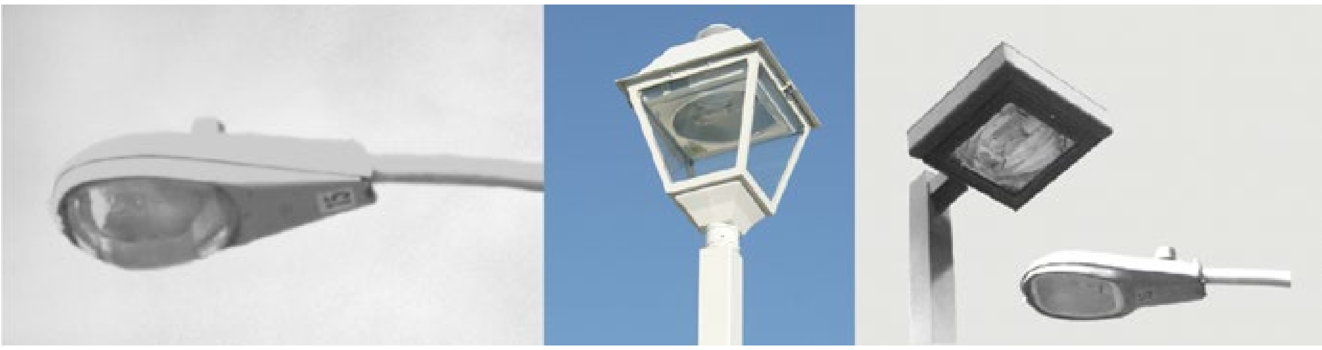
The hardware and poles for mounting luminaires are often more expensive than the luminaire itself. For economy, the light distribution should be as wide as needed with as few luminaires as practical. But the wide spread of light should also be carefully controlled as it may increase glare and light trespass. These competing tasks are performed by the optical components recessed in the luminaire.

Simple luminaires have minimal optics. They emit their light equally in all directions. This leads to a steep decline in illumination with distance (Figure A4.3). The brightest patch is directly below the luminaire. At a distance of only 1.5 times the mounting height the illumination drops to 1/6 compared to the nadir. This is so low that the bright patch overwhelms the scene, giving the appearance of pools of light separated by darkness. This relatively poor light distribution means that a pole spacing of three mounting heights is needed, increasing the number of poles and the cost of the system. Two effects define the light distribution: the distance from the lamp to the ground, and the angle at which the emitted light hits the ground. The illumination is reduced to 1/4 for each doubling of the distance. Also, the illumination angle gets smaller with distance. These combine to produce a rapid fall-off in the illumination with distance from the lamp.

The basic distribution of light can be improved by the luminaire optics. Optical components are able to throw more light into the periphery to level out the illumination and allow a wider separation of poles, i.e. fewer lights. Optical components can use refractive lenses and reflective mirrors. These components can either scatter or focus the light into the desired illumination pattern. An example of refractive scattering optics is the left image in Figure A4.1. It produces a large illuminated area but cannot prevent light from scattering beyond the target area, which produces glare.

Examples of reflective optics are shown in the right-hand pane of Figure A4.1. The curvature of the mirror behind the lamp produces more uniform illumination. For single light applications (Figure A4.4), this uniformity provides two additional benefits. More useful illumination is spread over a wider area, and the mounting height can be lower to further reduce glare off-site. Creating better uniformity of the illumination pattern has a side effect. Casting more light

Figure A4.1. Unshielded and shielded enclosures. On the left is a common unshielded luminaire known as a cobra lamp. Source: Robert Dick



to the periphery also means the emitted light is closer to the horizontal, requiring better shielding to reduce the glare of this low-angled light and requiring more careful installation to ensure the luminaire is mounted level.

Lamp

The lamp is the source of the emitted light and has evolved over the last one and half centuries. It began with incandescent lamps that used metal filaments heated to incandescence by electric current. But they convert only a few per cent of the electrical energy into visible light. The rest is lost as heat. Although still in use today, they are being replaced by light emitting diodes (LEDs) that produce over fifty times more light per watt than incandescent lamps. Even though typical LEDs have multiple diodes, they are inherently very small and their light is easily controlled by optics. In contrast, the light from the other lamps is generally scattered. Large light sources such as fluorescent lamps can interfere with the light reflected from a rear-reflector. Compact fluorescent lamps are a popular replacement for incandescent lamps, but some light is lost in the curled glass ampoule. A high intensity discharge lamp is about the size of a human fist. Its relatively high electricity-to-light efficiency has made it a very successful lamp for high-luminance applications such as street lighting. Common lamps are illustrated in Figure A4.5.

In both refractive and reflective optics, the smaller the light source the more effective the shielding and focussing of the light. LEDs are much smaller than typical light bulbs and their light can be more accurately controlled by optical components. In many cases each LED within a single lamp array has its own lens, which focuses light to specific patches in the illumination pattern, enabling uniform illumination with minimal glare and light trespass. LED technology has surpassed the efficiency of fluorescent and high intensity discharge technologies and is rapidly becoming the default for both indoor and outdoor lighting.

Mounting height

The cost of light poles is usually more than the cost of the light fixture. Mounting the fixture at a greater height will reduce the number of poles required, and hence the costs of the lighting system, even though more powerful lamps are needed for a given brightness of illumination. However, this also increases the visibility of the installation at a distance. The inevitable scattered light is also seen farther away and undermines the effectiveness of the shielding.

A common application for tall pole-mounted luminaires is roadway and pathway lighting. High poles reduce their number, but this also increases the width of the illuminated track. Therefore, high pole-mounted luminaires should have more aggressive shielding than those on shorter poles. Extra shields can be mounted to the exterior of the luminaire. They can be as simple as metal skirts that extend farther below the bottom of the fixture, or louvres that restrict the light away from the road or path without limiting the illumination along the track itself.

Nearby buildings, trees and bushes can augment shielding. Taking advantage of these requires that the luminaire be mounted below the height of the structures or vegetation. A maximum mounting height of six metres is recommended. Any higher and trees and small buildings will not be as effective at limiting the extent of scattered light.

Figure A4.2. Poor shielding casts glare and creates pools of darkness. Source: Robert Dick

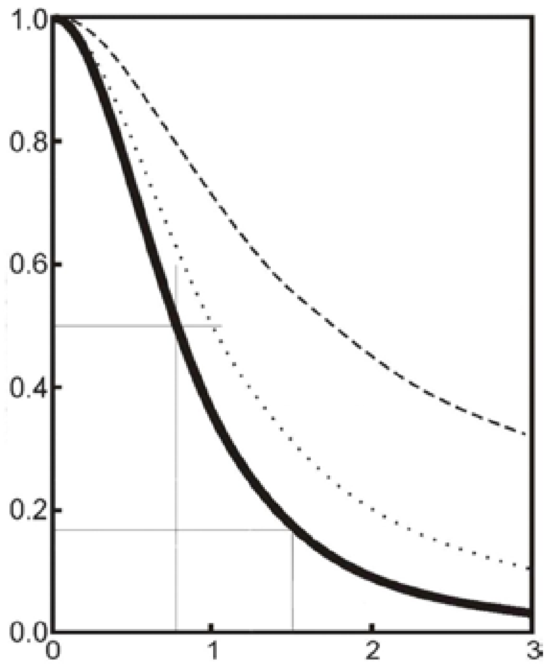


Figure A4.3. Illumination from a basic lighting system with no optics. Vertical scale is the relative illumination. Horizontal scale is the distance from the nadir in relation to the height of the pole. Source: Robert Dick

Figure A4.4. ILED luminaire with a lens array to control light distribution. Source: Robert Dick

