Ecological and astronomical aspects of light pollution

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Editor's note

Artificial lighting, which brightens the darkness of night, is often considered a symbol of modernity and one of the main achievements of civilisation. Sometimes, the level of development of various parts of the world is even assessed on the basis of satellite images of the Earth's surface taken at night. Artificial lighting extends our daily activities while giving a sense of security. However, night lighting, formerly used sparingly, is now often abused due to the development of light sources, which are cheap with regard to both production and operation. Those light sources which are incorrectly constructed or are too bright are harmful to the natural environment and to people. This applies not only to cities but also to remote protected areas, illuminated by artificial light dispersed in the atmosphere. Moreover, such scattered light also makes it difficult, and often even impossible, to make astronomical observations.

The overall detrimental effect of artificial lighting on the natural environment has been called "light pollution". A distinction can be drawn between two types of light pollution: "astronomical" light pollution, affecting the quality of astronomical observations; "ecological" light pollution, affecting the natural environment. This distinction is reflected in research and scientific studies, which usually fall within one of these categories.

This multi-author monograph aims to present different points of view on the really common problem that is light pollution. Scientists representing various disciplines discuss miscellaneous aspects of the discussed issue.

In the following chapters, the authors, working in the fields of biological science or medicine, as well as astronomy or architecture, show how light pollution affects both the natural environment and everyday life. Several chapters are also devoted to initiatives aimed at limiting this phenomenon and creating conditions in which humanity would be able to continue to enjoy the benefits of night lighting while minimising its impact on the natural environment.

This monograph is the first in Poland describing so many aspects of light pollution. It owes its creation to the cooperation of many people. In particular, thanks are due to Anna Młyńska for coordinating the entire editing process.

Editor,
Tomasz Ściężor

1. LIGHT POLLUTION AND NOCTURNAL MAMMALS – CASE STUDY: THE INFLUENCE OF ARTIFICIAL LIGHT ON INSECTIVOROUS BATS

Bronisław W. Wołoszyn[1]

Light is a complex environmental factor. The amount of radiant energy, its wavelength and the resulting colour of light are all factors affect living organisms, both plants and animals. Circadian rhythms of the day-night changes of light in plant and animal physiology have been well known for a long time. This phenomenon is called "photoperiodism".

The rotation of the Earth causes the daily change of light (day and night) while the change in the inclination of the Earth axis in relation to the Sun is the cause of the annual cycle of seasonal climate changes. The Moon orbiting around the Earth provides illumination at night and is this an additional factor affecting the activity of living organisms. Both plants and animals have evolved their biological rhythms as an adaptation to these environmental changes. This allows them to synchronise themselves with the environment, ensuring that their functioning is efficient, useful and safe.

Diurnally active plants and animals, as well as humans, suffer from the scarcity of darkness at night because the lack of full darkness caused by artificial lighting disrupts their rhythm of activity. Similarly, nocturnal animals dependent on the darkness are exposed to danger of loss of life because the intense light at night disrupts their ability to acquire food and hinders migration and reproduction. Straca et al. (2020) proposed the acronym ALAN (Artifical Light At Night) for this phenomenon in their important publication.

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1.1. Background information about bats

Thus far, over 1200 different bat species have been described inhabiting all continents (excluding Antarctica). There are large bats with a two-metre wingspan and small species with bodies measuring only 3 cm long. Their food is also very varied, ranging from pollen and nectar to fish, frogs and lizard, for example. Over 70% of all bat species are insectivorous.

Bats are generally small, endothermic mammals. On the left in Fig. 1.1 is the grey long-eared bat (*Plecotus austriacus*); this species mainly lives close to forested areas. On the right is the brown long-eared bat (Plecotus auritus). Most common species live in the large open roof spaces of older buildings. They feed in woodland, parklands and gardens and hibernate in a wide range of underground sites. They usually choose cold sites and are tolerant of temperatures close to 0°C. They have high metabolic rates and large food intakes. However, food supply for insectivorous bats is usually seasonal. For this reason, animals such as bats and other small insectivorous mammals inhabiting the temperate climate regions need to choose adequate strategies in order to survive during the periods when food is scarce.

Fig. 1.1. Two species of long-eared bats living in Poland (photo: B.W. Wołoszyn)

Among some survival strategies are switching to an alternative and more plentiful food supply, storing food in time of plenty, migrating to where there is food or lastly, hibernation. Most bats from temperate zones across the globe choose the last of these options. We can name such a survival strategy as "escape in time", this is in contrast to the survival strategy used by a lot of migratory bird species, namely "escape in space" (Wołoszyn 2008; Wołoszyn and Murariu 2016).

Bats have relatively few natural enemies. They are sometimes caught by predatory birds and can also be prey to small predators, e.g. martens. There is a possibility that some snake species (e.g. Aesculapian snake) are in same circumstances able to hunt sleeping bats. Parasites, both internal and external, are also a limiting factor to a number of bats. However, the biggest enemy to the bat population is man and his "civilisation"; among such factors, we should mention artificial light.

1.2. The bats of Poland

There have so far been over twenty-five bat species confirmed in Poland and these belong to two families: horseshoe bats (*Rhinilophidae*) – two species and vesper bats (*Vespertilionidae*) – twenty-three species. For the purpose of comparison, in Europe there are over forty-nine species of bats and they belong to four families: horseshoe bats (*Rhinolophidae*), vesper bats (*Vespertilionidae*), long-winged bats (*Miniopteridae*) and free-tailed bats (*Mollosidae*). In the temperate climate of the Palearctic ecozone, where Poland lies, several bat species reach the northern limit of their range. Close to this boundary, the sensitivity of the population of bats to even the smallest of changes in the environment is significant; this includes the influence of artificial light.

1.3. Bat hibernation

For bats hibernating, it is particularly important to find a safe and ecologically adequate hibernaculum. Before they began to use man-made shelters, bats used two main types of roosts: caves and trees. Most of the winter roosts of bats in Poland are found in underground structures. In the regions where caves are abundant like the Jura Krakowsko-Częstochowska Highland, or the Tatra mountains, bats use them for hibernation. In the remaining regions of Poland, where caves no exist, bats frequently underground structures built by humans use for hibernation, such as tunnels, cellars, abandoned fortifications etc., such as the famous "Nietoperek" which is a several-kilometres-long artificial fortification system in western Poland, close to Międzyrzecz (Fig. 1.2).

Fig. 1.2. A medium-size vesper bat (most probably Daubenton's bat) hibernating just behind a "courtain" of stalactites (photo: B.W. Wołoszyn)

Bats prepare for hibernation by building large reserves of fat. To achieve this many bats appear to depend more on regular post-feeding torpor than increased feeding activity. In temperate climate regions, it occurs mainly at of the end of the astronomical summer and at the beginning of autumn (September-October in the northern hemisphere).

A bat will typically enter hibernation with fat reserves of 20-30% of body weight (Altringham 1996). The most important stimulus for the onset of hibernation itself appears to be the ambient temperature. Once hibernation begins, changes of physiological factors are profound. Heart rates measured during hibernation range from 10-16 to 42-62 beats per minute (depending on the bats species) in contrast with 250-450 beasts at rest, and 800 beats during flight. Only the vital organs such as the brain and heart retain their normal, regular amount of blood supply. The oxygen consumption rate of a hibernating bat is over 100 times slower than that of a fully homoeothermic individual. As much as 165 days has been estimated to be the maximum, uninterrupted hibernation period possible for a medium-size vespertilionid bat (Altringham 1996; Kunz and Fenton 2003; Mitchell-Jones et al. 2007). In the wild, hibernation is usually interrupted by frequent periods of arousal.

Torpor is engaged on a daily basis for energy budgeting, or for long periods of hibernation, and is considered to be an important and integral component of the life strategy of bats, above all in the temperate regions, such as Europe.

Caves are important because they provide large and permanent roosts available to many generations of bats (Fig. 1.3). However, hibernating bats inhabit not only natural caves but also any cave-like structures, such as tunnels, mines, cellars, old buildings, the ruins of castles, underground fortifications and other similar and suitable constructions made by humans.

Fig. 1.3. A cave – a natural habitat for bats (photo: B.W. Wołoszyn)

1.4. ALAN and the hibernation period

Bats can use underground shelters depending on the prevailing local microclimatic conditions and the geographical position. During hibernation, bats may be exposed to various disturbances which may limit their chances of surviving the winter. For this reason, protection of hibernacula is crucial for bat protection.

During the winter, when there are no insects, bats hibernate relying upon the fat reserves acquired in Autumn before the arrival of winter. Each bat awakening provoked by artificial light during this period causes a significant consumption of these stocks, thus reducing the chances of surviving during the winter when there are no insects.

1.5. Bats and artificial light during the summer quarter

Bats are usually associated with villages, woodland areas and the countryside in general, but bats use a lot of places of refuge such as man-made constructions: buildings and other constructions in towns. At present, the life cycles and numbers of bats are significantly affected by anthropogenic factors. Their major positive is that many bat species can find shelter in human buildings; their negative effects are associated with the transformation of ecosystems and environmental pollution, disturbance to and/or killing of bats in their shelters and bats being disturbed by artificial light or extensive noise.

1.6. Churches as a refuge for bats

Bats have used roofs and attics of churches for shelter for a long time. During summer, bats frequently use churches and similar buildings as places to form their maternity colonies. Churches provide excellent roosting places inside but may be dangerous because bats (mainly *Rhinolofids*) when illuminated by artificial or natural light may become prey to nocturnal birds such as owls. Older churches usually have substantial roofs offering safe refuge for bat colonies. Some church administrators prevent some bat species (e.g. *Rhinolophid* bats) from inhabiting their buildings for reasons of hygiene. Modern churches often use overnight illumination and this disturbs bats.

1.7. Ambivalence regarding the influence of artificial light on insectivorous bats

Despite the negative consequences of artificial light on bats described above, there remains a degree of ambivalence concerning the impact of artificial lighting on the nocturnal activity of insectivorous bats. The nocturnal insects orient themselves in flight maintaining a constant angle to light sources, which are, in an anthropogenically undisturbed environment, the moon or stars. The local artificial lights change the rectilinear flight routes of insects into helical routes, directing the insects to the light source which generally ends their life. Street lights, attracting the insects, causes insectivorous bats, those inhabiting the Holarctic temperate zone, to use the lamplight as a place of effective hunting for insects. On the other hand, the lighting of bat roosts may disturb the rhythms of their activity.

The examples presented above support the ambivalence of the question of whether artificial light has any significant and negative effect on the activity of nocturnal animals, particularly bats.

Conclusions

This chapter is based on the personal experience of the author and the critical evaluation of literature by the following authors: Bird B.L. et al. 2004; Gaisler J. 1979; Kłys G. et al. 2016; Krzanowski A. 1980; Kunz T.H. (ed.) 1982; Ransome R. 1990; Rich C. and Longcore T. 2005; Richardson P. 1985; Rydell J. 2009; Rydell J. and Racey P. 1995; Stone E.L. et al. 2009 and 2015; Straka T.M. and Wołoszyn B.W. 1996, 1998, 2008, 2015, 2019; Wołoszyn B.W. and Bashta A.T.V. 2001; Wołoszyn B.W. and Murariu D. 2016.

1. Light is a complex environmental factor. The amount and physical nature of radiant energy affect organisms, both plants and animals.
2. Anthropogenic light pollution has become an increasing global problem affecting all ecological interaction across a range of taxa and negatively impacting upon critical animal behaviour including foraging, reproduction and communication.
3. Artificial light at night (ALAN) may be a factor which is a major cause of the worldwide decline in biodiversity.
4. Diurnally active plants and animals, as well as people, may suffer from the scarcity of darkness at night due to the disruption of their diurnal rhythms.
5. Similarly, nocturnal animals dependent upon darkness are exposed to danger because the intense light at night disrupts their ability to acquire food and hinders their migration and reproduction.
6. All twenty-five species of bats inhabiting Polish territory belong to the insectivorous group.
7. The supply of food for bats in temperate regions is available seasonally. Bats need to choose adequate strategies to survive during the period when food is scarce. During winter, when there are no insects, bats hibernate using fat reserves acquired in autumn. Such a survival strategy can be considered as “escape in time” in contrast to the “escape in space” strategy used by migratory birds.
8. During winter, when there are no insects, bats hibernate relying upon the fat reserves acquired in autumn. The awaking of bats provoked by artificial light during the hibernation period causes a significant consumption of fat reserves, thus reducing the chances of surviving the winter. For this reason, the protection of bats should be addressed firstly with regard to winter shelters.
9. During the summer, bats frequently use buildings like churches as a place for their maternity colonies. The external illumination of churches may prevent some bats from living there, especially Rhinolophid bats.

10. Artificial light may also have a positive effect on the activity of nocturnal animals like bats. Street lights attract insects causing insectivorous bats to use the lamp light as an area of effective hunting for insects.

Acknowledgements

I would like to thank Professor Tomasz Ścieżor of Cracow University of Technology for providing me with the opportunity to present opening lectures during two conferences organised by him in Cracow in 2015 and 2019.

My thanks also go to Professor Krzysztof Piksa for drawing my attention to additional publications on the influence of artificial light on bat activity. I also wish to acknowledge the very kind help of Mr Gabiel Zaidel in the preparation of this chapter.

2. NIGHT SHIFT WORK DESYNCHRONISES CIRCADIAN RHYTHM VIA EPIGENETIC MECHANISMS

Krystyna Skwarło-Sońta[1], Krystyna Zużewicz[2]

Life on the Earth has evolved together with endogenous mechanisms, allowing living organisms to survive in the regularly changing environmental conditions, expressed by light and darkness phases, i.e. by day and night. Given that these changes are generated by the Earth's rotation, their sequence is fixed and easy to anticipate since the day and night cycle always lasts for 24 hours (with the proportion of daytime and night-time length changing in accordance with the season). This sequence of external changes imposes cyclic variations on the physiology and behaviour of all organisms because the intensity of a given biological process may have to be adjusted to the differing needs arising from consecutive periods of activity and rest. These diurnal variations, known as biological rhythms, with values changing from the minimum (nadir) to maximum (peak), regularly restart day by day. As they oscillate over approximately 24 hours, diurnal rhythms are better known under the name "circadian", coming from the Latin word meaning "about a day".

The above-mentioned circadian changes are generated by the biological clock, an endogenous molecular mechanism, which has been gradually deciphered by numerous research groups. Biological clock system is a global and evolutionary conservative phenomenon since the molecular mechanism is quite similar regardless of the structural and anatomical diversity of particular organisms (Bell-Pedersen et al. 2005). Eventually, a group of researchers from the USA dealing with chronobiological studies was awarded the Nobel Prize in Physiology or Medicine in 2017. The scientists Jeffrey C. Hall, Michael Rosbash and Michael W. Young received this award "… for their discoveries of molecular mechanisms controlling the circadian rhythm…" that "… explain how plants, animals and humans adapt their biological rhythm so that it is synchronised with the Earth's revolutions…" (from the verdict of the Nobel Assembly at Karolinska Institutet, https://www.nobelprize.org/prizes/medicine/2017/summary/).

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The molecular mechanism of the circadian clock has been precisely described in numerous excellent review papers (e.g. Foster and Kreitzman 2014; Giebultowicz 2018) and will not be discussed in this article. We only wish to underscore that using fruit flies as a model organism, these Nobel Prize winners explained how the biological clock functions, showing that it works according to the same principles in every multicellular organism, including humans. They have also demonstrated the importance of proper timing and duration of sleep, as the rest-activity circadian rhythm (RAR) is a primary output marker of the endogenous clock.

2.1. The endogenous clock system in humans

The biological clock of humans and the majority of mammalian species is a complex system composed of the central (master) clock (pacemaker), located in the anterior hypothalamic suprachiasmatic nuclei (SCN) and numerous peripheral (slave) clocks, present in virtually every tissue (Fig. 2.1). Peripheral clocks are, inter alia, well known within the gastro-intestinal tract, liver, and adipose tissue (Froy 2011; Fonken and Nelson 2014). The molecular mechanisms of the master and peripheral clocks are the same, with neural and endocrine signals from SCN controlling peripheral clock functioning.

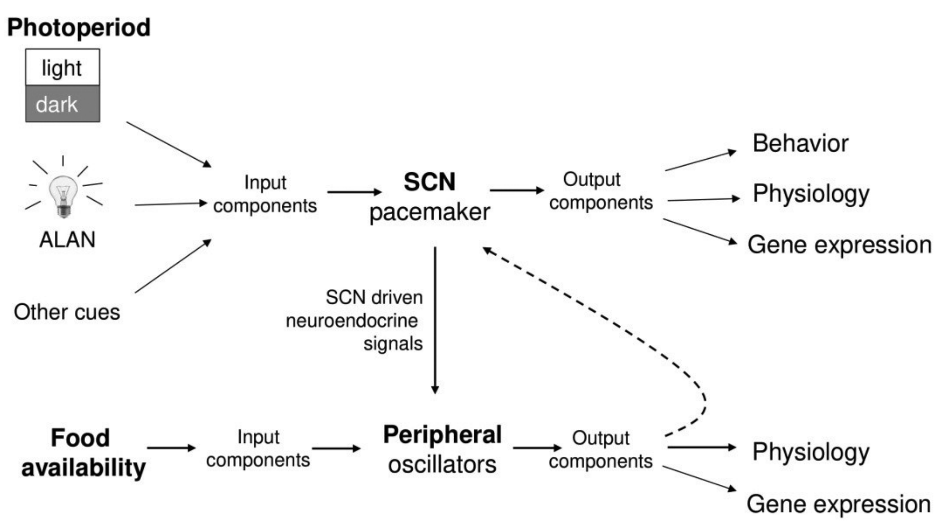

Fig. 2.1. Organisation of the mammalian biological clock system

The coordinating role of the endogenous clock requires its synchronisation with the environment by external cues (in chronobiology they are called *Zeitgeber*, meaning “time giver” in German), easily perceived by specialised receptors and conveyed to the clock itself via special pathways (input). For SCN, the most potent *Zeitgeber* is light, or more precisely, the natural sequence of day/night, allowing the human body to distinguish between the time for activity (day) and the time for rest/sleep (night). Conversely, for the peripheral clocks, non-photic cues, such as food availability, its composition and timing, are the most potent cues (Froy 2011; Arellanes-Licea et al. 2014). Peripheral clocks are not interconnected, but they exert the feedback effect on the master clock, and this mechanism, including metabolic processes, peripheral clocks and SCN, allows synchronisation with the environment to be much more precise. Biological clock synchronisation by food, however, is far beyond the scope of this article and the reader is directed to some of the excellent recently published reviews (e.g. Delezie and Challet 2011).

2.2. Linking lighting conditions with circadian organisation – the role of the pineal gland

To be synchronised by external light, clock neurons present in the SCN pacemaker have to receive information conveyed by the retinal photoreceptors (Fig. 2.2). Apart from the rods and cones being vision-related photoreceptors, light is also perceived by a set of non--vision related photoreceptors, intrinsically photosensitive melanopsin containing retinal ganglion cells (ipRGCs), which convey information directly to the SCN via the retino--hypothalamic tract (RHT) (Berson et al. 2002). From SCN, information is subsequently relayed by a multi-synaptic pathway to the pineal gland (see Fig. 2.3) where it controls the magnitude and duration of melatonin biosynthesis, strictly correlated with the length of darkness (Claustrat et al. 2005). Melatonin synthesised in the pineal gland is immediately released to the circulation. Therefore, its blood concentration corresponds exactly to the environmental lighting conditions, and eventually, the circadian rhythm of blood melatonin concentration is considered as the best peripheral outcome of the master clock in humans (Fonken and Nelson 2014).

The pineal gland (in Latin: *Glandula pinealis*) is a unique unpaired structure of the brain located near the third ventricle and functioning as a neuroendocrine organ translating

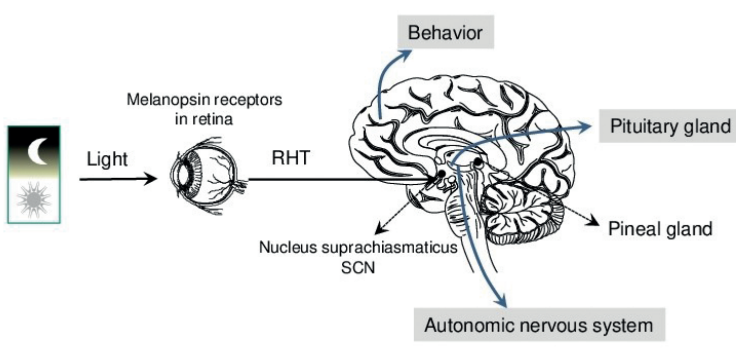

Fig. 2.2. Mammalian master clock, SCN: localisation in the brain, input, and output pathways; RHT – retino-hypothalamic tract

information about the external lighting conditions into melatonin, the chemical message of darkness (Arendt 2019). The principal cells of this gland, pinealocytes, are able to synthesise and release their main hormone, melatonin, derived from the exogenous amino acid, tryptophan, in the four-step biosynthesis pathway. As mentioned before, melatonin synthesis in the pineal gland is related almost exclusively to the darkness because light inhibits this process and the level of endogenous melatonin (both in the pineal gland and the blood) during the day should be virtually neglected. Inversely, melatonin synthesis in mammals remains under the stimulatory control of the adrenergic innervation from postganglionic sympathetic fibres, active during the dark phase of the diurnal cycle. The neurotransmitter adrenaline, released in darkness via β- and α_1-adrenergic receptors, activates molecular events in pinealocytes, leading to increased melatonin biosynthesis (Zawilska et al. 2009). It is obvious that the presence of melatonin in the blood serves as a message of darkness for organs and tissues, also perceived by the SCN pacemaker itself that, in turn, adjusts its own electrical and biosynthetic activity to this information (Fig. 2.3). Afterwards, it sends its neuro-endocrine messages to the whole body thereby synchronising physiology and behaviour with the external lighting conditions (Korkmaz et al. 2009).

The duration of this elevated melatonin biosynthesis is strictly correlated with the length of the dark phase (night). This is especially important for wild animals since it provides information about the seasonal changes in the proportion of day-to-night, which in turn is

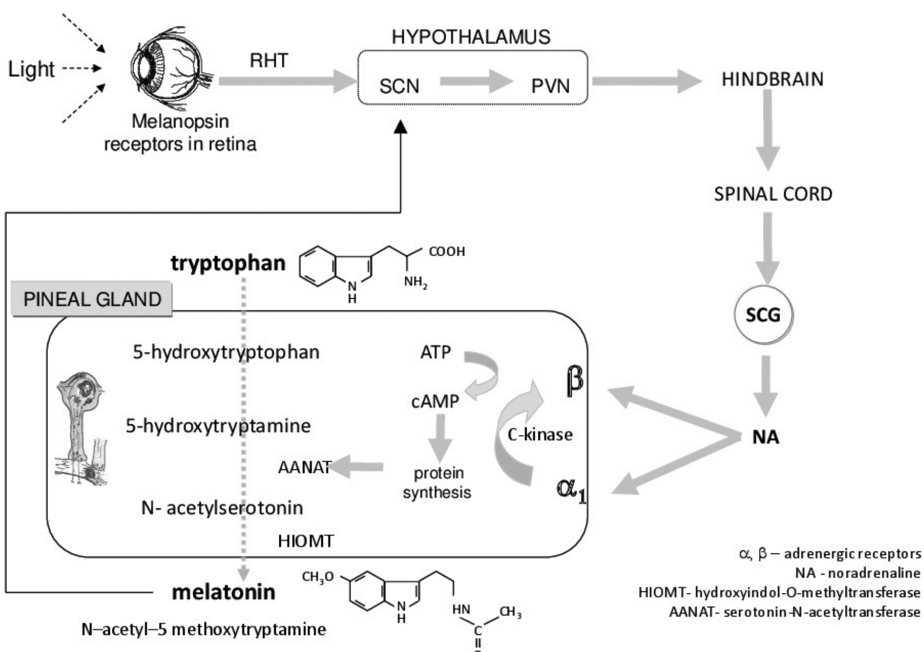

Fig. 2.3. Melatonin biosynthesis pathway in the mammalian pineal gland and its interconnections with light and the master clock (SCN) (modified from Arendt 1994)

used by these species as an environmental cue indicating the proper breeding season. Apart from being a chronobiotic, melatonin fulfills several other functions related to its receptors that are widely distributed throughout the body (Dubocovich and Markowska 2005) as well as to the chemical properties (Tan et al. 2010), which will be not discussed in this review (for the latest description see Arendt 2019).

2.3. Light pollution: definition, sources, effects

In humans and other diurnally active mammalian species, energy production and expenditure are naturally associated with the light phase of the 24-hr period, while the night is the time of sleep and resource regeneration. However, in developed countries, unlimited artificial light is present throughout the 24-hr period with a very weak diurnal-nocturnal difference. Moreover, in contemporary westernised countries, natural light is no longer accessible to people, especially those living in cities with omnipresent artificial illumination. During the day, big city citizens are in their offices exposed to artificial light with an illuminance level of around 500 lux, which is established as an optimal/sufficient level for average professional activity. They are only occasionally exposed to natural light which, by contrast, reaches hundreds of thousands of lux on sunny days. Contrastingly, at night, European citizens are very often exposed to much brighter illumination than that obtained from a full moon (Bonmati-Carrion et al. 2014). Collectively, natural light is no longer a sufficiently potent *Zeitgeber* for the endogenous clock, which is, therefore, not properly synchronised with the environment (Roenneberg et al. 2019).

Since the introduction in 1879 of an electric light bulb for everyday use, artificial light at night (ALAN) has become the most frequent environmental pollutant. Light pollution is defined as improperly controlled artificial outdoor lighting, which can adversely affect the environment (Bulletin of the International Astronomical Union 2018). It is emitted not only by street and car lights, but also by the excessive illuminations of historical buildings, bridges, churches and so on. When the light source is improperly installed, the light is wasted by being scattered by aerosols (clouds, fog, or particulate atmospheric pollutants) and forms the skyglow, the most common form of light pollution. The most popular spectrum of ALAN significantly differs from that of direct moonlight, especially when the incandescent bulbs emitting yellow wavelengths started to be replaced by lamps using LED (Ligth Emitting Diodes) technology. These are economically favourable but typically emit a whiter light with wavelengths peaking near blue and green, influencing not only the sky glow (Gaston et al. 2015) but also exerting a very potent adverse effect on human health (see next section).

Secondary reflection is an additional source of skyglow, much more visible in rural areas where the standalone light sources create a greater impact on skyglow than in cities. Other components of light pollution are light trespass (unwanted external ALAN entering, for example, through the windows) and glare (excessive brightness of light creating high contrast and decreased visibility). All these adverse effects should be minimised, at least partly, by a reduction of the number of locations and the number of hours when lights are on or by the appropriate installation of outdoor light sources, i.e., in such a way that their footprint on the ground is visible from a distance but the light source itself is not (Bulletin of the International Astronomical Union 2018). These problems are profoundly serious but do not fit the topic of this article and will thus not be discussed in detail.

Every morning, an organism faces a challenge to be ready to undertake new behavioural and physiological activities; therefore, the existence of a correctly functioning internal clock, measuring the time, is an obvious necessity (for a review, see Foster and Kreitzman 2014). The self-sustaining mechanism of the biological clock, moving from one state to another, entrains regular metabolic and behavioural oscillations in synchrony with the environmental conditions. The retinal melanopsin receptors are particularly sensitive to blue light (a wavelength of approximately 480 nm), which corresponds to the colour of a clear morning blue sky and sends the best signal of the night to day transition, allowing a strict synchrony between the organisms' function and the sun (Stevens and Zhou 2015). However, when ALAN is present in other phases of the 24 hr period, it exerts such an inhibitory influence on the pineal gland function as to negatively affecting a nocturnal increase in melatonin biosynthesis. The same inhibitory effect on melatonin synthesis and its blood concentration is exerted by the blue light emitted by numerous electronic devices (including tablets, mobile phones and notebooks), which are used more and more frequently nowadays (e.g. Wood et al. 2012; Chang et al. 2015). Moreover, the 24/7 type of activity (24 hours a day, 7 days a week) poses a big challenge for the circadian adaptation of the regulatory mechanisms exposed to the desynchronising of the environmental information, as the intimate interplay between the circadian clock and cellular metabolism has recently started to be evidenced. Circadian misalignment affects not only the timing and quality of sleep but also deregulates metabolism, leading to negative health outcomes, including metabolic syndrome and diabetes, obesity, depression, and several other civilisation-related illnesses (Wyse et al. 2011).

As mentioned above, the omnipresent ALAN generates several benefits and costs impacting upon every aspect of life, not only on human wellbeing, but also on the economy, wildlife and ecosystems. These multifactorial effects are discussed in depth in various review articles (e.g. Gaston et al. 2015) and exceed the scope of this article. For the purposes of the main topic, we will concentrate on nocturnal shift work and its influence on human health, including adverse effects and the supposed molecular mechanisms involved.

2.4. Night shift work and its influence on the circadian system

Modern life involves several human activities including the unrestricted timing of work along with social activities, both of which also being related to the irregular time of sleep. This results in the impaired quality of sleep (sleeping during the day versus the night) as well as poor levels of alertness and performance at night (Arendt 2010). Additionally, such conditions generate another type of desynchrony between the individual biological clock and the so-called "social clock", leading to social jetlag, defined as the difference between sleep on workdays and that on days off, leading to circadian misalignment (Roenneberg et al. 2019).

Nowadays, life makes certain groups of people work 24 hours a day, 7 days a week. Work affects their extra-occupational life as well as their family and social lives and socio-economic activities. Shift and night work modify lifestyles, change meal times, limit physical activity and shift bedtime to daytime. Normal sleep is night sleep when melatonin synthesis peaks at minimal body temperature (Arendt 2010). The quality of sleep in the daytime is worse and sleep time is often divided into several short periods and its total duration is less within 24 hours. Forced work at nighttime (between 1 a.m. and 5 a.m.) where psychophysical fitness, alertness and effectiveness are at their lowest levels, increases the physiological cost of work.

The discrepancy between the diurnal rhythm of activity and the natural day-night cycle, together with exposure to ALAN, are among the environmental factors affecting epigenetic modifications in SCN cells (Ecker and Beck 2019). They are not noticed until they result in measurable health consequences. The primary symptoms may include the well-known *jet lag*, due to desynchrony of the endogenous circadian rhythmicity after travelling through several time zones or *shift lag* resulting from night work. In both cases, the symptoms are the manifestation of the body's response to the disturbed relationship with natural light and/or the prolonged exposure to ALAN, which can last for several hours. The most commonly observed symptoms include vexation, distraction, sleep and digestive disorders, impairment of muscular strength, and improper perception of distance and time lag. The symptoms are either transient, e.g. in the case of tourists travelling by plane, or chronic, such as those observed in shift workers. They are always accompanied by the disturbance of time

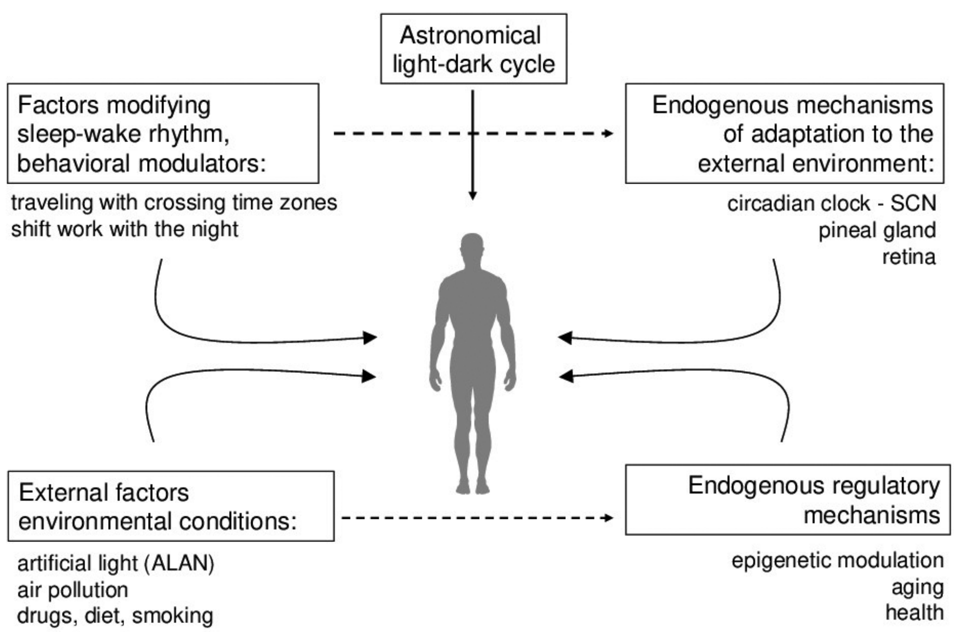

Fig. 2.4. Interrelationships between environmental factors and endogenous regulatory mechanisms

cohesion between endogenous rhythm phases; the scope of the aforementioned problem depends, inter alia, on individual predispositions and age. Impairment of the mechanisms responsible for the adjustment of body functions to signals from the external environment is manifested by health problems, including those of epigenetic origin (Fig. 2.4). The relatively high number of shift/night workers with cancer is particularly alarming (Alpert et al. 2009; Costa 2010; Richter et al. 2011; Zubidat and Haim 2017).