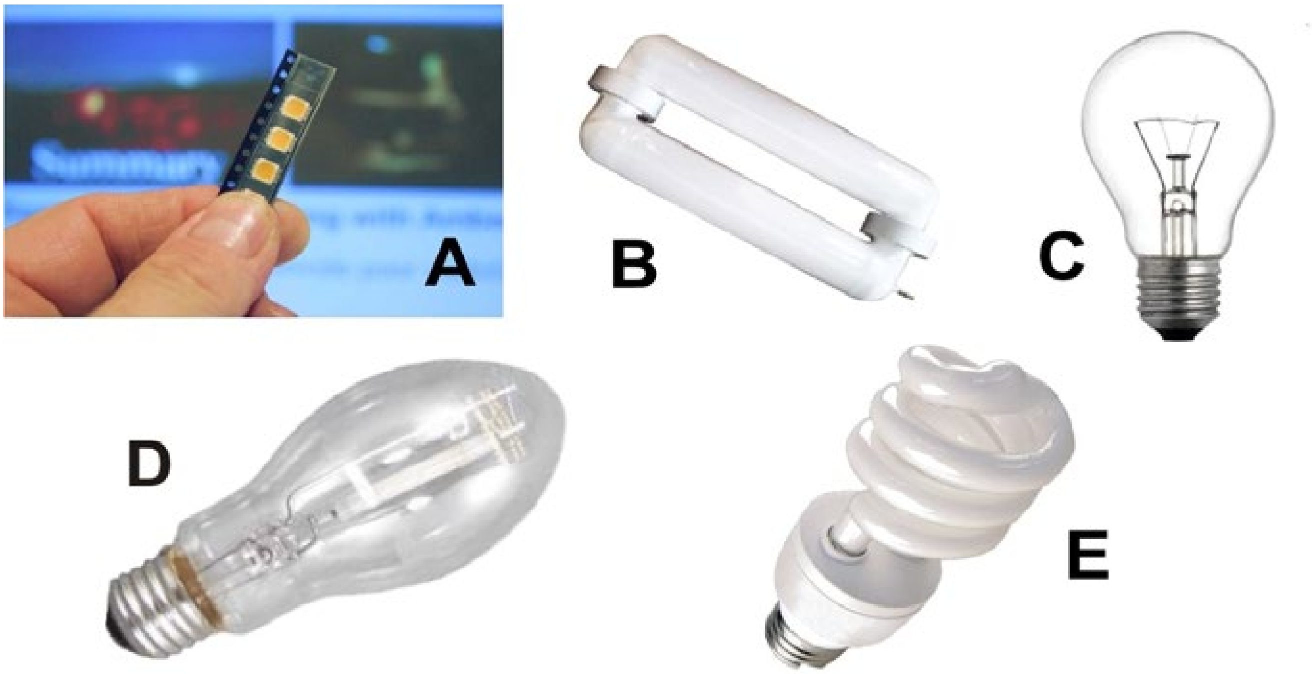


Figure A4.5. Assortment of common lamps. A LEDs, B fluorescent, C incandescent, D high intensity discharge, E compact fluorescent. Not to scale. Source: Robert Dick

Power supply

The power supply and control circuits turn the light on when needed and dim it or turn it off when the need is low or absent. Lamps and luminaires are available with a wide range of power. The greater the power the brighter the lamps, but more light does not mean better visibility. Bright light usually results in visibility over a limited area with the periphery appearing too dim to permit fair visibility.

Humans have evolved good night vision, so walking outdoors does not need more than a few times the brightness of the full Moon, 0.1 lux. However, activities that exceed walking speed require more than natural ambient light. Depending on the reflectivity of typical paper, reading instructions on a map requires a minimum limiting illumination level of 1 to 3 lux, ten or more times that of moonlight.

The luminance of the illuminated ground also allows one to see the ground. For a given amount of incident light (lux), the ground luminance (candelas/m^2) will vary widely depending on the nature of the surface. The proportion of light scattered off the ground (albedo) can range from 10% for green grass to 70% for sand and 90% for snow.

This ground reflectivity impacts the living things. Therefore the wattage of the lamp should be tailored to the surface cover.

Table A4.1 shows how much power is needed for a few different lamp types to comply with the ecologically based recommendations in this report. The power required is significantly lower than what is often assumed for urban areas. This is because consideration is given to the use of night vision. The power levels are for mounting heights that correspond to five typical applications. The power levels are further given for the two levels of average illumination, 1 lux and 3 lux, which also correspond to applications typical of dark sky parks. Other levels may be interpolated. To use the table, first identify the application, mounting height and situation, then select the corresponding column for the height and the row for lamp type.

Table A4.1. Power levels for lights at five mounting heights

Mounting Height and Applications	1m Bollard or pathway		2.5m Over door		3m Under eave or canopy		4m Overhead pathway		6m Road parking lot	
Lux (lumens/m2)	1	3	1	3	1	3	1	3	1	3
LED power (watts)	0.1	0.2	0.4	1.2	0.6	1.7	1	3.1	2.3	6.9
HPS power (watts)	High pressure sodium. Do not use.									
CFL power (watts)	Compact fluorescent. Do not use.									
Incandescent (watts)	0.6	1.9	4	12.1	5.8	17	10	31	23	69
Average lumens	6.4	19	40	120	58	174	103	309	231	694
Notes	Pick desired mounting height, then desired lux, then match to preferred light source. Assumes 50% fixture efficiency and no backlight, since backlight is lost. Approximate coverage area = 4.5 times mounting height squared. Assumes 3:1 uniformity, i.e. maximum lux is 1.5 average, minimum lux 0.5 average. Incandescent lights may still have a use where low brightness is required.									
Assumed efficacy: LED 150 lumens/watt; Incandescent 16 lumen/watt.										

Figure A4.6. Sample illumination schedule for low ecological impact. Actual times will vary depending on time of year, daylight versus standard time, latitude, etc. The graph starts at sunset and ends at sunrise. The raised part indicates desired lighting for evening activity. The lower part to the right represents lights turned off or dimmed during dark time, the rest of the night till sunrise. Source: Robert Dick

These powers are only approximate because of the range in ground reflectivity as well as the type of fixture, shielding, optics and degree of in-use degradation. Therefore lamps should not use more than twice these levels. These values also assume the use of night vision, so all lamps must only emit amber light.

An electronic controller can automatically schedule the light. Humans are the only creatures that want artificial light, so it should be minimised or turned off when activity is low or people are not present. A sample schedule is shown in Figure A4.6. The actual brightness should depend on how vigorous are the active and sedate periods. To suit typical activity, the controller should turn the luminaire on at sunset. Then, after a period of activity, typically into the late evening, the luminaire can be dimmed or turned off. At sunrise the luminaire should be turned off. This schedule is based on the plasticity of animal behaviour for about two hours after sunset. After sunset the luminaire is set to its maximum required illumination, then is dimmed to less than 20% after most human activity ceases in the late evening. It then automatically turns off at sunrise.

Appendix 5: Signage

This appendix describes several techniques to optimise sign readability while minimising impacts. There are two main types of signs. Either they provide information or assist navigation. The latter are critical to travel even in natural areas, whether on foot or by car. All signs must be seen and readable, so they may require more than ambient light. However, most signs are intended for use during the day and are not necessary at night, such as those that direct people to facilities that are closed after dark. In some cases other techniques may be employed that avoid the need to illuminate signs.

Readability

Signs take incident light (illuminance) and scatter it (luminance) to be readable. Either the light source must be bright or the reflectivity of the sign must be high. It is more energy efficient, and reduces ecological disruption, to use less bright incident light but more reflective lettering.

Messages should be printed in high contrast with the background surface. Many urban signs tend to have dark letters on a bright background, like a printed page. However this does not work well at night because the large bare surface area produces high luminance and glare making the message harder to read. It is better to have light coloured lettering on a dark surface, as illustrated in Figure A5.1.

Readability is improved with uniform illumination. However, for ecological reasons the illumination should not extend beyond the sign area. Therefore the lamp should be well baffled to prevent light shining away to the side of the sign.