Epidemiologic studies, mainly of nurses, have revealed an association between sustained night work and a 50-100% higher incidence of breast cancer. The International Agency for Research on Cancer (IARC) has classified shift work in group 2A of "probable carcinogens to humans" since "they involve a circadian disorganisation" (Costa 2010; Touitou et al. 2017).

As previously explained, melatonin is a source of information on the phase of the diurnal cycle for an organism – its synthesis is closely correlated with darkness;therefore, the circadian level of released melatonin and the duration of its elevated concentration in circulation depends on the duration of darkness (Claustrat et al. 2005). In shift workers, during 24-hour-periods that include night shift work, the levels of endogenous melatonin are lower than during 24-hour periods with daytime work and nocturnal sleep. In 24-hour periods with night work, the overall time of exposure to natural and artificial light is extended. During night work, workers are exposed to artificial light of a constant intensity and spectral characteristics, and after working hours, they are also exposed to natural light the intensity and spectral composition of which are subject to changes from dawn to dusk. The degree of melatonin suppression depends on the intensity and spectral characteristics of the lighting (Jou et al. 2013).

In humans, the range of visible lighting wavelength is 380-780 nm. However, the strongest influence on the circadian and neuroendocrine responses is evoked by spectral lighting ranging from 450 to 550 nm. For monochromatic light, the wavelength evoking the strongest or longest extraocular responses ranges from 460 to 480 nm (Arendt 2019). It has been shown that the exposure of human beings to monochromatic blue light (473 nm) evokes stronger stimulation of the brain structures responsible for interactions between alertness and the cognitive functions as compared with exposure to violet (430 nm), green (527 nm) or orange (620 nm) lighting (Vandewalle et al. 2007; Carrier 2018). Moreover, the short exposure to blue lighting during the processing of auditory stimuli evokes a stronger emotional cerebral response than exposure to green light (Vandewalle et al. 2010). The results of this and similar studies are important both for researchers and employers seeking approaches for improving alertness in night workers. The lowest levels of psychophysical fitness and high levels of sleepiness noted between midnight and 5 a.m. may pose a risk of errors and accidents at work both for workers and for employers, as well as impairing the quality and efficiency of work performed (Ruger et al. 2006). It has been concluded that devices emitting more light with a wavelength near blue or green light would be a reasonable solution (Viola et al. 2008) since nowadays the application of such devices as a litebook or light tower is possible owing to widespread LED technology. Light visors could also be applied for such purposes. The practical application of such devices would require a selection of lighting parameters which, while decreasing sleepiness levels and improving alertness, would cause no discomfort to the eye. The effectiveness of the applied device would depend on the effectiveness of the light stimulus in circadian regulation. An individual response to light depends on automatic behaviour in relation to the light source, light transduction through pupils to the retina, the sensitivity of photoreceptors to the wavelength, the distribution of photoreceptors and the ability of the nervous system to integrate stimuli in time and space (Brainard and Hanifin 2005). Another serious problem in night workers is obtaining a compromise between the benefit of alertness improvement and the adverse effect on health resulting from melatonin suppression.

In 2000, the European Foundation for the Improvement of Living and Working Conditions conducted research in fifteen European countries on more than 21,000 workers. It was demonstrated that the "normal" or day workers whose working time did not exceed forty hours weekly and ten hours daily, who did not work in shift system or at night or on Sundays and/or Saturdays, constituted only 24% of the working population (IARC 2010).

The extension of working hours to an atypical time within a 24-hour period and days dedicated to extracurricular activities and rest has become commonplace. Shift and night work is performed both by women and men in different age groups, although according to WHO recommendations, the upper age limit should not exceed 50 to 55 years (ILO 1990; Monk et al. 2000). With age, such work becomes increasingly burdensome, which results from the progressive aging process affecting sensory organs, e.g., the visual organ. Functional changes in circadian organisation are observed, which in human beings may be associated with subtle degenerative alterations in the SCN and other parts of the biological circadian system (Hofman 2000; Carrier 2017). In young individuals, the cornea, the aqueous humor and the vitreous body are the tissues transmitting almost 100% of visible and UV light. With age, the total transmission of radiation to the retina by the lens is reduced, especially within the range of shorter wavelengths (Brainard et al. 2001).

Non-visual effects of light could also decrease with aging, and may contribute to cognitive complaints and sleepiness in older individuals. However, both the brain and the eye change in aging. The effect of light on non-visual cognitive brain activity was compared using functional magnetic brain imaging (fMRI) in both younger and older individuals. During exposure to monochromatic blue light (480 nm), brain responses to executive tasks and brain connections were analysed. It has been found that the effect of light on visual cognitive brain activity decreases with advancing age (Carrier 2017).

In humans after their forties, melatonin production rapidly decreases and an additional drop in melatonin levels, resulting from the exposure to light at night, may accelerate the aging process. This hypothesis can be confirmed by research comparing mental fitness in people working only in the daytime with shift workers who also work night shifts. In shift/night workers, a decrease in short-term memory appeared to be directly proportional to the duration of shift work. This decrease is clearly visible in persons who have worked in shift systems with night shifts for 10-20 years. The results of cognitive function assessment obtained in persons who worked shifts or at night for more than 10 years are similar to the values obtained in persons 6.5 years older (Rouch et al. 2005). The problems with maintaining an adequately high level of alertness during night work in the older population are further aggravated by more frequent sleep disorders experienced by this group. The risk of microsleep or the need for a nap increases the risk of accidents at work (Sallinen et al. 2005). In this case, it is worth noting that the exposure to ALAN with properly selected parameters may be beneficial for a worker (Arendt 2019). It is believed that in the case of night-shift employees exposed to ALAN enriched with blue light to improve alertness, the risk of cancer is increased (Alpert et al. 2009; Richter et al. 2011; Haim and Zubidat 2015; Zubidat et al. 2015; Zubidat and Haim 2017).

Apart from the direct influence of exposure to artificial light, another negative effect of night work on health and mental fitness results from the lack of compatibility between the light-dark rhythm and the sleep-wake cycle, i.e., external desynchrony. For this reason, the night worker can be compared to “a permanent traveller”. Such journeys, involving frequent flights crossing multiple time zones, may result in brain function impairment, which has been described in stewardesses. Magnetic resonance imaging (MRI) has revealed shrinking of the right temporal lobe (Cho 2001; Stone 2002) in this group of workers, which may lead to the transient loss of part of the information memorised during their entire life and the ability to only remember the new events and to understand speech, changes in physical and mental activity, excessive excitement, and false joy. A study conducted on animals, involving jet lag simulation over one month, revealed a loss of half of new neurons in the hippocampus, the structure responsible for memory. The decrease in the neuron count was probably due to the inhibition of cell proliferation and neurogenesis (Gibson et al. 2010). We can only hope that the above-mentioned changes are reversible and also that in older persons after finishing their night work employment, a regular re-adjustment to the natural light-dark cycle will be observed.

2.5. The involvement of epigenetic mechanisms in the adverse effects of ALAN

2.5.1. A brief introduction to epigenetics

Epigenetics examines modifications to gene functions that are heritable and reversible and appear without any changes to the nucleotide sequence of DNA. These modifications determine when and whether various sets of genes are expressed in a tissue or cell, and include DNA methylation, histone modifications, nucleosome positioning and aberrant expression of the microRNAs (Glavaški and Stankov 2019). As DNA methylation and histone modifications are the most frequently studied of the above factors (Zhang and Ho 2011), these mechanisms will be briefly presented in the context of adverse ALAN effects on mammalian physiological functions. However, a reader particularly interested in the other aspects of epigenetics is addressed to the excellent reviews published elsewhere (e.g. Bell et al. 2011; Hardeland 2014).

As mentioned above, the most frequently studied epigenetic modification is DNA methylation (DNAm), i.e. the addition of methyl groups to the CpG sites. In these sites, cytosine-guanine dinucleotides are separated by only one phosphate group in the linear sequence of bases along its 5′ → 3′ direction. They occur relatively seldom in the mammalian genome but are in particular abundance within the promoter regions (transcription start of a gene) and are referred to as “CpG island” (Gardiner-Garden and Frommer 1987). In humans, about 70% of promoters contain CpG islands where cytosines can be methylated by enzymes called DNA methyltransferases (DNMs) to form 5-methylcytosines. In most instances, the CpG islands of the actively expressed gene promoters are unmethylated while the presence of multiple methylated CpG islands is noted in the stable silencing genes. These observations collectively lead to the conclusion that methylation of CpG sites in the promoter may block a gene expression (Jabbari and Bernardi 2004). This inhibition of gene expression is affected either by the recruitment of special proteins (with methyl-CpG-binding domain MBD) or by the direct inhibition of the transcription factor binding (Glavaški and Stankov 2019). Furthermore, loss of gene expression in cancers is related about 10 times more frequently with hypermethylation of promoter CpG islands than with mutations (Hashimoto et al. 2010).

Histones (H) are proteins involved in the packaging of DNA into nucleosomes that build the chromatin. Nucleosomes are formed by sets of histone octamers (composed of subunits 2xH2A, 2xH2B, 2xH3 and 2xH4) wrapped with approximately 146 bp of DNA, connected via a short linker DNA (Fig. 2.5a). N-termini of the histone amino acid tails are

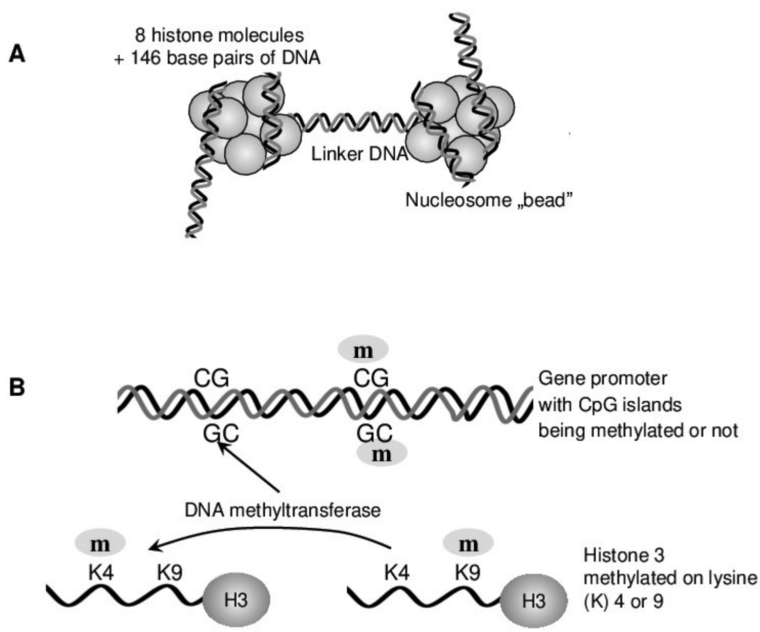

Fig. 2.5. Schematic organisation of the “epigenetic code”: a) Simplified structure of nucleosome (for details see text); b) Reciprocally associated methylation of DNA and histone H3 lysines (K4 and 9). Recognition of H3K4me0 by DNA methyltransfease directs methyl groups towards DNA CpG island (modified from Hashimoto et al. 2010)

subject to considerable post-translational modifications, including the acetylation (ac) and methylation (me) of lysine (K). These modifications influence the chromosome structure and function in a way which determines the transcriptional accessibility or repression of chromatin. Generally, it is assumed that repressive chromatin is related with trimethylation of histone H3 on lysine 9 and 27 (H3K9me3 and H3K27me3, respectively) while H3K4me3 is associated with chromatin more accessible to transcription (Fabrizio et al. 2019).

The epigenetic "code" is composed of the combination of DNA methylation and histone modifications, finally deciding upon the gene expression pattern resulting from the activation or silencing of particular genomic domains (Fig. 2.5b). DNAm in CpG islands depends on the folowing histone modifications: the absence of H3 lysine4 methylation (H3K4me0) and the presence of H3K9me3 (Hashimoto et al. 2010). Molecular coupling of these two mechanisms is the subject of advanced research nowadays; however, it remains far beyond the scope of this article.

2.5.2. Epigenetic modifications in the context of ALAN-evoked circadian desynchrony

The epigenetic modulation of the clock gene expression underlying the involvement of various epigenomic mechanisms in the fine tuning of biological rhythm control has recently been summarised (Ahmad et al. 2019). However, regardless of the continuously increasing interest in epigenomics, studies directly addressing the involvement of epigenetic modifications in the effects of ALAN on the circadian rhythm desynchrony are rather scarce.

Recent experiments (Grygoryev et al. 2018) performed on mice subjected to the light phase being advanced by six hours (corresponding to ALAN applied in the middle of a twelve-hour night) have demonstrated an effect on both the level (increase) and circadian phase (advance) of H3K4me3 (the marker of transcriptionally active chromatin) in the promoters of core clock genes (*Per1*, *Per2*, *Cry1*, *Cry2*, *Bmal1* and *Clock*) in the liver. The diurnal rhythm of the H3K4me3 level in the liver of control mice corresponded to that of locomotor activity – it was low early in the light phase and peaked in the darkness. However, while the initial locomotor desynchrony was re-entrained within one week of the new lighting conditions, the level of H3K4me3 still peaked in the light phase. It indicated an acute effect of light on the liver epigenome leading to the disruption of the H3K4me3 diurnal rhythm that was impossible to be re-synchronised during one week of new lighting conditions. Moreover, eight weekly phase advances with one-week recovery between each lighting phase shift further disrupted this rhythm. A similar effect was not observed in the submandibular gland epigenome. This finding indicated the tissue-specific desynchronising effect of the light phase shift. The aforementioned results should be interpreted as misleading, at least with regard to the peripheral clock present in the liver and responsible for internal desynchrony and metabolic perturbations.

The study cited above has clearly demonstrated that the liver epigenome responds to perturbed lighting conditions, yet the authors did not examine the mechanism(s) involved in the signal transduction from the SCN master clock to the peripheral clock in the liver. This should be accomplished via the autonomic nervous system, however, additional hormonal or behavioral pathways, not operating (or switched off) in the described experimental conditions, may contribute to desynchrony of the circadian clock in the liver (Grygoryev et al. 2018). It is appropriate for perturbed melatonin synthesis in the pineal gland to be taken into consideration. It is hard, however, to distinguish between the affect of ALAN on the circadian system and melatonin level – the clock may be reset according to the phase response curve while the melatonin biosynthesis and release is stoped by ALAN (Hardeland 2014).

Another research group presented a set of papers describing the possible association between ALAN and hormone-dependent cancer incidences, and the epigenetic mechanisms evaluated by global DNA methylation. The experimental protocol comprised the inoculation of female mice with the human breast cancer cell line (4T1) and subsequent treatment for one month with various combinations of ALAN and melatonin supplementation in drinking water. The monitored parameters included those evaluating tumour growth and metastase formation, melatonin release measured by its urine metabolite (6-sulphatoxymelatonin, 6-SMT) content along with global DNA methylation in tumours and isolated organs (such as the spleen, lungs, and liver).

The first approach (Zubidat et al. 2015) involved a comparison of the effects observed in the tumour-inoculated mice exposed to a thirty-minute-long nocturnal illumination with incandescent (yellow light, control) or LED (blue light, ALAN) lamps. The nocturnal exposure to the blue LED lighting stimulated tumour growth and promoted metastases formation in parallel with a decrease in urinary 6-SMT and DNAm in the tumour and liver but not in lung and spleen cells. These parameters significantly differed from those found in the control mice. Moreover, the urine content of 6-SMT negatively correlated with the tumour volume and positively with the DNAm in the tumour. Additionally, melatonin supplementation in drinking water reversed the harmful effects of the blue ALAN. In summary, tumour proliferation together with aberrant DNAm resulted from the suppressed pineal melatonin synthesis and release caused by the blue ALAN, as these effects were reversed by the exogenous melatonin supplementation (Zubidat et al. 2015). These observations corroborate the previous suggestions that melatonin suppression could mediate the ALAN effect, either directly or indirectly, by induction of the aberrant global hypomethylation of DNA. It has been evidenced that melatonin is able to modulate, inter alia, epigenetic enzyme DNM, which is crucial in the methylation of DNA (Korkmaz et al. 2012).

The same research group (Zubidat et al. 2018) extended their experimental protocol in a such way that nocturnal 30-min illumination consisted of four different spectral compositions (500-595 nm), applied as in the previous study to female mice bearing 4T1 breast cancer cells. The results revealed an inverse relationship between wavelength and melatonin suppression – a shorter wavelength (particularly near 500 nm) increased tumour growth, promoted lung metastasis formation and advanced DNA hypomethylation in comparison to the longer waves, being much less efficient in melatonin suppression. These results are in agreement with those of the research conducted in the other group (Cos et al. 2006), showing the effect of ALAN on the desynchrony of the circadian rhythm, tumour progression and a lower survival rate along with the lower 6-SMT urine excretion in female rats with chemically-induced mammary carcinoma. Epigenomic parameters were not examined, but an adverse effect of ALAN on tumour growth via inhibiting melatonin release was demonstrated. In the experiments conducted in this research group (Zubidat et al. 2018; Haim et al. 2019) melatonin supplementation counteracted the adverse effects of ALAN and resulted in reduced tumour growth (Fig. 2.6). Taken together, the experimental data led these authors to conclude the presence of a close association between ALAN and cancer, where the suppression of nocturnal melatonin synthesis is responsible for the aberrant global methylation in both tumours and organs of experimental animals, while exogenous melatonin supplementation can antagonise these adverse effects (Haim et al. 2019).

Since the observed aberrant DNA methylation was evoked by pineal melatonin suppression, the authors suggest introducing these relationships as promising biomarkers for the early diagnosis and therapy of human breast cancer (Zubidat et al. 2018).

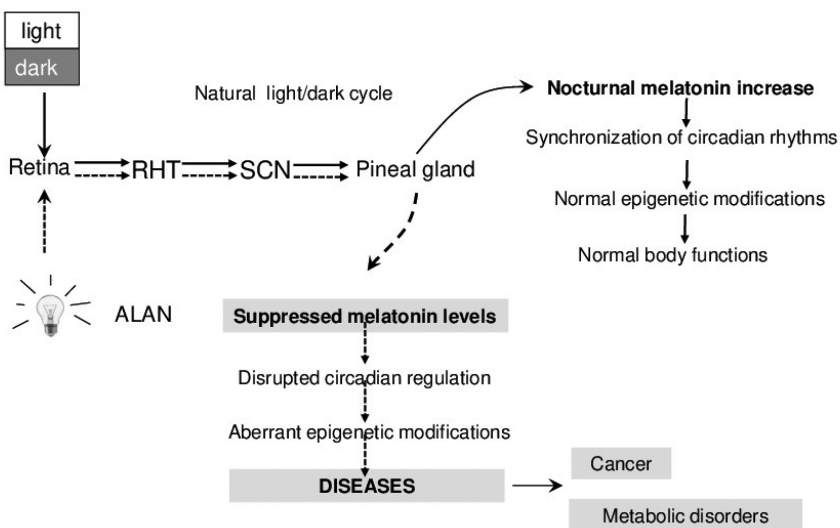

Fig. 2.6. The link between environmental lighting conditions and epigenetic modification-related pathology. Suppressed nocturnal melatonin synthesis influences global DNA methylation resulting in breast cancer development (modified from Haim and Zubidat 2015) – see text for more details

Finally, quite a recent study of the same research group (Yonis et al. 2019) evaluated the affect of ALAN on DNA global methylation in the pancreas and liver of male rats exposed to the ALAN applied 2×30 min/night for three weeks. This treatment was selected to strengthen the suppresive effect of light on nocturnal melatonin synthesis while the control rats were kept in normal L:D conditions. Body mass gain, urine production and body temperature were higher in the ALAN group whereas food intake, water consumption, blood glucose and insulin content, and 6-SMT in urine were markedly lessened in response to ALAN.

DNA hypomethylation was detected in ALAN-treated pancreatic tissue but not in hepatic tissue. Under the influence of ALAN, the diurnal rhythm of all measured variables was altered as expressed in mesor, amplitude and acrophase values. ALAN affected the metabolic and hormonal status of the organism at different levels, including a relationship between melatonin and both epigenetic and metabolic measures. An involvement of the above mechanisms in mediation of the effect of environmental light exposure on the molecular level subsequently leading to altered physiology has been suggested (Yonis et al. 2019).

Conclusions

Both the accumulated observations and the experimental data strongly support the general notion on the harmful effects of ALAN, which is regarded as a very frequent and dangerous environmental pollutant. Exposure to ALAN is almost inevitable due to current lifestyle factors in developed countries, including: (i) omnipresence of electrical light, which is most frequently blue LED for economical reasons; (ii) extended professional and social activity manifested on a 24/7 basis; (iii) night-shift work, performed by about 30% of the global population; (iv) unlimited usage of the light-emitting electronic devices. Moreover, the increasing incidence of civilisation-related illnesses like cancer, metabolic disorders (obesity, diabetes mellitus type 2 (DMT2) and metabolic syndrome), several neuro-psychiatric and many other disorders, clearly indicate the effect of environmental factors on circadian system desynchrony which in turn result in misleading the endogenous organisation of physiology and behaviour. Among the factors responsible for this desynchrony, suppression of the nocturnal synthesis of melatonin in the pineal gland by ALAN seems to be the most important. There are certainly numerous mechanisms involved in the mediation of the ALAN effect on metabolism, behaviour and/or oncogenesis, and the recently examined epigenetic modifications (DNAm and histone modifications) are taken into consideration. These should by used as biomerkers of desynchrony along with melatonin diurnal rhythm to diagnose and prevent the most advanced adverse consequences for human health and wellbeing.

As epigenetic modifications evoked by exogenous factors are at least partly reversible, it has to be underscored that circadian missleading occurring under the influence of ALAN should be re-programmed once the harmful environment with the excessive illumination has been eliminated. Protected dark skies could counterbalance the ALAN-evoked desynchrony of the circadian system.

3. THE EFFECT OF LIGHT POLLUTION ON PLANTS. A PRELIMINARY METHODOLOGICAL STUDY ON SMALL-LEAVED LIME

Magdolna Dani[1], Kornél Baráth[1], Péter Molnár[1], Flóra Siska[1], Klaudia Turbucz[1], Anna Skribanek[1]

Light is a vital source of energy for photosynthesis and its intensity is closely related to the amount of incorporated CO_2. In the case of angiosperm plants, the synthesis of chlorophyll occurs exclusively in the presence of light and it is also important for photomorphogenetic control. Light and dark hours can act as a resource for organisms for various physiological processes (Kronfeld-Schor and Dayan 2003; Gerrish et al. 2009) and changes in the availability of light and dark hours can have either positive or negative effects.

The effect of light pollution on plants has not yet been thoroughly studied; it is mainly photomorphogenetic and photosynthetic effects that have been described (Xu et al. 2009; Škvareninová et al. 2017; Meravi and Prajapati 2018). In photomorphogenesis, phytochrome systems (photoreceptors) play the major role. In vascular plants, phytochromes exist in two photo-interconvertible forms – a biologically inactive red-light-absorbing form (Pr) which upon absorption of red light is converted to a biologically active form (Pfr). Pfr is converted back to Pr on absorbing far-red light, so under steady light of a given red/far-red ratio, the active form of phytochrome reaches equilibrium (Lin 2000; Neff et al. 2000; Smith 2000). The phytochrome system has been shown to influence vegetative growth, the timing of germination, flowering, bud opening and dormancy, senescence and the distribution of resources to roots, stems and leaves (Smith 2000).

The presence and intensity of night light in cloudy weather is 1-2 times higher (16--24 lux) than in clear skies, affecting leaf fall and leaf coloration. The leaf coloration (senescence) of some tree species is prolonged, the leaves fall off a few days later due to light pollution. Light pollution thus affects the biorhythm of trees (Škvareninová et al. 2017).

The PAR (photosynthetically active radiation: wavelengths between 400 and 700 nm) associated with night-time light pollution is extremely low relative to daylight

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(< 0.5 μmolm-2s-1 compared with between 100 and 2000 μmolm-2s-1 for daylight) and therefore the effect of light pollution on net carbon fixation is likely to be negligible in most cases (Meravi and Prajapati 2018).

Light pollution reduces the photosynthesis of plants and decreases Fv/Fm (and indirectly, the maximum photochemical quantum yield of PS II), which indicates the stress level of plants (Björkman and Demmig 1987). Quantum yields of photochemical system II (YII) and non-photochemical quenching (NPQ) are also reduced (Meravi and Prajapati 2018), indicating the efficacy of light protection mechanisms. Y (NO) estimates the photochemical and non-photochemical loss, which is higher in plants exposed to light pollution, thereby reducing their photochemical efficiency (Meravi and Prajapati 2018).

In this preliminary study, we investigated the effect of plant orientation on flowering time, the number of flowers, leaf macromorphology and photosynthesis.

3.1. Materials and methods

The light-polluting effect of street lighting has so far been investigated by comparing specimens collected near to lamps (light polluted) and far away from lamps (non-light polluted) (Škvareninová et al. 2017; Meravi and Prajapati 2018). By contrast, in order to avoid environmental influences such as water supply, soil, nutrient supply and genetic differences, we plan to examine the light-polluted (facing towards the lamp) and non-light polluted (away from the lamp) side of the same plant. However, this does not eliminate the effect of the changing amount of sunlight at different times of day. The effect of cardinal directions was investigated on *Tilia cordata* plants in natural, light-pollution-free environments in early summer. Measurements were made on branches facing north, south, east and west. The intensity of flowering (the number of buds, open flowers, withered flowers per inflorescence) was determined in the mass flowering period.

Leaf morphology in each group was characterised by the measurement of the length and width of all leaves on five shoot sections, and the length and width of fully developed leaves with the same orientation from twenty shoot tips. On the same leaves, net photosynthesis was measured with LICOR 6400 (LI-COR Environmental, USA) photosynthesis system in ten replicates at a constant 1000 PAR (photosynthetically active radiation) exposure. Data was collected for two minutes, and net photosynthesis and transpiration were evaluated.

Photosynthetic activity of the leaves was studied by measuring variable chlorophyll fluorescence. In order to detect heterogeneity in fluorescence emission, fluorescence images were taken with an imaging-PAM M-Series chlorophyll fluorescence system mini-head (Heinz Walz GmbH., Effeltrich, Germany). Samples were dark-adapted for twenty minutes prior to the onset of actinic light to obtain measures of minimal (F0) and maximal (Fm) fluorescence in darkness and with a saturating flash, respectively. The maximum quantum efficiency of photosystem II (PSII) was calculated as Fv/Fm = (Fm-Fo)/Fm (Björkman and Demmig 1987). Photochemical parameters were measured every twenty seconds using low intensity (80 μmolm-2s-1) actinic light for five minutes. The light response curve was also measured by keeping the sample at various, increasing photosynthetically active radiation (PAR) levels. Each level of actinic light was maintained for twenty seconds, and then the fluorescence was measured before (F0) and after (Fm) saturating flash. The following parameters were calculated on the basis of the nomenclature and equations summarised by Rosenqvist and van Kooten (2003): the quantum yield of PSII photochemistry [YPSII = (Fm'-F')/Fm'], the Stern-Volmer non-photochemical quenching [NPQ = (Fm-Fm')/Fm'] and the rate of electron transport (ETR = ϕPSII*PAR*0,5*0,853) as µmolm-2s-1 electrons transported. Data was subjected to an analysis of variance (one-way ANOVA) and a paired Pearson's t-test.

3.2. Results and discussion

Significant differences in leaf morphometry and photosynthesis physiology were found between different parts of the same plant exposed to different cardinal directions (Table 3.1). Unfortunately, large differences in the morphological and morphometric characteristics of all the leaves measured even on a single shoot resulted in a large variance which prevented effective statistical comparisons. Moreover the length, width, weight, and length/width ratios were significantly higher for fully developed leaves oriented to the west. The smallest weight and size were typical of the leaves on the south side. During mass flowering, blooming was delayed on the eastern and northern sides of the tree compared to the southern and western sides. While the number of open flowers on the south and west sides of the tree reached 50%, on the eastern side it was 40% and on the northern side only 26%. The number of flowers was significantly ($p \leq 0.01$) lower on the western side and northern side than on the southern side and eastern side (Table 3.1). The net CO_2 incorporation (Fig. 3.1) was significantly higher in leaves facing to the west than in those oriented to the east. Low net photosynthesis was also observed in the southern and northern leaves, but the difference was not significant. Higher CO_2 incorporation also resulted in higher water use on the western side. The maximum quantum efficiency (Fv/Fm) of the photoelectric system II (PSII) was higher only in leaves on the west side (Fig. 3.2). In ideal conditions, in the case of vascular plants, its value is between 0.75 and 0.82 (Björkman and Demmig 1987), below this level, this parameter is frequently used to measure stress.

Table 3.1. Effect of cardinal directions on flowering of *Tilia cordata* Mill (*** significant at $p \leq 0.01$ with north, east, west and south directions)

	North	**East**	**West**	**South**
Flower number (piece/ flowers)	3.83+1.510	5.56+1.390	4.63+1.601	5.47+1.849
Leaf length (cm)	6.36+0.500	6.51+0.514	7.51+0.802***	6.17+0.411
Leaf width (cm)	5.19+0.525	5.369+0.379	5.90+0.627***	4.99+0.422
Leaf length/width (ratio)	1.232+0.093	1.213+0.050	1.277+0.09***	1.242+0.087
Leaf fresh weight (g)	0.424+0.089	0.469+0.068	0.558+0.134***	0.399+0.060

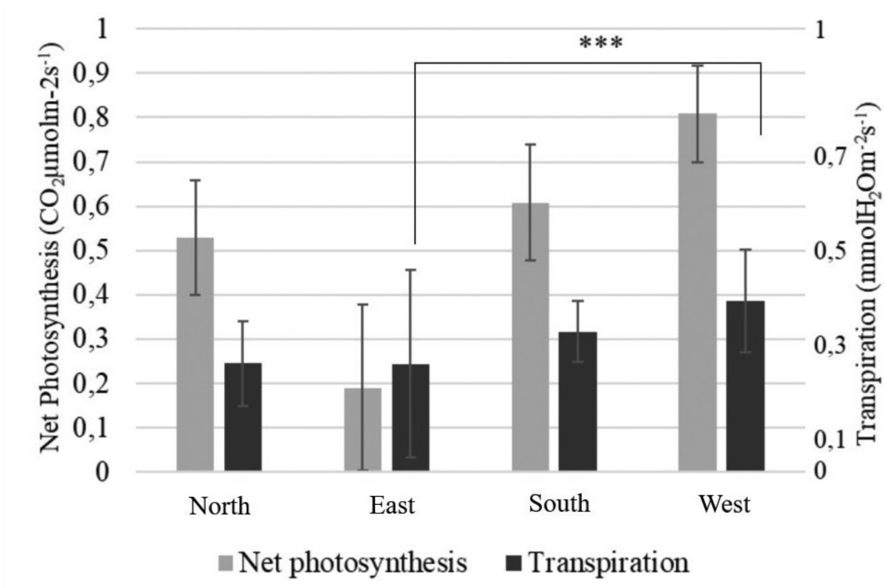

Fig. 3.1. Effect of cardinal directions on the photosynthesis and transpiration in *Tilia cordata* Mill. (*** significant at $p \leq 0.01$). The most efficient photosynthesis was measured in the leaves on thewestern side, which is significantly lower only on the eastern side and most of the water is evaporated on the western side