It is not practical to make night signs that do not need some artificial illumination. The ability to read small letters with our night vision is about one tenth than during the day. A reasonable compromise is to provide sufficient illumination for the use of day vision without undermining the more sensitive night vision. This compromise is satisfied by using amber illumination of about 1 to 3 lux.

Figure A5.1. Sample sign with direction and information, letters and pictographs. Note the use of bright information letters and symbols against contrasting darker backgrounds. Source: Robert Dick

Contrast

Some signs take advantage of contrasting colours rather than bright illumination. Signs may have relatively dark surfaces with brightly coloured letters (Figures 3.1 and A5.1). This makes the sign less intrusive during the day. However, colour recognition at night is relatively poor even at 3 lux. To improve readability, contrasting colours should also have different perceived brightness such as a dark background and a bright yellow or white message. In this way, reflected light carries the message that can be detected by night vision and the darker surface provides sufficient contrast for readability without the glare of a white background.

Illumination

New luminaires and internally lit signs typically use white LEDs. White light is very disruptive to the environment and undermines our sensitive night vision. A sign lit in white will render the surrounding area relatively dark. Filtering out the blue light components will both reduce the impression of glare and will help preserve night vision. With the blue light removed, the illumination appears amber while allowing readability with over 90% of day vision cells.

Filtering out the blue part of the spectrum can be done by using amber or yellow lights or filters. Retrofitting filters can be achieved using commercially supplied plastic film available in relatively large sheets at low cost. The plastic film should be protected from the weather between transparent plates or mounted inside the fixture and away from hot light sources.

Other options are to use fluorescent lettering on signs so they will stand out even when not in the centre of a flashlight beam. Retro-reflective surfaces may be considered, but most retro-reflective paints reflect light back along the incident light path, so may not be readily visible to a visitor's eyes if it is illuminated from the side, above or below. The facility manager should verify that retro-reflective signs are readable in the context of the application.

Mounting

Pedestrian signs should be mounted below eye level so they will be noticed by walkers with flashlights that are usually aimed toward the ground. These signs should be passive, in other words, with no active lighting, and designed for illumination by personal flashlights. This reduces the need for running electricity to low traffic areas. For readability, as previously noted, the colour of the message and the perimeter of the sign should be in white or a light colour that contrasts with a dark background. This helps visitors avoid walking into the edges of a sign.

Passive indicators

Many parks make paths with dark asphalt. While this is inexpensive and suitable in daylight, the surface is not visible during the night without artificial lighting. Asphalt reflects only about 5% of the incident light, causing it to blend in with peripheral vegetation. Fortunately there are several inexpensive techniques that simply show the path. Some parks use light grey or white crushed stone (Figure 5.7) which appears to glow under moonlight or starlight. Such stone paths will reflect over four times as much ambient light as vegetation, making the path and its surface appear to stand out from the surroundings without artificial light.

Figure A5.2.
Phosphorescent road markers at Mont-Mégantic.
Source: Guillaume Poulin

Alternatively, the edges of asphalt paths may be painted white or yellow to help reflect ambient nocturnal light or flashlights. Since night vision is more sensitive to short wavelength light, white lines will be seen farther into the distance. A path may also be delineated by phosphorescent disks that store energy during the day and re-emit it as light throughout the night. These are used at the Mont-Mégantic Observatory in Québec, an RASC Dark-Sky Preserve and IDA International Dark Sky Reserve (Figure A5.2).

These techniques help to convey information and make navigation in the dark much easier, and they help to preserve the ambiance of the night. Passive techniques will reduce the need to buy and install luminaires and cut the cost of electricity and maintenance of electric cable and outlets.

Appendix 6: Scales and units for measuring light pollution

Introduction: skyglow and scattering

This appendix concerns light pollution scales and the units used to measure and express the amount of light pollution present. The night sky has a certain natural brightness known as airglow, due to emissions from the air molecules in the upper atmosphere. These are generally the recombination of photo-dissociated nitrogen and oxygen molecules to form nitric oxide and reactions involving the hydroxyl radical. The brightest emission is green (558 nm) light from oxygen atoms in a layer 90 to 100 km high. Vibrationally and rotationally excited hydroxyl radicals emit red and infrared in a narrow layer centred at about 86 to 87 km. Another airglow component is yellow light from sodium atoms in a layer at 92 km. There are also weak blue emissions from excited molecular oxygen at about 95 km. Airglow also arises from zodiacal and auroral light.

Light pollution increases the sky brightness as a result of Rayleigh scattering by air molecules and Mie scattering by aerosols. Both these mechanisms scatter the shorter blue wavelengths of light pollution more effectively than longer visual wavelengths and thereby contribute to skyglow. This brightens the sky with the consequence that fewer stars can be seen with the naked eye.

The magnitude of a star is a measure of its apparent brightness as seen by the human eye. In the second century CE Ptolemy devised a scale of magnitudes with the brightest stars being set at magnitude one and the faintest at the naked eye limit being at magnitude six. The scale of magnitudes has since been more precisely defined and extended to fainter stars seen only by telescopes. The brightest star in the sky, Sirius, is now recognised to be magnitude -1.46. There are 9,110 stars in the Yale Bright Star Catalogue (Hoffleit & Jaschek, 1991) which lists all stars brighter than magnitude 6.5, the approximate naked eye limit. The magnitude scale is now described as an inverse logarithmic scale whose logarithmic base is the fifth root of 100 (= 2.512).

Naked-eye limiting magnitude (NELM) method of estimating light pollution

Using the magnitude scale, the number of stars of different magnitudes visible on a clear moonless night is given in Table A6.1.

In practice in most locations, stars are only visible down to about 10 degrees above the horizon, so at a given location only about 40% of a full sphere can be seen, i.e. less than a hemisphere. The last column in Table A6.1 gives the total number of stars visible above 10° elevation to different limiting magnitudes for a dark-sky location.

Even in the best conditions few people can see below magnitude 6.5. More likely the practical limit is closer to 6 even in the absence of light pollution and on a clear, moonless night. The numbers are very approximate but indicate that at any given place and time and with the naked eye, one is unlikely to see more than three and a half thousand distinct stars. In this context, distinct means not counting the billions of stars that make up the visible bands of the Milky Way.

If there is light pollution, the brighter sky lowers the limiting magnitude to perhaps 3 or 4, typical of many urban environments. Table A6.1 shows that under such conditions only a few hundred stars can be detected with a naked eye. In the most light-polluted cities the limiting magnitude might be zero or one. In that case, the number of stars visible could be in the single digits.

For those who know their stars, or have a star-finder gadget, or have a star map showing magnitudes, instead of counting stars they can find the faintest stars visible under given conditions, and thereby estimate the sky brightness. For every ten-fold increase in sky brightness, the limiting magnitude will reduce by 2.5 magnitudes, for example, it would go from 6.5 to 4.0, which corresponds to about ten times fewer stars being visible.

The limiting magnitude depends on many factors in addition to light pollution, including sky transparency, phase and position of the Moon, time since sunset or before sunrise, age of the observer and whether the observer's vision has completely adapted to the dark. These factors combine to make star counts or estimating the limiting magnitude a very crude indicator of light pollution.

The Bortle Scale

This scale of night sky brightness was introduced by the American amateur astronomer John Bortle (2001). It uses a nine-point scale for the night sky at a given location (Figures 1.2 and A6.1). Class 1 is an excellent dark sky site, 2 a typical truly dark site, 3 a rural sky, 4 a rural-suburban transition, 5 suburban, 6 bright suburban, 7 suburban-urban transition, 8 city sky, and 9 inner site sky.

Table A6.1. Number of visible stars in the sky as a function of magnitude

Magnitude	Range	Number of stars per range	Cumulative stars	Number of stars visible above 10° elevation
-1	-1.50 to -0.51	2	2	1
0	-0.50 to +0.49	6	8	3
1	+0.50 to +1.49	14	22	9
2	+1.50 to +2.49	71	93	38
3	+2.50 to +3.49	190	283	116
4	+3.50 to +4.49	610	893	368
5	+4.50 to +5.49	1929	2822	1165
6	+5.50 to +6.49	5946	8768	3621
7	+6.50 to +7.49	17765	26533	10958
8	+7.50 to +8.49	51094	77627	32059

Source: Haworth (2003).

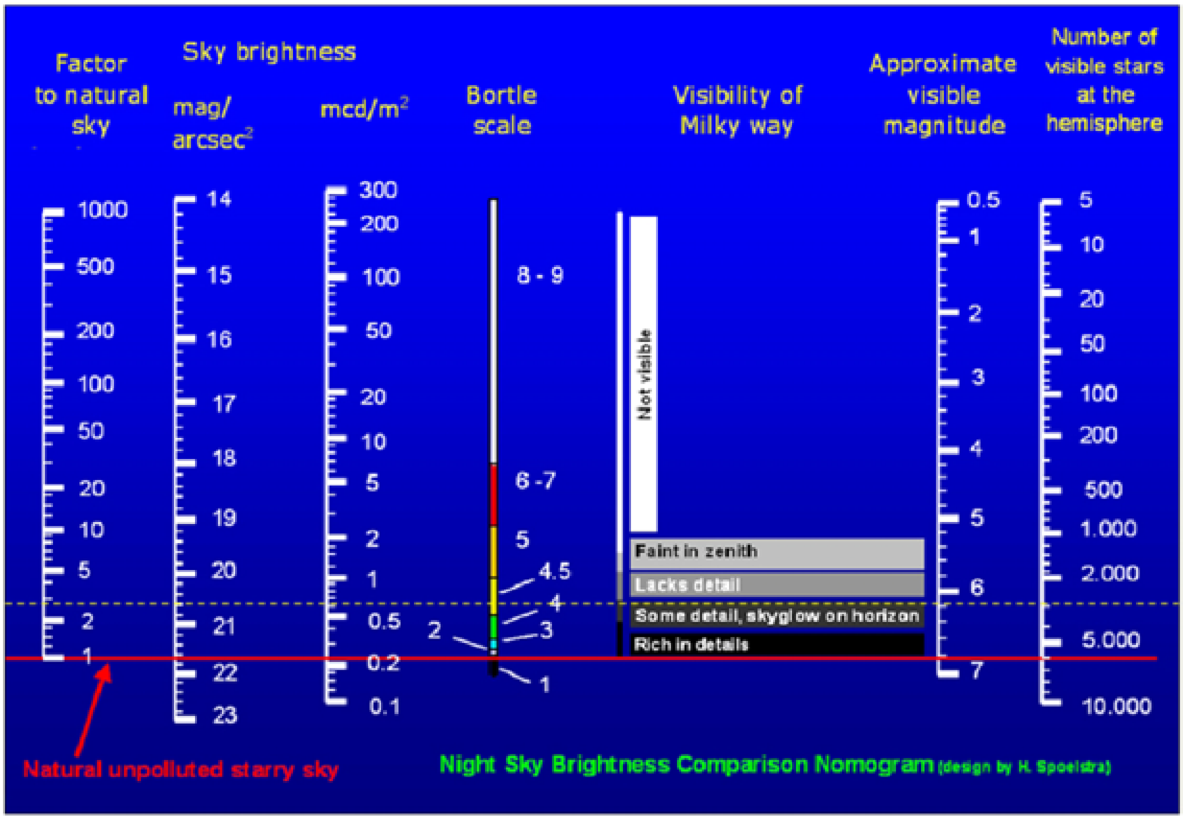


Figure A6.1. Sky brightness nomogram, comparing Bortle to other scales. This nomogram illustrates the Bortle scale in column 4. It relates it to sky brightness in millicandelas/m^2, the visibility of the Milky Way, in column 5, limiting visual magnitude in column 6, and the number of stars visible above the horizon in column 7. Source: Spoelstra (2002)

Bortle recognised the limitations of the naked-eye limiting magnitude method of categorizing sky brightness. However, he ascribed approximate limiting magnitudes to each class on his scale. They range from 7.6 to 8.0 for Bortle class 1, to 4.0 for the most light-polluted inner-city skies, Bortle class 9. For many observers these magnitude limits are unrealistically faint. Even in the darkest of locations, few people have the visual acuity to detect eighth or even seventh magnitude stars. Certainly such faint stars would require exceptional eyesight, a fully dark-adapted eye of a younger person, and experience in using averted scotopic (night) vision, consciously seeing objects away from the centre of the eye. This is where the more sensitive peripheral regions of the retina are used, where there is a greater density of scotopic cells (rods).

In one sense, the Bortle scale does not make estimating sky quality and darkness any easier, as it only ascribes an arbitrary class number to a given site and set of observing conditions. Determination of the Bortle class relies partly on the limiting magnitude of stars, though it also is based partly on the visibility of faint natural sources of light such as the zodiacal light, gegenschein and airglow, and on diffuse celestial objects such as star clusters, nebulae and galaxies. In the final analysis, the Bortle class is a subjective, qualitative estimate by a given observer and location. It is not a quantitative objective measurement.

Magnitude per square arcsecond

A quantitative way of expressing night sky brightness is to use physical units for surface brightness, given that the night sky can be considered as a hemispherical surface with the observer at the centre. One popular unit of night sky brightness is magnitudes per square arcsecond (mag/arcsec2). First consider a star of magnitude 21, which is exactly a million times fainter than a star of magnitude 6. Although stars are essentially point sources of light, one considers their light being spread over a tiny square in the sky, whose side in angular measure is 1 arcsecond, or 1/3600 of a degree. A hemisphere comprises 2.7 × 1011 square arcseconds, so 1 arcsec2 is a very tiny area of the sky. If the whole sky had the same surface brightness as this tiny area, then the sky brightness would be written 21 mag/arcsec2. This corresponds to a fairly dark sky, about 4 on the Bortle scale. This is shown in the second column of Figure A6.1.

The darkest possible skies are close to 21.8 mag/arcsec2. This represents a typical value of the natural airglow which is always present, though somewhat variable in direction and in time. A sky which is 20 times brighter than this natural airglow background would be at about 18.7 mag/arcsec2 and this would be a typical value in many urban environments. If the sky is one hundred times brighter than the natural airglow background, then the brightness would be about 16.9 mag/arcsec2, a value found in the central areas of the world's large cities with Bortle class 8.

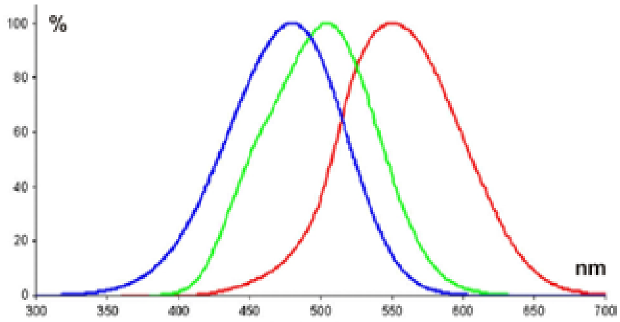


Figure A6.2. Photopic, scotopic and retinal ganglion cell response curves. The vertical scale is per cent absorption in the human eye. The horizontal scale is wavelength in nanometres. Red curve: photopic absorption. Green: scotopic absorption. Blue: photosensitive retinal ganglion cell absorption. Source: Cuthbertson *et al.* (2009)

Magnitude per square arcsecond is the most common sky brightness unit used in considering sites for dark sky certification. A guide to acceptable levels is shown in Appendix 9, Aspirational Skyglow Values for Dark Sky Places.

The units of magnitudes per square arcsecond are an inverse logarithmic scale, and therefore not very intuitive for those not used to dealing in stellar magnitudes. Sometimes it is more convenient to use a linear scale in which larger numbers represent brighter skies. One such unit is S10, the number of tenth magnitude stars per square arc minute, assuming their light were spread uniformly over this small area. One S10 unit corresponds to 27.78 mag/arcsec2, which is darker than any night sky. Typical airglow will be at about 145 S10, while zodiacal light would be 60 S10 and scattered starlight would contribute just 15 S10. A very polluted sky at 16.7 mag/arcsec2 would correspond to about 27,000 S10.