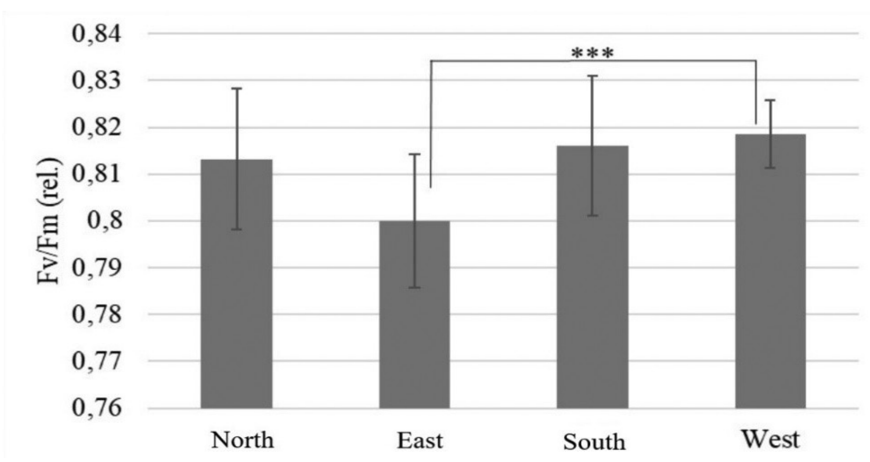

Fig. 3.2. Effect of cardinal directions on the maximum quantum efficiency of photosystem II in *Tilia cordata* Mill. leaves (*** significant at $p \leq 0.01$). Photosynthetic stress is most pronounced in the leaves on the eastern side

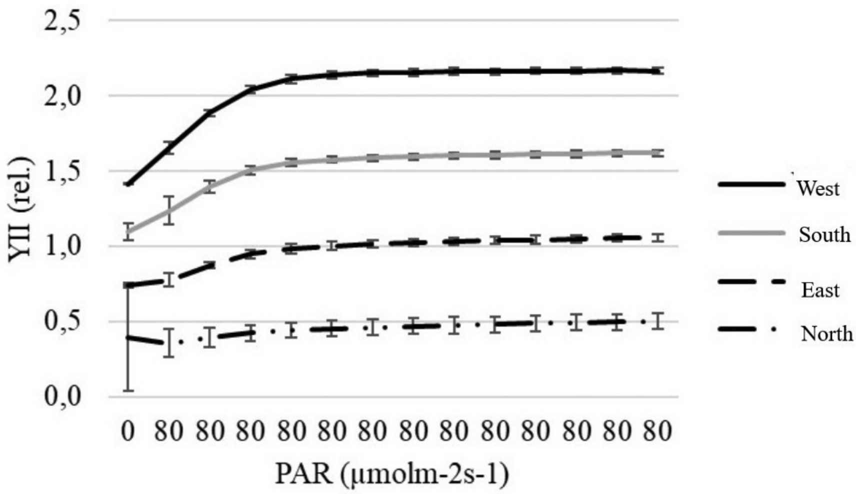

Fig. 3.3. Effect of cardinal directions on the quantum yield of PSII in *Tilia cordata* Mill. leaves

The quantum yield of PSII (YII) is also the highest on the western side (Fig. 3.3), on this side of the tree, the photosynthetic apparatus operates most efficiently and incorporates most of the organic matter in the leaf.

The observed differences are similar to those published for leaves in light versus leaves in shade. Leaves growing at high luminous fluxes are characterised by higher maximum quantum efficiency Fv/Fm and quantum yield (YII) than leaves in shade (Xu et al. 2009). The cardinal effect could be explained by the lower luminous flux on the north side, but low illumination intensity is less pronounced on the eastern side, although lower photosynthetic activity was also observed there.

Cardinal effects were also evident in leaf morphology and physiology on the *Tilia cordata*. According to our other observations, there might be differences between individuals of a given species, so it is advisable to study the effects of light pollution on the same individual to eliminate the effects of genetic differences.

Therefore, in our experience, it is important that when designing studies on the effects of light pollution, consideration should be given to possible cardinal effects when selecting the individuals involved in the experiment, and that species/individuals' responses to cardinal effects should also be examined beforehand.

4. ARTIFICIAL LIGHTING AND LIGHT POLLUTION FROM THE PLANT'S POINT OF VIEW

Anna Kołton[1], Monika Czaja[2], Olga Długosz-Grochowska[3]

As sessile organisms, plants are affected by many environmental factors during their life cycle. Light condition, temperature, air humidity and soil parameters fluctuate daily and seasonally; however, during their evolution, plants have adapted to these changes. Day and night fluctuations are recognised by plants and regulate their metabolism and life cycle. Recently, plants exposure to light pollution has increased, especially in urban areas, and we should ask questions about the consequences. Mechanisms of the effect of light (radiation intensity, direction of incidence, length of the day and spectral composition) on the functioning of plants are studied. For plants, light is a source of energy necessary for photosynthesis as well as a source of information about the environment and time of both year and day. Even a low intensity of radiation can cause the photomorphogenic reactions of plants. The appropriate radiation intensity, the direction of lighting, the spectral composition and the light/dark cycles provide the proper growth and development of plants.

Some plants are important in the human diet as a source of nutrition, and they should be available as fresh throughout the year. Therefore, indoor production with the possibility of adjusting light conditions and other cultivation factors is carried out. To optimise the lighting used in plant production for obtaining good yield with high quality, a number of studies are conducted. LED lamps are a very promising, modern light source for under-cover crop production. Their use increases the growth and improves the quality of the yield. Unfortunately, the escape of light during the natural night often occurs in under-cover plant production.

It is also worth mentioning that plants accompany humans not only as source of food but they are also a natural part of ecosystems or are introduced into the environment for many important functions (such as: noise suppression, phytoremediation, temperature reduction, decoration). These plants are often illuminated at night unintentionally, e.g. by street lights. Their metabolism and natural day and night cycle are disturbed. As a result,

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changes in the timing of bud burst, flowering, dormancy or senescence are observed. It is expected that the life expectancy of light-polluted plants is shortened in a species-dependent manner and that the phenological phase shift will have an impact on ecosystems and other living organisms (animals, including insects).

Used properly, artificial lighting can have a positive effect on plant growth and development. However, the uncontrolled escape of light at night may negatively affect the functioning of plants.

4.1. The sensing of light by plants

Each of us can observe plants in nature and it is easy to see that plants react to changing light conditions. We can observe that higher trees grow in a dense forest, and trees of the same species growing in the open area have a shorter trunk and more branches (Fig. 4.1a, b). Some species of plants open flowers during the day and close them in the dark (Fig. 4.1c, d), others bloom only at certain times of the year (for a certain length of day and night). Plants growing in shady conditions look completely different from those growing in good lighting exposure (Fig. 4.2a, b). It can sometimes be observed that some plants change the position of the leaflet in a compound leaf during the day (*Oxalis triangularis* – false shamrock, *Phaseolus vulgaris* L. – common bean, *Robinia pseudoacacia* L. – black locust Fig. 4.3a, b), or plants growing on a window sill "turn" their leaves or flowers towards the glass and better lighting. All these observations lead to the conclusion that plants react to light and, more precisely, to its intensity, the duration of the light phase during the day, the direction of incidence and wavelength. People have performed these kinds of observations for centuries and descriptions of such phenomena were made as early as those of Theophrastors of Eresos (380-287 BC) and Marcus Terentius Varro (116-27 BC) (Schäfer and Nagy 2006, 1). Light can be a source of information for the plant about the surrounding environment and a source of energy for biochemical processes. Such a reaction of plants to an external stimulus (light) is possible by having photoreceptors enabling the receiving of information about the stimulus and its further transmission. Several photoreceptors have been found in plant tissues. They are sensitive to specific radiation and regulating selected reactions. Plant photoreceptors include: phytochromes, phototropins, cryptochromes, F-box containing Flavin binding proteins (e.g., ZEITLUPE, FKF1/LKP2) and UVR8, which regulate a number of growth and developmental processes (Paik and Huq 2019, 114-116; Galvão and Fankhauser 2015, 46-48). Thus, they are involved in the process we call photomorphogenesis. With the participation of these photoreceptors and light, the following are regulated: seed germination, seedling deetiolation, growth and development, transition from the vegetative to the generative phase, photoperiodism, the aging of leaves and whole plants, entering and waking from senescence, biological rhythms, shadow avoidance phenomenon, and the movements of chloroplasts, stomata or whole organs (phototropism). Additionally, light controls the circadian and annual clocks of plants. The above-mentioned photoreceptors are sensitive to specific types of radiation: far red, red, blue, as well as UVA and UVB radiation (Fig. 4.4).

However, plants can also use light as an energy source. In the process of photosynthesis, plants are able to transform radiation energy into chemical energy and accumulate it in chemical compounds, e.g. sugars. Light receptors in photosynthesis are chlorophylls and carotenoids, absorbing blue and red radiation (Fig. 4.4) (Bennie et al. 2016, 614). Thus, we can conclude that light regulates many processes in plants. However, we should underline here that darkness is also necessary.

The intensity of light, its spectral composition, direction of incidence and the length of the period of light and darkness in the circadian cycle are important. This is the effect of adaptation to changing environmental conditions. Plants have adapted to the fact that the natural light coming from the sun, stars and moon, changes in its intensity not only in the circadian and annual cycle but also due to changing weather factors. At night, the light intensity is much lower than during the day; usually from sunrise, the radiation intensity increases until noon and decreases in the afternoon. However, on a cloudy day, the intensity is low even at noon. On a cloudless night, it is brighter than during cloud cover and during a full moon, it is brighter than during a new moon. Usually in summer, the intensity at noon is much higher than in winter. Interestingly, the angle of sunlight also changes, which is associated with the apparent motion of the sun in the sky. Moreover, the spectral composition of sunlight changes both in the circadian and annual cycles, which Brelsford et al. (2019) present in their publication.

The sources of light on Earth change with the development of civilization. Plants are now affected not only by sunlight, moonlight and starlight but also by artificial light produced by devices invented by humans. This artificial light escapes into the environment and changes the natural length of day and night. The typical light intensities during the day and night, and including street lights are presented in Table 4.1 and expressed as illuminance in lux (visible light flux on the surface, brightness to the human eye) and photon flux

Table 4.1. The level of light intensity measured as illuminance or photon flux density of natural sources and street lighting

	Illuminance (lux)	**Photon flux density (μmol m^{-2} s^{-1})**
Daylight	1-100,000*	1-1,900**
Twilight	0.1-10*	26.5**
Moonlight	0.01-1*	0.005**
Starlight	0.00001-0.001*	0.0001-0.05**
Street lighting	0.00001-1000*	0-60***
Skyglow	0.00001-0.05*	

* according to Bennie et al. (2016, 613)
** according to Taiz et al. (2018, 276, 458)
*** own measurements with SpectraPen mini (PSI, Czech Republic)

density in μmol of photons $m^{-2}s^{-1}$ (important in plant biology). Photosynthesis requires light as an energy source – the optimal irradiance for photosynthesis of sunlit leaves in trees is much higher than for shaded trees (for example 1000 μmol $m^{-2}s^{-1}$ and 200 μmol $m^{-2}s^{-1}$, respectively). Photomorphogenesis or photoperiodism reactions can be caused by a much lower intensity of light (0.01-10 μmol $m^{-2}s^{-1}$) (Wojciechowska 2017, 44-45), which is observed in the environment due to light pollution.

Fig. 4.1. Plant reactions to light conditions – examples. Growth of pine (*Pinus*) tree in a dense forest (a) and in better light exposure (b). Flower opening of African daisy (*Osteospermum hybrids*) during increased light (c) and closing during decreased light intensity (d) (photo: A. Kołton)

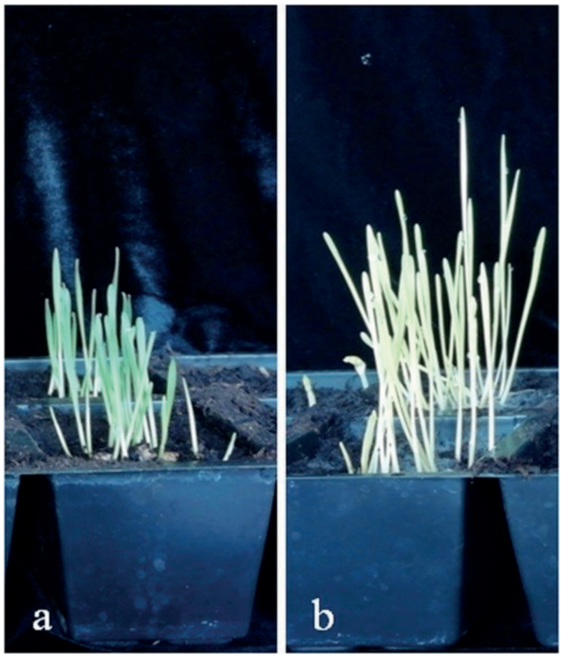

Fig. 4.2. Plant photomorphogenesis. Growth of wheat (*Triticum aestivum*) plants with access to light during the day (a) and in 24 h darkness (b) (photo: A. Kołton)

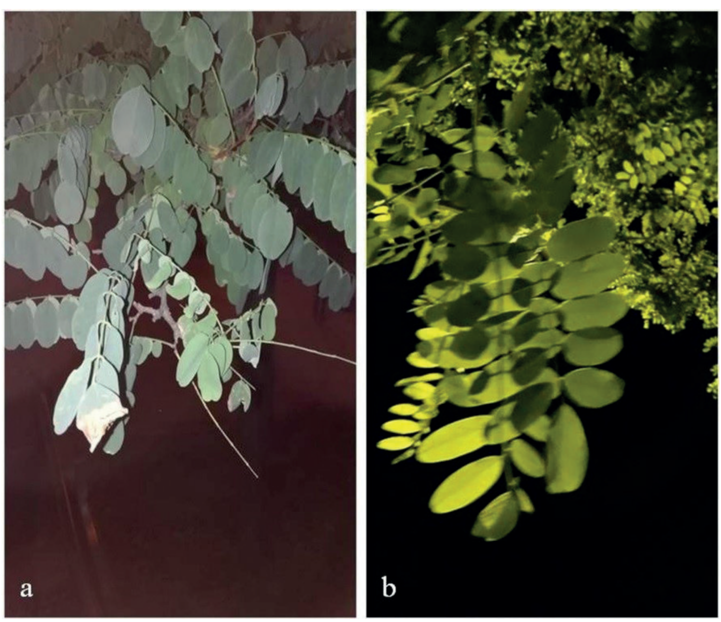

Fig. 4.3. Movements of Black locust (*Robinia pseudoacacia*) leaflets in compound leaves during dark night (a) and with artificial light at night from street lamps (b) (photo: A. Kołton)

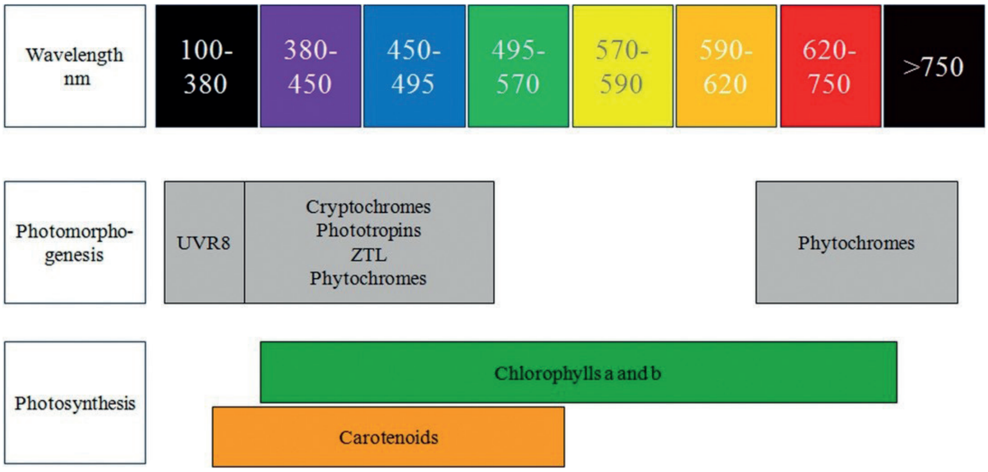

Fig. 4.4. Response of plant photoreceptors to specific wavelengths, including photomorphogenesis and the photosynthesis process (based on: Galvão and Fankhauser 2015; Paik and Huq 2019)

4.2. Artificial lighting in horticulture and plant production

In the temperate countries, the length of the day, the angle of incidence of sunlight and weather conditions vary significantly throughout the year. The changing seasons cause the stopping of plant vegetation during the autumn-winter months, which also applies to fresh plant-based food production. The constantly growing human population, together with increasing consumer awareness about the importance of fresh plant food intake for health maintenance has caused the rapid development of the production of crop plants under covers.