Photometric units

Another quantitative way of expressing night sky brightness is to give the brightness in Système International (SI) units, as used in the physical sciences. The SI unit that records the amount of visual light emitted per second is the lumen. Visual light means the light to which a human's day-time eyes are sensitive, using the cones in our retinas. These wavelengths are centred on yellow light at around 550 nm wavelength.

A typical household light bulb might emit one to several thousand lumens. If all the photons emitted had the same yellow wavelength of 550 nm, then 683 lumens corresponds to one watt (1 joule per second of radiated energy). In practice, light sources radiate over a range of wavelengths, and photons at greater or lesser wavelengths contribute less to the lumen count. Hence there are fewer lumens per watt of photon energy at wavelengths other than 550 nm, or more watts per lumen (Figure A6.2).

The calculation of the luminous flux in lumens requires folding the radiated flux with the photopic, or visual, distribution curve which peaks in the yellow, and integrating over wavelength. The photopic visual curve, using colour-sensitive cone cells, is shown as the red curve in Figure A6.2. Of course at night one is more probably using dark-adapted or scotopic vision involving the rods, being the cells in the retina which are sensitive to brightness. Scotopic vision has a peak sensitivity in the green at 505 nm, as shown by the green curve in Figure A6.2.

Table A6.2. Typical illuminance values from natural and artificial light sources

Source	Lux	Source	Lux
Full sunlight	103000	Partly sunny	50000
Cloudy day	1000 to 10,000	Full Moon under clear conditions	0.1 to 0.3
Quarter Moon (half disk seen)	0.01 to 0.03	Clear starry night	0.001
Overcast night sky (no ALAN)	0.00003 to 0.0001	Operating table	18000
Brightly lit office	400 to 600	Most homes	100 to 300
Typical main road street lighting	15	Typical urban side street lighting	5
ALAN urban skyglow (ground level illuminance scattered back)	0.15		
Source: Rich and Longcore (2006).			

Light sources often radiate in all directions and the luminous intensity determines the lumens radiated into unit solid angle, and is measured in candela (cd), which is a lumen per steradian. For some light sources, such as a laser, the distribution of intensity is highly directional, so the intensity has a high value in that direction, but low or zero elsewhere.

The surface brightness of a light-emitting surface is measured in candelas per square metre, where 1 cd/m^2 is sometimes referred to as a nit. For the night sky, the microcandela per square metre is a more useful unit (μcd/m^2). Natural skyglow is about 174 μcd/m^2 (Falchi et al., 2016). Any sky brightness above 1000 μcd/m^2 is significantly light-polluted. The nomogram Figure A6.1 column 2 shows the typical sky brightness values in mcd/m^2. Note that elsewhere in this report μcd/m^2, i.e. 1000 mcd/m^2 is used. The mean surface brightness of the Sun's disk is about 1.6 × 109 cd/m^2, though it varies over the solar disk, being higher in the centre.

One property of the surface brightness of any radiating surface is that its value is an intrinsic property of the radiating surface and is independent of distance. The surface brightness of the Sun would have the same value for an observer on Mars or any other planet in the solar system. It would just look smaller. For that reason, specifying the surface brightness of the night sky does not require specifying the distance to the light scattering hemispherical surface of the sky.

The surface brightness of the night sky (S) in μcd/m^2 can be calculated from a given value in visual magnitudes per square arcsecond. The equation relating these two parameters is:

$$S\,(\mathrm{mcd/m^2}) = 1.08 \times 10^8 \times 10^{(-0.4\,\mathrm{mag/\square''})}$$

For example, the full Moon has a magnitude of -12.7, giving a surface brightness of 4,471,000,000 μcd/m_2, or 4,471 cd/m^2.

Another important photometric unit is the lux, which is a measure of illuminance of light onto a surface such as the ground. One lux is one lumen per square metre. Table A6.2 shows typical illuminance levels in natural and artificial lighting. Full sunlight casts 105 lux on the ground, while a full Moon in a clear sky gives nearly 0.1 lux. A clear starry night gives only a millilux, mainly from starlight.

Photopic lumens, scotopic lumens and melanopsin lumens

As already discussed, the lumen, or photopic lumen, is a measure of visual light energy per second radiated from a source. However, for a dark-adapted observer interested in observing stars, scotopic vision is employed, using rods in the retina instead of cones, and the scotopic sensitivity curve, the green curve in Figure A6.2, should be used to weight the spectrum of the light. For a partially dark-adapted human observer, both rods and cones are used for vision, and this is the so-called mesopic vision with a peak sensitivity at about 530 nm. Note that other species perceive different spectral ranges and sensitivities.

The scotopic curve can be used to calculate scotopic lumens that record light levels to which a dark-adapted eye is sensitive.

$$\Phi_{\mathrm{phot}} = 683 \int_{400}^{750} F(\lambda).V_{\mathrm{phot}}(\lambda).\,d\lambda$$

$$\Phi_{\mathrm{sco}} = 1700 \int_{400}^{750} F(\lambda).V_{\mathrm{sco}}(\lambda).\,d\lambda$$

where the spectral energy distribution, F(λ), of the light source is in watts per unit wavelength interval, where Vphot(λ) and Vsco(λ) are the photopic and scotopic sensitivity functions, and where Φphot and Φsco are the quantities of photopic and scotopic lumens. The multiplying factors 683 and 1700 indicate the number of lumens per watt respectively for photopic and scotopic vision. The larger number for scotopic vision is the result of the greater sensitivity of a dark-adapted eye.

For any given lamp type and hence spectral power distribution, F(Å), the quantities Φsco and Φphot can be calculated and the scotopic to photopic ratio found, often written as S/P. The ratio is a measure of the relative physiological responses of the eye to scotopic and photopic vision. For blue-rich LED lights (CCT of 5000 K), the S/P ratio is 2.0. For many white fluorescent lamps it is about 1.7, for tungsten halogen lamps 1.32, for standard incandescent lamps 1.26, for warm white fluorescent lamps 0.98, for high pressure sodium lamps 0.76, and for low pressure sodium lamps 0.38.

For night sky observations, skyglow pollution is mostly light from the sky coming from lamps on the ground and scattered by aerosols. Except for monochromatic low pressure sodium lights, the scattered skyglow will be bluer than the light radiated directly by the lamps, a result of the strong wavelength dependence of the scattering by air molecules and by aerosols. Calculating night sky brightness in terms of scotopic lumens per steradian per square metre (scotopic nits) is therefore a complicated process, as it would require knowing the lamp type for every luminaire that sends light into the sky, and adjusting the S/P ratio for the scattering. The S/P ratio of the polluted night sky is always about 45% greater than that of the lamps causing the pollution.

The retina contains a layer of ganglion cells immediately in front of the rods and cones used for vision. A few per cent of the ganglion cells, perhaps 4,000 to 8,000 of them, are sensitive to blue light in the range 446 to 477 nm with a peak in the sensitivity function, Vmel(Å), at about 465 nm (Figure A6.2). The photosensitive ganglion cells are not used for imaging. Rather, they send signals to the suprachiasmatic nucleus (SCN) in the brain. This is the organ which entrains our circadian rhythm to the alternating day-night cycle of nature. The photosensitive retinal ganglion cells are also used for controlling pupil diameter by dilating the pupils in low light levels. The SCN in turn sends a signal to the pineal gland where the hormone melatonin is produced at night. Even low light levels of a few lux at night can suppress melatonin production (Dauchy, 2014). This contributes to sleeplessness, tiredness, stress and possibly depression, obesity and diabetes. Melatonin also helps combat some cancers, especially breast and prostate cancers. Thus depleted melatonin production at night is a health hazard. To simplify, if you can read, it is too bright for good sleep.

Measuring pollution from blue light therefore is of great interest for maintaining good human health. For this purpose melanopsin lux has been proposed as a unit of blue luminous flux. Melanopsin lux can be defined by the equation

$$\Phi_{\mathrm{mel}} = 4.213 \int_{400}^{750} F(\lambda).\, V_{\mathrm{mel}}(\lambda).\, d\lambda$$

and from that a corresponding melanopsin to photopic ratio equal to Φmel/Φphot, or simply M/P, for any light source can be obtained. M/P ratios correlate strongly with colour temperature of a light source and vary from about 1.7 at CCT of 2000 K, corresponding to low pressure sodium lamp, to 5.9 for a CCT of 7500 K for a very blue-rich LED. In effect, M/P ratios are a bit like a logarithmic colour index widely used in astronomy which compares the blue spectrum to the green and yellow spectrum. M/P ratios represent a simple blue to visual ratio, i.e. not logarithmic, and are weighted according to the relative response of the light sensitive cells in the eye. Melanopsin lux are useful for calculating the effects of blue light at night on the human body through disruption of hormone production.

More information is given by Berman and Clear (2019), though they adopt a slightly different definition of the M/P ratio, which is 4.213 times smaller than that given here. One watt of radiated flux at 465 nm corresponds to 4.213 melanopsin lux.

Appendix 7: Lighting recommendations for low ecological impact

Table A7.1. Lighting recommendations for low ecological impact. Source: Guidelines for Outdoor Lighting (RASC, 2020)

Rationale	Shielding	Spectrum	Brightness	Schedule
General appearance	No up-light. No light beyond area of activity.	Amber.[1] Easy on the eyes. Preserves night vision. Less attractive to flying insects.	Preserve night vision. Reduce reflected up-light. Reduce bright patch below fixture (good uniformity).	Turn off when not needed. Dim after hours.
Luminaire[2]	FCO or ShCO shielding. Add shields to non-shielded fixtures. Mount fixture level.	λ >500 nm with Phosphor Converted LEDs, Narrow-band Amber LEDs, or use filters.[3] If light contains more than 2% <500 nm, use ShCO shielding and set to 40% GOL brightness.	Roads 3 lux (max). Parking lots 3 lux (max). Paths 1 lux (max). Buildings 3 lux (max). Uniformity better than 6:1 (max/ave[4]). Luminance per luminaire beyond illuminated area <1 cd/m^2.	Timers turn off fixture at end of scheduled activity. Dimmers set to <50% after hours when pedestrian traffic is still expected.
Ecological impact	Restrict contamination to the area of human activity. Keep foraging areas dark. Preserve animal night vision. Do not enhance predator advantage.	Minimise attraction of flying insects. Minimise impact on aquatic species. Minimise distraction of migratory birds. Minimise loss of animal night vision. Reduce plant stress from seasonal change.	Minimise scattered light beyond area of activity. Maintain natural night beyond illuminated area. Discourage human activity in wildlife habitat.	Dim or turn off lights when nocturnal wildlife is foraging or hunting.
Fixture selection parameters	FCO or ShCO shields. After-market shields.	Use LEDs with CCT <2200K. Use amber bulbs, or mount amber filter[1] inside fixture window.	Paths <10 lumens/10m^2. Areas of human activity <300 lumens/100m^2. Roads and parking lots <3 lux.[2]	Programmable timers. Motion detectors. Dimmer controls.
Installation requirements on-site	Add shields to non-shielded fixtures. Mount fixture level.	Use amber bulbs, or cover fixture window with amber filter.	N/A	

1. Amber means light with a spectrum greater than 500 nm.
2. Specifying maximum, not minimum illumination, encourages uniform illumination.
3. For example, [bhphotovideo.com/c/product/43872-REG/Rosco_RS1511_15_Filter_Deep.html].
4. Reference: IES RP-08 for low-density low-speed (local) traffic, R1 pavement.

Appendix 8: Measuring equipment and protocols

Unihedron Sky Quality Meter

A sky quality meter (SQM) is an instrument for measuring the luminance of the night sky. It is typically used by amateur astronomers to quantify the skyglow aspect of light pollution. The Unihedron SQM is the most widely used device for taking scientific-quality measurements of sky brightness. It is a hand-held device with a 9V battery and measuring approximately 9.5 x 6.0 x 2.5 cm (Figure A8.1). There are several models measuring different angular areas of the sky. They are also available with automatic measurement and data logging or data communication capabilities. SQM-L is recommended, where L represents the addition of a lens to gather light from an approximately 20° cone-shaped field of view. SQM-L models have options for being hand-held or in a fixture, and with USB connectivity.

An SQM displays units of magnitudes per square arcsecond as favoured by astronomers and described in Appendix 6. It gives readings between 16.0 and 22.0, i.e. from brighter to darker skies. Current versions have only one spectral band of observation. Unfortunately this can produce misinterpretations when the light pollution changes from sodium-vapour lamp (more yellow) to LED (more blue component).

The International Dark-Sky Association provides a basic protocol for conducting an SQM survey [https://darksky.org/resources/guides-and-how-tos/how-to-conduct-a-night-sky-quality-survey/]. An SQM is easy to use. Simply hold the device above your head, point the photometer to the zenith, and click the button. The screen will then display the sky brightness in magnitudes per square arcsecond. Take at least six measurements per location per visit, discarding the first measurement. Report all the remaining measurements.

Always take measurements with a clear, open, cloudless sky when the Moon is below the horizon and the Milky Way is not prominent. Never take a measurement directly underneath a light source or anything that might block the sky. Measurements taken while the Moon is visible will not accurately reflect the natural darkness of your location. Similarly, keep in mind the impact of twilight on your measurements. Only take readings under conditions of astronomical darkness, meaning that the Sun is at least 18º below the local horizon, or about one hour after sunset. Information for times of the beginning and end of astronomical twilight at your location on and on a given night can be found at [timeanddate.com/astronomy/search.html]. You may need to know your latitude, longitude and local time offset from Coordinated Universal Time (UCT) or Greenwich Mean Time.

Decide on at least several sites for measurement. Include areas that will be the darkest and the brightest to achieve a comprehensive survey of your area. Table A8.1 shows a typical format for planning and recording the number and location of a set of measurements. For example, include measurements of the borders, active areas and presumed darkest areas of a park. These data can then be organised into a table and a map showing approximate location of measurements.

Figure A8.1. Unihedron Sky Quality Meter. Source: IDA

Figure A8.2. TESS-W Photometer. Source: TESS

TESS

The Telescope Encoder and Sky Sensor (TESS, Figure A8.2) is an inexpensive but reliable photometer developed for the Spanish-led Stars4All initiative and used to measure night sky brightness (Zamorano et al., 2016). The bandpass is extended to the red with respect to that of the Sky Quality Meter (SQM). TESS connects to a router via wifi and automatically sends the brightness values to a data repository using Internet of Things protocols. It includes an infrared sensor to estimate the cloud coverage. It is designed for fixed stations to monitor sky brightness. It can also be used in local mode connected to a computer

Table A8.1 Sample table for recording SQM measurement.

Location*	High	Low	Mean	Date	Time	Description	Notes
Coordinates			to 2 decimals	yy/mm/dd	hh.mm	Buffer Zone	Main star party site
Place name						Footbridge	Nearby light unshielded
Map reference						Core Zone	Darkest Area
* Could be latitude and longitude, preferred, or a specific place name or a local map sheet reference.Source: IDA							

to gather data from a moving vehicle. It is currently in use mainly by professional networks, but there are plans to extend its use to citizen-based networks.