Some of the unfavorable weather conditions for plant vegetation have been overcome by providing protected horticultural strategies, including greenhouse or indoor plant cultivation, which has allowed the crop plant production throughout the whole year. However, protected horticulture remains limited by several factors which include the restricted quantity and quality of sunlight (short photoperiod, low angle of sunlight incidence, small number of sunny days), has been of significant concern (Gruda 2005, 242). To avoid the negative results of limited light access and quality, along with the development of lighting technology, these solutions were successively adapted for use in plant cultivation. The concept of protected plant cultivation in greenhouses and controlled-environment crop production keeps evolving and incorporates innovative technological solutions in order to obtain high quality products while at the same time trying to minimise the negative side effects affecting the environment.

The use of artificial lighting for plant growth was mentioned for the first time in 1860s, but commercial application of electrical lamp for crop production occurred in the early 20th century (Gupta and Agarwal 2017, 2). Throughout the decades, various types of lamps have been developed: "electric arc" lamps (beginning of the 19th century), incandescent and gas discharge lamps (late 19th century). Their designs were further improved, increasing their light output and the lifespan of their lighting units. One of the most preferred light sources to use in plant cultivation has been high-pressure discharge lamps, high in PAR (photosynthetically active radiation) emission with a relatively high share of blue radiation and satisfactory electrical efficiency (Simpson 2003). However, the above-mentioned conventional light sources are characterised by two main disadvantages: inefficient energy consumption and the inability to control the emitted spectrum to match the photosynthetic and photomorphogenic requirements of plants. The breakthrough in lighting technology was the invention of the first commercial light-emitting diode (LED) in the late 1960s (Gupta and Agarwal 2017, 3, 12), which was further improved resulting in the design of an energy-efficient light source able to emit narrow wavelength bands ranging from UV to far-red.

Despite the unequivocal benefits of using traditional light sources (mainly incandescent lamps, fluorescent lamps, high-pressure mercury vapour lamps, high-pressure sodium lamps and metal-halide lamps) in plant production (Gupta and Agarwal 2017, 2), the advantages of LEDs (e.g. low energy consumption, small sizes, high efficiency, and the ability to compose the emitted spectrum) led to the first attempts to use LED lamps to illuminate plants in the early 1990s (Bourget 2008, 1944; Morrow 2008, 1947-1948; Gupta and Agarwal 2017, 3). The results were promising and opened new possibilities for the use of light in plant cultivation, not only to enhance the growth and yield but also to influence the physiological and biochemical properties of irradiated plants. However, so far, the most commonly used light sources in plant cultivation have been discharge lamps: fluorescent, mercury vapour, mercury-incandescent, low-pressure sodium and high-pressure sodium (HPS) lamps (Puternicki 2010, 76), amongst which HPS units are the widest applied in greenhouses around the world (Wheeler 2008, 1942). However, their emitted spectrum and energetic efficiency are not optimal for all horticultural purposes, so the introduction of LED lighting sources to plant production is promising (Ozounis et al. 2015, 1128). Thanks to further improvements, LEDs can currently emit radiation at wavelengths ranging from 250 nm (UV-C) to 1000 nm (infrared) and more (Bourget 2008, 1944). LED lamps are more efficient than the most popular HPS lamps and have a lifespan that is several times longer than traditional light sources, reaching even 100,000 h (depending on the structure and semiconductor used) (Bourget 2008, 1945; Singh et al. 2015, 145). Other advantages of LEDs are: a fast on-and-off cycle, low heat radiation, small size, lack of hazardous substances (Morrow 2008, 1947). From the crop producer's perspective, the most important feature is the possibility to combine specific diode colours to compose emitted spectra tailored to the demands of certain plant species and development phases. LED lamps may be integrated with electronic controllers, which allow programing of the photoperiod, intensity or light colour during cultivation, which provides the opportunity to obtain high quality and quantity yields in a shorter period of time (Yeh and Chung 2009, 2179; Grzesiak et al. 2014, 104-105; Cocetta et al. 2017, 1, 13).

Artificial light sources which have been used for supplementing natural sunlight in greenhouse plant production have been proven to have a beneficial effect on the growth and development of plants (Cathey and Campbell 1980; Krizek et al. 1998, 69). In subsequent years, further studies regarding the impact of supplemental lighting in protected plant production led to the improvement of lighting systems and strategies for artificial lighting implementation in greenhouses. For example, extensive studies on the plants' responses to different light intensities, daily light integral (DLI) and photoperiod duration have been conducted in the case of commonly grown plant species, such as radish, corn and cucumber (Gislerod et al. 1989, 295) or roses (Jiao et al. 1991, 245). Due to advantages in growth and yield production of greenhouse crop plants, supplementary irradiation with the use of traditional light sources (particularly HPS lamps) is still used in commercial greenhouses (Dominiczak 2018).

In the last twenty years, there has been a vast amount of research published on the topic of the usage of artificial lighting in plant production, specifically with regard to LED lighting in dozens of systems and configurations. Solid-state lighting (SSL) LED lighting systems applied in greenhouses as a source of supplementary lighting have shown a positive effect on biomass growth and yield of many economically important species, ranging from tomato and cucumber (Ménard et al. 2006, 291), through lettuce (Ngilah et al. 2018, 1300) and microgreens (Vaštakaite et al. 2017, 6529), to decorative plants such as begonia (Fu et al. 2018, 1007), gerbera (Llewellyn et al. 2019, 95) and rose (Harada and Komagata 2014, 443). The most recent work has shown the positive aspects of using LED supplemental lighting even in tree pre-cultivation, namely for *Picea abies* (L.) and *Pinus silvestris* (L.) (Hernandez et al. 2019, 159).

A high level of interest has recently been directed towards supplemental lighting applied in leafy vegetables production, as the demand for fresh leafy vegetables and

Fig. 4.5. Cultivation of lamb's lettuce (*Valerianella locusta*) with different LED lamps: pure red, red with blue in different proportions and white (photo: A. Kołton)

microgreens is increasing in the vegetable market. LED lamps located within a canopy of cowpea (*Vigna unguicultata* L. Walp.) improved fresh mass production as well as reduced the senescence of older leaves (Massa et al. 2008). The use of LED lamps designed specifically for the photosynthetic spectrum range showed an increased yield of lettuce compared to other, commercially available lamps (Urrestarazu et al. 2016, 271). Because the main peaks of photosynthetic pigment absorbance are in the range of blue and red wavelengths, studies on the effect of different red to blue light ratios on the growth of lamb's lettuce (*Valerianella locusta* L.) cultivated in greenhouse during the autumn and winter were conducted (Fig. 4.5) (Wojciechowska et al. 2013, 41-47; Wojciechowska et al. 2015, 80-86). The results suggested a strong influence of applied supplemental lighting at the end of the day on the yield of this popular leafy vegetable, with the most favorable spectral compositions being 90% red and 10% blue light (Wojciechowska et al. 2015, 83-85) and 80% red and 20% blue (Długosz-Grochowska et al. 2017, 444-448). Moreover, further studies indicated that specific spectra may also contribute to changes in the biochemical composition of this crop plant, resulting in an increasingly high-quality yield with high nutritional values. For example, the use of 90% red and 10% blue supplemental lighting resulted not only in gaining greater biomass but also dry mass and soluble sugar concentration (Wojciechowska et al. 2015, 83), ascorbic acid content, polyphenolic compounds level and radical scavenging activity (Wojciechowska et al. 2015, 84; Długosz-Grochowska et al. 2016, 233-234).

Applying this supplemental lighting composition also resulted in the reduction of nitrate concentration in lamb's lettuce leaves (in comparison with HPS supplemental lighting), which is a very desirable effect due to their possible harmfulness to humans in the event of an excessive supply in the diet (Wojciechowska, et al. 2016, 182-183). Furthermore, testing the storage ability and shelf life of lamb's lettuce grown in the greenhouse with the use of red/blue LED supplemental lighting indicated that the quality and usefulness of these plants were at least as good as that of plants cultivated under HPS lamps (Kołton et al. 2014, 161-163).

The overall costs of autumn greenhouse cultivation of this vegetable with red/blue LED supplemental lighting, compared to the use of HPS lamps, appear to be lower, which is an important issue for crop plant producers (Wojciechowska et al. 2016, 238, 240-241). Studies of the manipulation of crops' biological value with certain LED light parameters have recently been of high interest. Supplemental blue radiation positively affected polyphenolic compounds in both green and red lettuce varieties (Lee et al. 2019, 2225-2232). The use of different pulsed LED light spectra in the cultivation of microgreen vegetables resulted in elevated polyphenol concentrations (Vaštakaite et al. 2017, 6531). The application of 80:20 ratio of red to blue LED light during the sprouting of broccoli (*Brassica oleracea* var. *Italica*) caused higher accumulation of carotenoids, as well as the increase of magnesium and iron, in comparison to fluorescent and incandescent light use (Kopsell et al. 2014, 472-474). Study on kale (*Brassica napus*) led to the conclusion that far-red light application leads to shorter hypocotyls, very high pigment levels, and accumulations of general antioxidants and aliphatic glucosinolates (Carvalho and Folta 2014, 2-12).

The use of certain light composition may also be used depending on the aim the producer wants to achieve. For example, in grapevine cultivation in China, using blue emitting LED strips to irradiate leaves resulted in improved fruit composition (anthocyanin content, soluble sugars to organic acid ratio), whereas red LED use caused increased fruit mass (Li et al. 2017, 60-64). Supplementing natural sunlight with combined HPS and LED lights is also applied in the greenhouse growing of various crops. An increase in the total yield of sweet peppers has been achieved by using LED interlighting with HPS top lighting (Guo et al. 2016, 90-93). Applying LED interlighting to tomato crops also has promising results and is gaining popularity among commercial producers of this vegetable (Davis and Burns 2016, 225). The pre-harvest addition of red LED light to HPS lighting in the cultivation of various small leafy vegetables has contributed to an increase of polyphenolic compounds (Žukauskas et al. 2011, 90), antioxidant capacity (Samuolienė et al. 2012, 703-705), and nitrate depletion (Samuolienė et al. 2009, 1858-1859). By affecting the chemical composition of plants, the use of proper spectral composition may affect resistance to some pests or diseases, e.g. blue-light treatment increased resistance to *Botrytis cinerea* in tomato plants (Kim et al. 2013, 3-4).

Besides their use with vegetable crops, LED lighting is also considered helpful in ornamental plant cultivation in increasing both biomass production (high yield production), and quality parameters (e.g. pigment concentration), as well as shortening the production

Fig. 4.6. The effect of LED lamps on begonia (*Begonia semperflorens*) plant growth and flowering. From left: row of control plants followed by those treated with white, rose and violet light emitted from LED lamps (photo: A. Kołton)

cycle. In the greenhouse cultivation of *Begonia semperflorens*, applying evening supplemental LED lighting (white, rose or violet) resulted in a higher number of flowers in comparison to plants grown without supplemental lighting (Fig. 4.6) (Kołton et al. 2013, 45-46). Moreover, the use of rose and violet light resulted in higher biomass of the above-ground parts of these plants than non-irradiated and white-irradiated plants; furthermore, rose light caused an acceleration in the appearance of flowers in comparison to plants grown without supplemental lighting (Kołton et al. 2013, 44-48). Replacing HPS lighting with LED light in few cultivars of *Gerbera jamesonii* resulting in the equivalent or improved yield and quality of cut flowers. Interestingly, the vase life of cultivar 'Acapulco' flowers grown with LED supplemental lighting was 2.7 day longer than those cultivated under HPS lamps (Llewellyn et al. 2019, 97-98).

Other studies concerning LED supplemental lighting in *Lachenalia* spp. greenhouse cultivation showed significantly longer inflorescences with higher stem diameters and the highest number of florets when plants were exposed to 90% red and 10% blue light in comparison to plants not receiving such treatment (Wojciechowska et al. 2019, 96). Additionally, *Lachenalia* grown under lights with blue wavelength range in the spectrum were characterised by a higher content of anthocyanin pigments in corolla (which contributed to a more vivid flower colour) than flowers grown without supplementary lighting or under pure red light (Wojciechowska et al. 2019, 97). Recent studies indicate that implementing certain schemes of supplemental lighting may reduce chemical use. For example, growing poinsettia with the addition of low-intensity red light resulted in shorter internodes (Islam et al. 2012, 138, 140; 2014, 81; Bergstrand et al. 2016, 36), which, without red light exposure, requires chemical retardant use.

Fig. 4.7. View of light emitted from an operating greenhouse. One section of the greenhouse is lit with LED lamps (A – red and blue light); the rest of the greenhouse is illuminated with HPS lamps (B – yellow light) (photo: A. Kołton)

The use of artificial lighting in protected plant cultivation contributes to obtaining a high yield of high quality across all types of horticultural crops, allowing the growing of plants in growth chambers and greenhouses all year round. Besides increasing the yield, the implementation of certain spectral composition schemes may contribute to the improvement of storage properties, biochemical composition, taste, and disease resistance, even replacing some chemical treatment.

Despite the advantages of artificial lighting in horticulture, the light beams originated from artificial light sources often reach beyond the area to be purposely illuminated. The covering of greenhouses during periods of night lamp operation to prevent light escape is not standard practice unfortunately due to difficulties in temperature and humidity maintenance. Using supplementary lighting in greenhouses to prolong the photoperiod during the night causes unnatural illumination of the area outside of the greenhouse (Fig. 4.7) and atmosphere, making artificial glow in the sky. Usually, light-polluting greenhouses are of a large area and are equipped with high-power lighting installations operating several hours a day throughout the year. Measurements of luminance performed at night in the immediate vicinity of a greenhouse equipped with a lighting system consisting of around one thousand HPS lamps 600 W each (in total over 600 kW of installed power) showed a contrast of the greenhouse's luminance to the background luminance within the range of 84:1 to 115:1 (Raczak et al. 2018, 202). According to the presented data, illuminance used in greenhouse crop cultivation is desirable and useful for plants grown in greenhouses. However, this raises the question of how the uncontrolled glow of multi-watt lighting systems affects organisms living in the immediate vicinity of greenhouse complexes. The good news is that plants cultivated under cover also need regular dark periods, so the artificial lighting used in greenhouses is not programmed to work 24h a day.

4.3. Plants and light pollution

Several factors need to be in cooperation for the harmonic growth and development of plants. From the external factors, the most important are air and soil temperature and the availability of nutrients, water and light. If there is a disruption to one of the above-mentioned elements, plants are under stress conditions. Such circumstances lead to numerous changes in physiology and phenology (sequence of growth phases) (Dale and Frank 2017, 2; Xie et al. 2018, 127). Groups of plants that are constantly subjected to many stress factors are urban trees and shrubs. As they live for many vegetative seasons, they need to cope with the long-lasting effects of high urbanisation. Drought, air pollution, excessive air temperatures, a lack of nutrients, limited area for growth and shading from high buildings are some of these unfavorable factors (Calfapietra et al. 2015, 72-75). During recent decades, these factors have been widely studied and some technological solutions and also species selection for urban areas have been proposed. However, improper lighting is still new issue. The growing problem of light pollution by artificial lighting extensively used in cities can generate a massive disruption to plant phenology (Fig. 4.8). This phenomenon is a relatively new field of study, and until now, we do not know much about how exactly the plant will react in such a modified environment. For example, the phenological cycles depend on temperature and day length. How these factors interact is species dependent (Laube et al. 2014, 170). The disturbances of temperature and day length due to climate changes such as global warming and light pollution will have unpredictable effects. Plants need a certain duration of cold conditions for dormancy completion – these are known as chilling requirements. As Laube et al. (2014, 174, 178) prove in their study, generally photoperiod has minor influence on budburst while temperature has greater effect. When chilling requirements are not fulfilled then photoperiod may affect budburst. However, in the aforementioned study,

Fig. 4.8. Illumination of urban greenery by street lamps and light pollution (photo: A. Kołton)

the cycles of light and dark conditions were maintained. This case underlines the complexity of interaction between temperature and light in a changing environment. Furthermore, the reactions of plants to such stress are still not well studied, and so the available literature often concerns model plants such as *Arabidopsis*. The need for investigation of the plants' reaction to light pollution is of high importance. However, the number of experiments and insights are increasing every year and this can bring us closer to the essence of the problem and make it possible to propose potential solutions.