All-sky Camera

The US National Park Service (NPS) developed a camera system to collect high resolution images of the night skies (Duriscoe et al., 2007). The NPS All-sky-Camera, Figure A8.3, is composed of a commercial Nikon lens, a filter wheel with V and B band filters, and a full-frame monochromatic charge-coupled device. The V band filter only lets visible light pass through, allowing the detected signal to closely represent what human eyes see. Images taken in the B band are used to quantify the amount of blue light. Comparing images in both bands can be used to characterise the colour of the skyglow.

Figure A8.3. NPS All-Sky Camera. Source: NPS

Because each image has a limited field of view, 45 images are taken to cover the entire sky. Each image has a 24° x 24° field of view with a resolution of 1.4 arcminutes per pixel. A robotic mount is utilised to automatically position the camera for each image. A complete image set takes about 40 minutes to complete, with exposures first in V and then B bands in each camera position. The images are processed using NPS software to generate a complete hemispheric view of the night sky with a resolution of 0.05 degrees per pixel. The basic data reduction includes bias and dark subtraction, flat fielding and detector linear response correction. Absolute brightness and position calibration are done by using the standard stars captured in the images. The images in a set are then stitched together to form 360° panoramic images in V and B bands. Next, a natural sky model can be built in the V band based on the time and the location of the observation (Duriscoe, 2013). The components of a natural sky model include zodiacal light, the Milky Way, airglow and atmospheric diffused light. The modelled natural brightness can be subtracted out to obtain panoramic images and measurements in the V band with anthropogenic light only, as exemplified in Figure A8.4.

Sky Quality Camera

The Sky Quality Camera system was developed by Andrej Mohar of Euromix Ltd. based in Ljubljana, Slovenia. It consists of a digital SLR camera with hemispherical lens, together with custom image processing software. Quantitative data produced includes sky brightness (visual magnitude), luminance, illuminance and colour temperature. The process of measuring sky quality starts with photographing the night sky during astronomical darkness. Photographs are made with the camera mounted and levelled on a tripod. The images are geo-referenced with GPS data and are processed with the Sky Quality Camera software, resulting in quantitative sky maps (Figure A8.5). These maps can be shown in various projections. Within the software, light pollution sources and skyglow can be added to the quantitative maps and the full-sky photographic image.

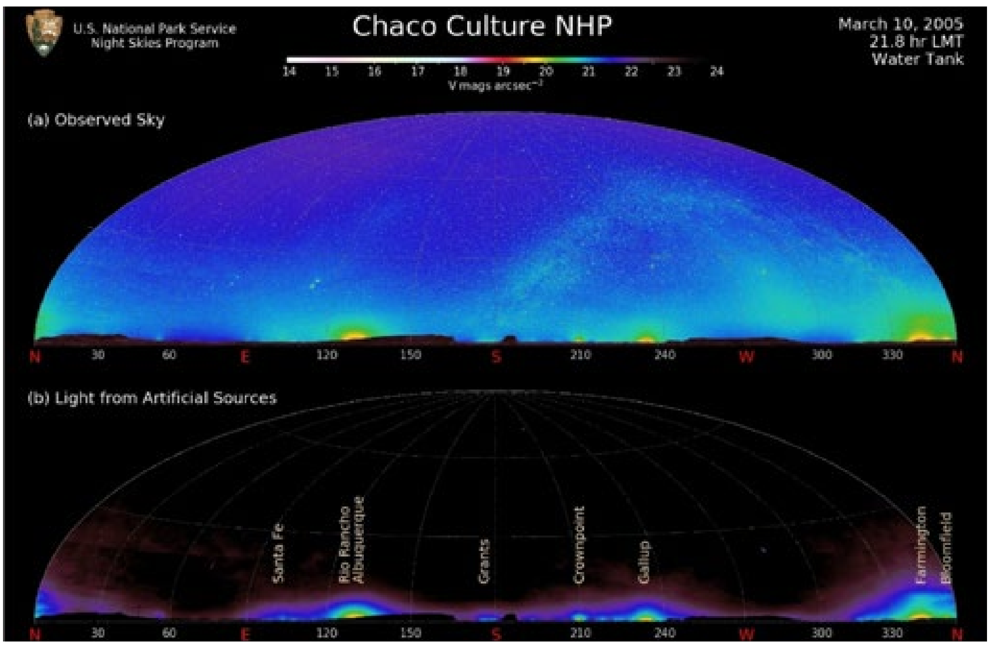


Figure A8.4. Night sky panoramic mosaic using the NPS All-sky Camera system. Chaco Culture National Historic Park, US. Source: US National Park Service

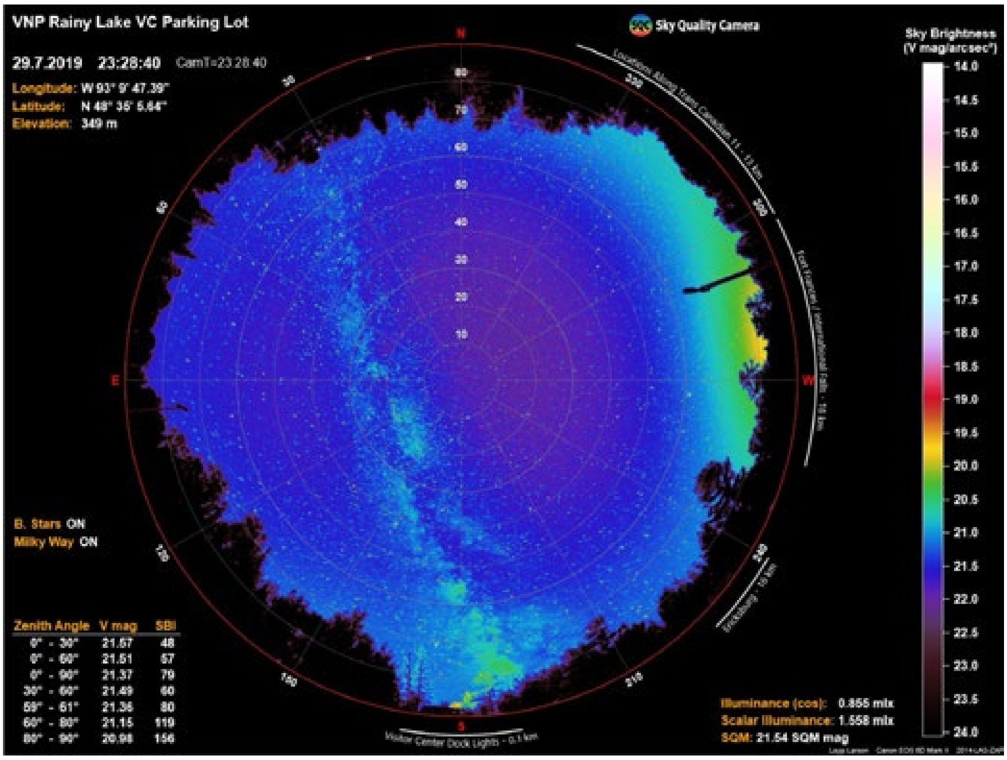


Figure A8.5. Night sky image using a Sky Quality Camera. Voyageurs National Park US. Source: US National Park Service and IDA

Appendix 9: Aspirational skyglow values for dark sky places

While protected area and conservation managers have no direct sway over external light pollution sources and the resulting skyglow, one may ask what levels of sky brightness might be hoped for in different dark sky place classes. The International Astronomical Union and the International Commission on Illumination recommend that for astronomical observatories it should be no more than 10% additional brightness beyond the natural background airglow at a zenith of angle 45°. Airglow normally ranges between 30 and 190 µcd/m². Adding other natural light sources, natural skyglow is usually between 200 and 250 µcd/m² (Cayrel et al., 1980; Falchi et al., 2016; John Hearnshaw, University of Canterbury, and John Barentine, IDA, personal communications). Choosing the middle of this range, rounding it and extending it to the DSAG dark sky place classes, Table A9.1 shows recommended values as a basis for seeking support for reducing light pollution. Of course, less skyglow and higher star magnitude values (fainter) are always desirable. See Figures 1.2 and A6.1 for the Bortle and other sky brightness scales.

Table A9.1. Aspirational skyglow values for DSAG dark sky place classes

These values are at the zenith on a clear moonless night, and without the Milky Way also at the zenith.

Class	Class name	µcd/m²	mag/sq. arc sec	Bortle	IDA thresholds
1	Astronomy site	<260 (1.10 x skyglow)	>21.7	1	Sanctuary >21.5
2	Park	<360 (1.5 x skyglow)	>21.4	3	Park: >21.2
3	Heritage site	<660 (2.75 x skyglow)	>20.7	4.5	N/A
4	Outreach site	<480 (2 x skyglow)	>21.0	4	N/A
5	Reserve	<480 (2 x skyglow)	>21.0	4	Reserve core: 21.2
0.25	Urban Community	<1000 (~4 x skyglow)	>20.3	4.5	Community: N/A
6b	Rural Community	<750 (~3 x skyglow)	>20.6	4.5	Night Sky Place: N/A

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Author profiles

As noted on page iv, in June 2023 the International Dark-Sky Association changed its name to DarkSky, and references to IDA below are to DarkSky.

All authors are present or past members of the Dark Skies Advisory Group, part of the Urban Conservation Strategies Specialists Group of the IUCN World Commission on Protected Areas.

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Karen Treviño holds a Juris Doctor degree from the Washington College of Law, American University, and a Bachelor of Arts in Communication, Michigan State University. For seventeen years she was Senior Counselor to the Assistant Secretary for Fish, Wildlife and Parks, Department of the Interior. In 2014 she became the Manager of the Natural Sounds Program in the National Park Service, and subsequently Chief of its Natural Sounds and Night Skies Division.

Clive Ruggles is Emeritus Professor of Archaeoastronomy in the School of Archaeology and Ancient History at the University of Leicester, UK. He has conducted research in many parts of the world and has published numerous books, papers and articles including the three volume *Handbook of Archaeoastronomy and Ethnoastronomy* (Ruggles, 2014), for which he was editor-in-chief. He has ongoing fieldwork and analysis projects in Hawaiʻi, Peru and Europe and is a leading figure in the joint initiative of the UNESCO World Heritage Centre and the International Astronomical Union working to recognise, protect and promote the world's most important astronomical heritage sites. In 2017 he was awarded the Royal Astronomical Society's Agnes Clerke Medal for a lifetime of distinguished work in the overlapping areas of archaeology, astronomy and the history of science.

Catherine Rich holds an A.B with Honours from the University of California, Berkeley, a J.D from the UCLA School of Law, and an M.A in geography from UCLA. She is co-founder and executive officer of The Urban Wildlands Group, one of the first nonprofit organizations in the US to focus on nature in cities. She co-authored the landmark article Ecological Light Pollution (Longcore & Rich, 2004) and co-edited the book *Ecological Consequences of Artificial Night Lighting* (Rich & Longcore, 2006). Together, these publications define a rapidly growing research area in ecology.

Travis Longcore is Associate Adjunct Professor at the University of California, Los Angeles (UCLA) Institute of the Environment and Sustainability and Science Director of The Urban Wildlands Group, a Los Angeles-based conservation nonprofit organization. He co-authored the landmark article Ecological Light Pollution (Longcore & Rich, 2004) and co-edited the book *Ecological Consequences of Artificial Night Lighting* (Rich & Longcore, 2006), which together have come to define a rapidly growing research area in ecology. He holds an Honours B.A in geography from the University of Delaware, and an M.A and Ph.D in geography from UCLA.

John Hearnshaw earned a Ph.D. in 1972 in astronomy at the Australian National University, Canberra. He then had two research fellowships, first at the Paris Observatory, 1972-74, and second at Harvard University and the Smithsonian Institution, 1974-76. He then joined the University of Canterbury at Christchurch, New Zealand, became a full Professor in 1995 and retired in 2014. For 25 of those 38 years he served three periods as Director of Mt John Observatory at Lake Tekapo, developing new instruments and training M.Sc. and Ph.D. students in astronomy. He has written six books on astronomy, most of them on the history of stellar astrophysics in the last 200 years. He continues to work for the International Astronomical Union (IAU). From 2003 to 2012 he chaired the IAU Programme Group for the Worldwide Development of Astronomy. This entailed travel to many developing countries to give lectures, to advise on teaching astronomy and to promote research collaborations. He is now the IAU Vice-President on the Executive Committee. He chaired the Aoraki Mackenzie International Dark Sky Reserve Board from 2012 until June 2020, continuing as a board member. The Board is a charity that helps maintain dark skies in the Mackenzie District in the central South Island of New Zealand. His latest book is the *New Zealand Dark Skies Handbook*, published in June 2021.

István Gyarmathy is one Hungary's leading experts on light pollution, its ecological consequences and dark sky park issues. He takes part in Hungarian initiatives to reduce the impacts of light pollution on protected natural areas. He uses his long experience to help establish and manage dark sky parks and raise awareness, and works on other issues like light pollution monitoring, legislation and astrotourism. He obtained his M.Sc. and post-graduate degrees at the University of Debrecen and is in Ph.D. studies at University Eötvös Loránd. István is Vice President of the Magnitúdó Astronomical Society, the founder and secretary of the Rónaörzö Society for Nature Protection and a research associate at the University Eszterházy, Eger. He is a senior advisor in nature protection and the dark sky park coordinator of the Hortobágy National Park Directorate.

Robert Dick is an aerospace engineer with a graduate degree in aerodynamics. He has been a member of the Royal Astronomical Society of Canada (RASC) since 1969. During the 1970s he was a prominent member of the RASC Ottawa Centre's Radio Telescope Team, responsible for the mechanical design and engineering of two large parabolic antennas. For a number of years it was the largest amateur radio telescope in the world. At the observatory's original site south of Ottawa, he co-discovered the breakup of Comet West in March of 1976 and the change in period of the Cepheid CY Aquarii. In the 1980s he was the project engineer on a major remote sensing satellite programme. In the early 1990s, when light pollution began to compromise astronomy observations, he led the development of a Canadian Light Pollution Abatement programme, promoting the use of shielded roadway light fixtures by the City of Ottawa, and was asked to expand the programme to the national scale. A highlight was the development of the Canadian Dark-Sky Preserve Program and the designation in 1999 of Torrance Barrens Conservation Reserve, Ontario, Canada's first dark sky preserve. He subsequently helped to develop the science of scotobiology, and developed and authored the Parks Canada guidelines for outdoor lighting for park facilities. This was adopted in 2008 by the RASC as the lighting protocol for dark sky preserves and by the International Dark-Sky Association in 2012 for its dark sky places programme. Throughout this time, he has remained active in astronomy outreach and education, developing a set of star maps for schools and outreach events, an educational TV programme *The Celestial Sphere*: *a Narrated Tour of the Night Sky*, and teaching astronomy and astrophysics courses at both university and college level.

Adam Dalton managed the International Dark Sky Places Program of the International Dark-Sky Association (IDA) untill April 2021. He is a graduate of the University of Utah's Master of City and Metropolitan Planning Program, where he specialised in ecological planning and interdisciplinary sustainability. While at Utah, he worked closely with the University's Consortium for Dark-Sky Studies to conduct comprehensive dark-sky lighting inventories for various municipalities. As an undergraduate, Adam attended Grinnell College with a double major in Economics and Mandarin Chinese.

John Barentine is the IDA's Director of Public Policy. He earned a Ph.D. in astronomy from the University of Texas at Austin and previously held staff positions at the National Solar Observatory, Apache Point Observatory and the Sloan Digital Sky Survey. Throughout his career, he has been involved in education and outreach efforts to help increase the public understanding of science. He is a member of the American Astronomical Society and the International Astronomical Union, and a Fellow of the Royal Astronomical Society. The asteroid (14505) Barentine is named in his honour. His interests outside of astronomy and light pollution research include history, art and architecture, politics, law and current events.

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