4.4. Spring and autumn phenophases

Second to temperature, day length is the factor that enables plants to sense the change of seasons. The amount of energy adequate for photoperiodic responses is significantly lower than that required for photosynthetic needs (Chaney 2002, 66). The increasing length of daytime during the spring is a signal for plants to reactivate growth (Maurya and Bhalerao 2017, 351-353). Day length influences budburst in some species; this can also occur in combination with temperature. An experiment with thirty-six different tree species showed that a longer photoperiod (8h versus 16h of daytime length) enhanced budburst in only four species: *Abies alba*, *Acer pseudoplatanus*, *Fagus sylvatica* and *Juglans regia*. In the presented study, chilling temperatures had a greater impact on budburst than the length of the day (Laube et al. 2014, 171-178). Nevertheless, the authors underline the importance of springtime light conditions. However, they do not estimate the effect of light pollution with 24h lighting per day, as is the case in urban areas. Blue light (which is present at a high ratio in cool LED light) increases the earliness of bud burst in the case of *Alnus glutinosa*, *Betula pendula*, *Quercus robur* from three to six days at 12 h photoperiod (in comparison to LED without blue light emission) (Brelsford and Robson 2018, 1159, 1161). Moreover, longer days can also reduce the temperature needed for bud burst (Way and Montgomery 2015, 1729). Trees growing in light-polluted areas can therefore start leaf development when temperatures are still too low and with a harmful frost risk. According to research conducted in Great Britain with data gathered over a thirteen-year period, bud burst was accelerated by up to 7.5 days in places with strong lighting. The authors argue that it is not only high temperature caused by the urban heat island that is the reason for earlier leaf development in urban areas but also light pollution (Ffrench-Constant et al. 2016, 8).

Light also affects bud set and the senescence of plants. The shortening of the day in autumn stimulates plants to retranslocate resources and enter into a period of dormancy and is also a signal to stop the intense growth in some species (Lagercrantz 2009, 2501-2509). Analysis of 166 individuals of *Fagus sylvatica* growing in a German forest show that canopies with better light availability start senescence earlier than those with poorer light conditions. In this experiment, trees were classified into three canopy height levels. Overstorey trees were the first to begin the autumnal phenological changes, followed by mesostorey and understorey trees. The authors concluded that air humidity and light availability were the reasons for such differences (Gressler et al. 2015, 185).

Leaf senescence triggering is a complicated issue, especially during climate change, while it depends on many environmental factors (Panchen et al. 2015, 870). The start of autumnal leaf senescence in poplars is connected with the photoperiod but not always with the temperature (Fracheboudet et al. 2009, 1987-1989). As presented in a review by Brelsford et al. (2019, 1-2) the start of autumn dormancy can be triggered by temperature or photoperiod depending on the species. Although, it is proven that both reducing temperatures and short days serve as signals for autumnal change (Brelsford et al. 2019, 1-2). Artificial lightning close to the canopy can interfere with sensing of the natural sequence of day and night. As a consequence, this may lead to a delay in autumn leaf senescence. Due to light pollution, the beginning of autumn phenological phases in cities, in sensitive tree species can be delayed by up to twenty-two days, and their duration can be extended by up to nine days (Škvareninová et al. 2017, 288). In such a case, light can disturb the photoperiod and thus expose non-senescing leaves to early frosts and taking away the opportunity to retranslocation of nutrients. Although, because of its photoperiod dependence, bud set and growth cessation seems to be unthreatened by climate warming (Way and Montgomery 2015, 1728-1729), it can be disordered by light pollution. What is interesting is that some of the common urban trees such as *Fagus sylvatica*, *Tilia cordata* are classified as being sensitive to the photoperiod while others like *Acer negundo*, *Carpinus betulus*, *Robinia pseudoaccacia* are classified as photoperiod insensitive. Some species remain equivocal with inconsistent classification between different studies, such as *Acer psudoplatanus*, *Betula pendula*, *Syringa vulgaris* or *Corylus avellana* (Way and Montgomery 2015, 1731).

Phenological changes due to light pollution are equally disturbed in spring and autumn. There is a risk of critical frost damage for trees which bud burst too early or bud set and enter dormancy too late (Ding and Nilsson 2016, 77).

4.5. Physiological changes

There may also be some advantages of longer light stimulation, such as longer photosynthetic activity in autumn, and earlier in spring, which can be connected with higher productivity. However, this is linked with a greater risk of harmful frosts in both cases and the longer canopy persistence is not necessarily linked with high photosynthetic activity (Way and Montgomery 2015, 1730). What is interesting is that light pollution can decrease photosynthetic performance by the degradation of pigments under such stress. A significant loss in green leaf colouration of night-light-exposed plants compared to controls was observed in *Liriodendron tulipifera* L. trees (Kwak et al. 2018, 20-21). The authors explain that this phenomenon was probably due to degradation of chlorophyll pigments in response to night-light treatment. Disturbances in photosynthetic apparatus functioning are also presented in the mentioned work after night-time light treatment (1, 3 and 50 μmol $m^{-2}s^{-1}$). The higher lipid peroxidation and electrolyte leakage in treated leaves in comparison to control leaves suggested that night-time light treatment was a stress factor. Moreover, the period of darkness, disrupted by light pollution, is needed for recovery from leaf damage caused by other environmental stresses such as atmospheric ozone and damage caused by solar UV-B radiation (Gaston et al. 2013, 918-919). Additionally, transpiration can be influenced by too long exposure to light, as well as by stomata movement.

It is known that transpiration trough stomata takes place round the clock. However, night time transpiration is, dependent on species, usually around 5-15% of the rate for the whole day (with maximum measured over 30%) (Caird et al. 2007, 1-6; Fricke 2019, 311-317). The cost of such a state is water loss, which is highly deficient in urban areas. Species from different functional groups (perennial grasses, shrubs, deciduous trees, broadleaf evergreen trees and conifers) are able to conduct transpiration at night due to the incomplete closing of stomata. Since transpiration rates during the night are negligible, it is a time for plants to recover from the temporary wilting state caused by high transpiration during the day (Singhalet et al. 2019, 195). Night lamps emit very low amounts of energy, but they disturb the natural photoperiod. It is proven that stomata opening is linked with light signaling. What is interesting is that both blue and red light have an important role in stomata regulation (Shimazaki et al. 2007, 237). Moreover, relatively small light doses, about 1-10 $\mu mol\ m^{-2}s^{-1}$, stimulate stomata opening (Chen et al. 2012, 567-568). Higher light intensity increases stomata opening in most plants, but there are some exceptions (Xiong et al. 2017, 441). For this reason, we can assume that artificial night light pollution can influence greater stomata opening than the natural environment, and thus increase water loss from plant tissues.

4.6. Flowering and pollinators

The purpose of flowering is the successful reproduction of plants. Research connected with floral initiation is mainly conducted on herbaceous species. Recognised pathways which lead to flowering are: autonomous, light, gibberellins and temperature dependent (Wilkieet et al. 2008, 3215-3217). What is of great importance is that the length of the day may influence flowering induction through the photoperiodic pathway. Some species are induced to flowering by long days, others by short days (Lagercrantz 2009, 2502-2503). Both can be disturbed by light pollution. Artificial light at night interferes with the plant's ability to accurately perceive the number of long days and completely excludes the occurrence of short days. Only the third group – day-length neutral plants would not be disturbed in this case.

A lot of information concerning changes in the phenological phases of plants (the start of flowering) between urban and rural areas is connected with temperature, but maybe factors of both temperature and light are important. In 2006, Neil and Wu (249) suggested that the effect of the photoperiod or the interaction of both the photoperiod and the temperature on plant flowering is known, but there is lack of research concerning the influence of urbanisation on daylength perception by plants. However, it is highly probable that light pollution will disorganise the light controlling flowering phenology. Since aforementioned publication we have only been able to find a little information regarding the effects of light pollution on flowering. By contrast, many reports describe the effect of light and the photoperiod on flowering (Jackson 2008, 517-528; Pearce et al. 2017, 1139-1149; Park and Jeong 2019). Tree flowering can be regulated by a range of factors including temperature and the photoperiod, and it is difficult to analyse them in isolation (Wilkieet et al. 2008, 3223). For example, apple tree flowering is more dependent on temperature but poplar floral initiation is more affected by long days. The results of field experiments concerning the impact of light pollution on grassland vegetation indicate significant changes in biomass production and plant cover in three grass species (Bennie et al. 2018, 446-449). However, the observed increases and decreases in biomass production were dependent upon the tested species. What is important is that the authors also observed changes in flowering phenology from four days earlier to twelve days later for plants under artificial light in comparison to plants exposed to only natural light. It is worth mentioning that negligible changes in flowering were observed when artificial light was introduced for only part of the night. To reduce the ecological consequences of light pollution at night, switching lighting off for a part of the night might be good practice.

The wild plant, foredune (*Traganum moquinii*), exposed to artificial light significantly decreases the production of flowers compared to shady plants or plants grown away from artificial light (Viera-Pérez et al. 2019, 9), which suggests a lower potential for seed production in the presence of light pollution. Disturbances in the time of flowering can be highly troublesome if it becomes not synchronised with the lifecycle of pollinators.

Light pollution also affects the life cycles of insects in different ways. Artificial light attract moths, which are more prone to attack from predator in lamp light. What is interesting is that it is possible to minimise this effect by changing the spectrum of the light wavelength. The use of lamps with larger wavelengths (without UV emission) reduced the negative effects of light pollution to moth population (van Langevelde et al. 2011, 2280).

Summary

Plants are sensitive to light and dark conditions. It is possible to use supplementary lighting in under-cover cultivation to improve the yield and quality of crops of both vegetables and ornamental plants. Properly used artificial lighting can have a positive effect on plant growth and development. Nowadays, due to the development of industry and urbanisation, we observe a huge escape of light into the environment. Artificial light reaching plants in the period of natural darkness primarily disturbs biological rhythms. Uncontrolled artificial light at night may negatively affect the functioning of plants and ecosystems. The final effects of light pollution on plants are difficult to predict.

Acknowledgements

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5. COMPARISON OF TWO MEASUREMENT METHODS – PHOTOMETRIC AND PHOTOGRAPHIC – IN STUDIES OF NIGHT-SKY BRIGHTNESS

Dominika Karpińska[1], Mieczysław Kunz[1]

Through his actions, man consciously or, increasingly rarely, unconsciously impacts the surrounding environment, and the consequences of these actions are experienced or observed within a very short time after the occurrence of the stress factor (Jechow et al. 2019, 212-223). At the same time, we attempt to protect the environment by establishing numerous protected areas, changing the law, introducing restrictions and penalties, as well as educating society at large, setting up organisations working to prevent environmental degradation or introducing eco-friendly products and economic and legal incentives for companies operating in accordance with the concept of sustainable development. Along with the rapid development of civilisation over the last two decades, we have observed an increase in pollution of anthropogenic origin with the emergence of other factors and forms of human impact. The most common and perceivable pollutants include: air pollution (e.g. particulates and ozone), water and soil pollution (e.g. pesticides and heavy metals), landscape pollution, noise pollution and radioactive contamination (Wang et al. 2004; Wyszkowska and Wyszkowski 2007, 231-235; Para and Para 2013, 88-97; Woźny et al. 2014, 251-258; Żurek et al. 2017, 54-56; Qadri and Faiq 2019, 15-26; Wani et al. 2019). Along with the progress of science, we become increasingly aware of new forms of pollution that have not been considered before. One of these new sources of environmental pollution is light.

Light pollution is a relatively new phenomenon that has not yet been fully explored in such a comprehensive and multifaceted way as to determine all the conditions and parameters that affect it. The main difference distinguishing this phenomenon from other types of ecosystem contamination is the fact that the factor causing it is light, which in itself is not associated with negative effects of human activity (Roge-Wiśniewska 2015, 15-28). Research aimed at hitherto unknown pollution, along with regular monitoring,

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was actually only initiated at the end of the last century. This type of research in Poland has been conducted by only a few academic institutions (Ścięż or et al. 2010), but it is currently becoming increasingly popular and various aspects of light pollution are being analysed (Hänel et al. 2017; Karpińska and Kunz 2019, 91-100). In order to explore the topic thoroughly, an interdisciplinary approach and joint efforts by researchers representing miscellaneous scientific disciplines is necessary. Furthermore, the establishment of a common measurement network to monitor this phenomenon and to collect data in different conditions would appear purposeful.

5.1. Light pollution

Apart from many positive aspects for man, the development of civilisation and technological progress has negative consequences for the environment, one of which is the increasing amount of light emitted into the upper atmosphere at night. The vast majority of people are not aware of such a phenomenon and its negative impact on the organisms of the biosphere and they do not associate it as being a side effect of human activity (Roge-Wiśniewska 2015, 15-28; Jechow et al. 2019, 212-223).

Plants, animals and ourselves are accustomed to the daily rhythm and any deviation from it can have negative consequences for our health and functioning (Kowalska 2017; Jechow et al. 2019, 212-223). In the case of the human body, an excessive amount of light at night can cause hormonal disorders, metabolic problems, melatonin deficiency as well as the deterioration of sleep quality and slow-wave sleep deprivation (Jones and Francis 2003, 328-333; Stevens 2009, 1-8; Depledge et al. 2010, 1383-1385; Skwarło-Sońta 2014, 223-231). Such a phenomenon is also significantly reflected in abnormalities in the development of plants and the daily functioning of animals and their migrations (Jones and Francis 2003, 328-333; Navara and Nelson 2007, 215-224; Stevens 2009, 1-8; Connors 2010, 146-156; Depledge et al. 2010, 1383-1385; Longcore 2010, 893-895; Falchi et al. 2011, 2274-2281; Davies et al. 2013, 1417-1423; Zimoch 2017).

Light pollution is becoming an important and contemporary problem for the inhabitants of urban areas. Surrounded by numerous light sources, they are unable to see the numerous star constellations at night, not to mention the view of the Milky Way. More than 60% of the European population and more than 80% of the U.S. population already live in areas with significant light pollution (Falchi et al. 2011; Falchi et al. 2016; Zimoch 2017).

The described form of environmental pollution can be measured in a number of ways that are intended for use by both amateurs and professionals. The methods used to measure this phenomenon can basically be divided into observational and instrumental methods (Kołomański 2015, 29-46). This paper describes the simultaneous use of two instrumental measurement methods – photometric and photographic. The SQM device was used in the photometric method and the measurement was performed by taking pictures of the night sky with a Nikon camera.

5.2. Measurement network

The objective of the research was to measure the brightness of the night sky in the area of Toruń (Poland) and to compare the two measurement methods used. In order to make the research, a measurement network was established throughout the city. The locations within the measurement network were selected so as to meet the design assumptions, including those concerning the representativeness of land cover/use.

5.2.1. Study area

The city of Toruń (Poland) was selected as the study area (Fig. 5.1), the spatial structure of which comprises all characteristic types of urban development. Toruń is a medieval, medium-size town on the Vistula river in the central part of the Kujawy-Pomerania province. It is inhabited by almost 185,000 residents over an area of less than 116 km^2. The urban area of Toruń is divided into twenty-four housing estates, each of which features a characteristic and dominant type of development. The Vistula river flows through the city, being one of its most recognisable elements. Toruń is surrounded by numerous small towns and villages, which have recently developed into attractive destinations for the city's citizens.

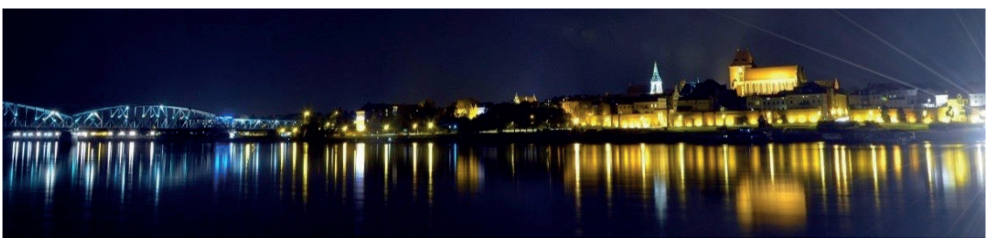

Fig. 5.1. View of the night panorama of Toruń (own photo)

Fig. 5.2. Toruń Old Town (source: https://www.flickr.com/photos/filipkata/44389157010/in/album-72157701116975972/)

We can distinguish several types of housing that are characteristic of the study area, including both high-rise and medium-rise multi-family housing, as well as dense city centre developments, single-family housing, industrial and commercial housing developments and open land. Each of these types dominates in specific housing estates and in a certain parts of the city. The most central area of the city features a characteristic city-centre development (Fig. 5.2).

5.2.2. Assumptions and conditions of the measurements

The main objective of the conducted research was a multi-criteria analysis of the night-sky light pollution in Toruń, taking into account the two applied measurement methods – photometric and photographic.

In order to achieve the objectives of the research and measurement data acquisition in the long term, an evenly distributed and easily accessible measurement network was established in Toruń. While planning the repeated measurement sessions, it was necessary to ensure the same weather and astronomical conditions so that both the measurements and analyses were accurate and comparable. The measurements were planned and performed during the astronomical night (the time when no influence of sunlight on the brightness of the sky is observed); outside the summer season, where such a phenomenon does not occur at the latitude of Poland, the measurements were performed when the sun was at the lowest position below the horizon (Karpińska and Kunz 2019, 91-100).

The following conditions wer chosen when planning the permanent observation network consisting of measurement locations (sites):

- regular distribution of the sites throughout the city limits;
- transport accessibility;
- representation of different land-cover categories;

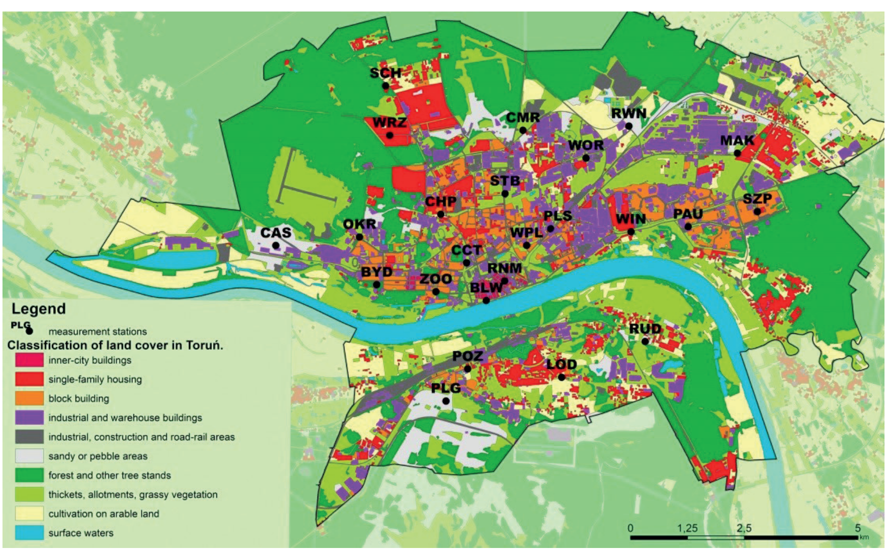

Fig. 5.3. Map of coverage of Toruń on a scale of 1:10 000 with measuring points (Kunz et al. 2012)

- different types of land development in the immediate vicinity;
- a relatively small number of apertures that could change the measurement conditions;
- location of the sites as far away from street and neon lights as possible, so that measurements were not artificially inflated.

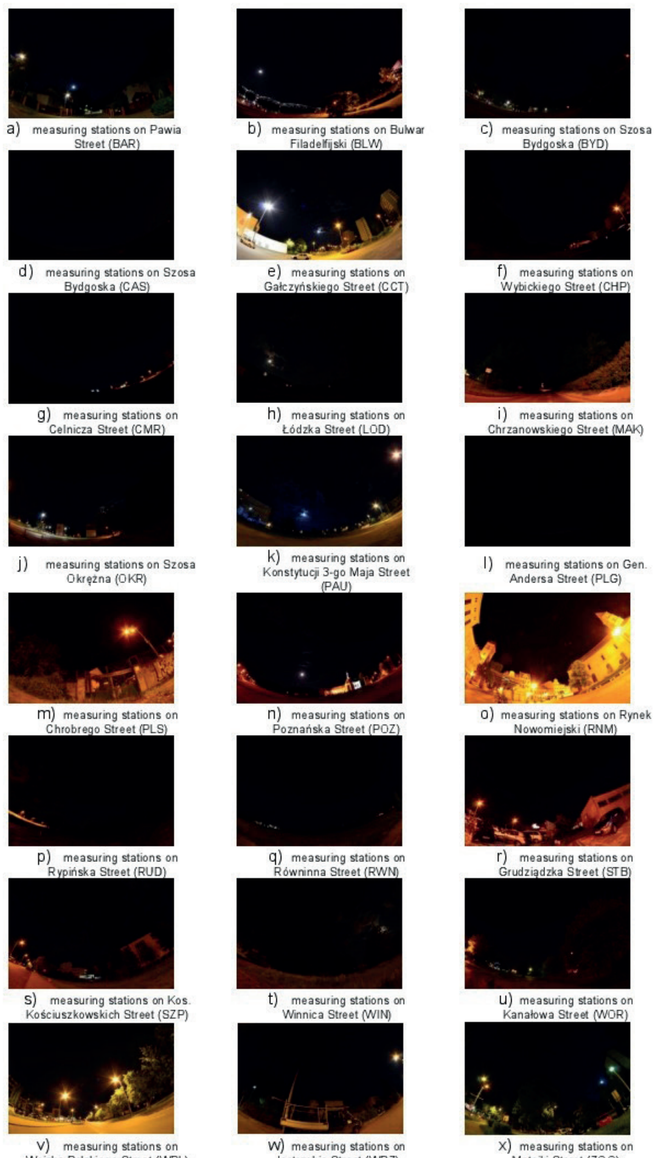

Fig. 5.4. Measuring stations in the area of Toruń (own photos)

In addition, four sites were selected outside the city limits to serve as a reference for measurements in the urban area. After considering all the conditions, a measurement network consisting of twenty-four sites was created in Toruń.

The selected measurement sites were analysed in relation to the distinguished land cover types in their immediate vicinity. The sites were assigned to the corresponding land cover types based on our own land cover classification at a scale 1:10 000, which was prepared for the needs of another project conducted in the area of Toruń (Fig. 5.3) (Kunz et al. 2012, 85-94).

After the location of the sites was determined, a field interview was conducted to check their accessibility, both during the day and at night. In addition, overview photos of all the sites were taken during the first measurement (Fig. 5.4a-x).

5.2.3. Measurement methods

The amount of light emitted at night can be measured in a number of ways (Kołomański 2015, 29-48). In this study, two measurement methods used for the estimation of light pollution values were compared.

The first method consisted of direct measurements of sky brightness using a professional L-version SQM photometer produced by the Canadian company Unihedron (Fig. 5.5). Table 5.1 presents some of the technical parameters of the photometer. This type of photometer enables the comparison of measurement results with those obtained by other research teams around the world (Kolláth 2010; Esbey and McCauley 2014, 67-77; Zhang et al. 2015, 1292-1306; Hánel et al. 2017; Jechow et al. 2019, 212-223; Karpińska and Kunz 2019, 91-100).

Fig. 5.5. SQM photometer version L from Unihedron (own photo)

Table 5.1. Selected technical data of the Unihedron SQM photometer
(source: http://unihedron.com/projects/sqm-l/)

Total weight	**0.14 kg**
Dimensions	9.2×6.7×2.8 cm
Light sampling time	approx. 8 s
Maximum light sampling time	80 s
Angle of light registration	20°
Recorded bandwidth	visible range (filter for infrared range)
Temperature	°C and °F

The SQM photometer displays sky brightness values in mag/arcsec^2, which can easily be converted to other basic units for easy analysis, e.g. candela or lux. The scale in the photometer comes from astronomical measurements of the brightness of objects in the sky, presented in the magnitude scale. Important information in the analysis of the results is that this scale is both logarithmic and inverse, so that the smaller the measurement, the lower the brightness of the sky will also appear to the observer (Fig. 5.6).

Fig. 5.6. The sky brightness scale used in the SQM photometer (own study)

The other method used in this project was the photographic method. Parallel measurements were conducted to check whether it was possible to determine differences in the sky brightness in an urban area using the photographic method. This method of light pollution analysis is used by certain groups of both scientists and amateurs. Different parameters of images are then compared during the exposure. In one of the projects performed in Sicily, the sky was photographed with a wide-angle lens covering the entire celestial sphere. Next, contour maps of the sky brightness at a given measurement site were created based on these images (Kubala 2015, 81-98). In Poland, a similar project was conducted in the Łódź agglomeration (Górko and Heim 2015, 99-108). The project addressed the analysis of the celestial sphere in terms of its darkening. A digital DSLR camera with a fisheyelens was used there, which makes it possible to capture the whole celestial sphere.

During the taking of measurements in Toruń with the SQM photometer, photos of the horizon were taken simultaneously at all observation sites using a Nikon D700 digital camera (Fig. 5.7). In order to maintain the same conditions, photos were taken using constant technical parameters: aperture – f/3.5, shutter speed – 0.5 sec. and sensitivity ISO 800. For comparison of the results from different measurement sessions, the average

Fig. 5.7. Nikon D700 photo camera
(source: https://image.ceneostatic.pl/data/products/1652856/f-nikon-d700-body.jpg)

value of the histogram was noted from each of the photographs, which was considered to be the most quantitatively reliable information. The obtained results were then compared with measurements from the SQM photometer.

5.3. Analysis and comparison of the results

Data from thirty-five measurement sessions were obtained during the whole twelve-month measurement cycle. The results obtained from all measurement sessions were collated and basic statistical relationships between them were calculated. In addition, each measurement session was analysed separately and the obtained results were properly compiled, analysed and interpreted. In order to check whether it is possible to determine the spatial distribution of light pollution measured by the photographic method, the obtained results were compared with those obtained using the SQM photometric method (Fig. 5.8 and 5.9). In both cases, the data were interpolated using the kriging method in ArcGIS (Esri), which enables comprehensive and multi-faceted spatial analysis.

The analysis of the obtained figures shows a significant similarity in the spatial distribution of the described phenomenon. We can observe three areas on the map of Toruń with a clearly brighter sky. Places with the highest light emission overlap in both measurement methods: the most central part of the city, a single-family housing estate in the north and a large multi-family housing estate in the east. There are also places with the darkest sky, characteristic of the southern and western parts of Toruń.

Values at the measurement sites using the SQM photometer range from 14.5 mag/arcsec^2 to 18.5 mag/arcsec^2, which equates to around 4 units of difference and about 40 times brighter skies. These results corroborate previous studies in this field conducted both in Europe and in other parts of the world (Ścieżor et al. 2010; Pun et al. 2013, 90-108; Hánel et al. 2017). A group of scientists from Kraków obtained similar results (Ścieżor et al. 2010).

Values of the SQM photometer measurements reached 13.5 mag/arcsec^2 in the most central part of the city and 20.5 mag/arcsec^2 at the sites located far from the city centre, outside the city limits. Similar results were obtained by scientists from Hong Kong, with an average value of 15.9 mag/arcsec^2 in urban areas and 18.4 mag/arcsec^2 in areas located far from the city centre (Pun et al. 2013, 90-108).

The results obtained for Toruń additionally supported the assumption that SQM measurements can serve as a reference for the analysis of results obtained from the mean value of the histogram in the photographic method.

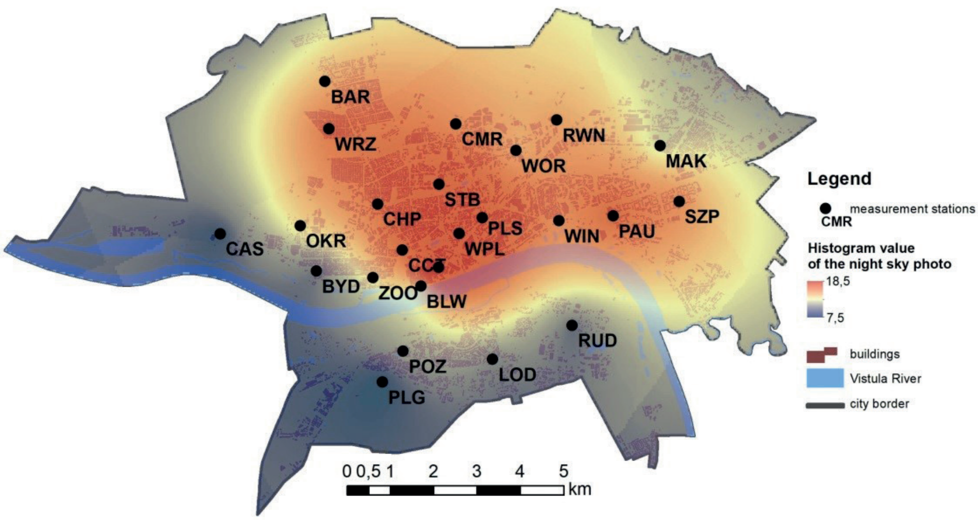

Fig. 5.8. Spatial distribution made on the basis of data read from the histogram of photographs (own study)

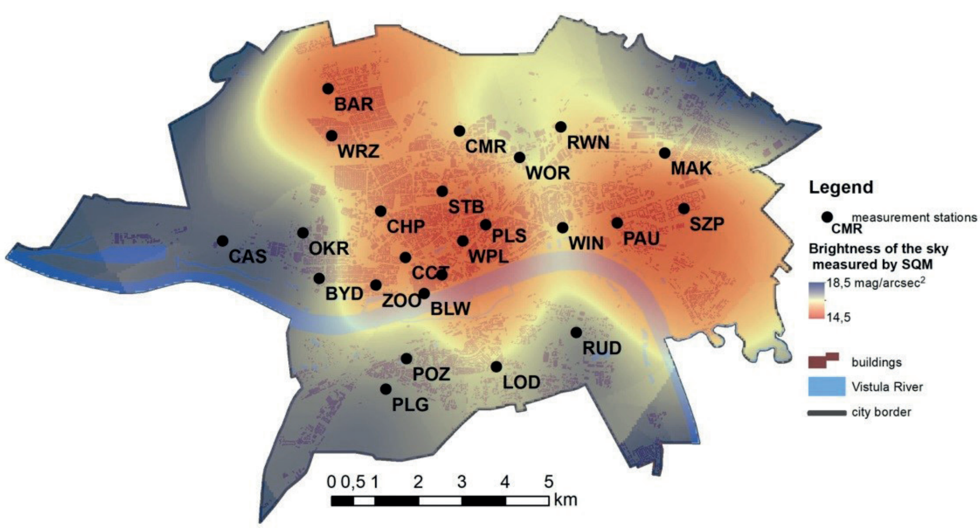

Fig. 5.9. Spatial distribution calculated on the basis of data measured by the SQM photometer (own study)

To quantitatively check the similarity of the two data-acquisition methods, the results obtained through photometric and photographic measurements were correlated. Table 5.2 presents the correlation coefficient calculated for each site. The analysis of the data shows that the data correlation is significant at most locations and reaches a value of over 0.7. The total correlation of mean values from all sites was 0.80, which serves as a basis for further analysis. Measurements at sites with very low coefficients (e.g. BAR) were burdened with random errors, and from the later inference, it follows that for this site, the light source may have been too close, thus inflating the measurements.

Table 5.2. Correlation coefficient between the measurements of the SQM photometer and the reading from the histogram of photos at each station

No.	**Station code**	**Correlation coefficient**
1	BAR	0.10
2	WRZ	-0.40
3	CHP	-0.82
4	OKR	-0.91
5	CAS	-0.94
6	BYD	-0.96
7	ZOO	-0.88
8	BLW	-0.90
9	RNM	-0.91
10	CCT	-0.74
11	POZ	-0.94
12	PLG	-0.93
13	LOD	-0.82
14	RUD	-0.82
15	WIN	-0.94
16	PAU	-0.71
17	SZP	-0.51
18	MAK	-0.93
19	RWN	-0.88
20	WOR	-0.95
21	PLS	-0.64
22	WPL	-0.60
23	STB	-0.48
24	CMR	-0.88
	average	-0.80

In the next stage of the analytical process, a linear regression of data was performed. For the purpose of accurate presentation and comparison, the results of measurements obtained during the two sessions conducted on a cloudless day (18 March 2018) and on an overcast day (2 January 2018) were compared (Fig. 5.10 and 5.11).

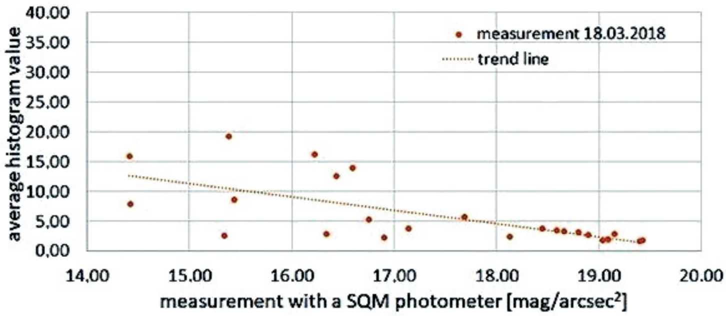

Fig. 5.10. Sky brightness measurement regression with SQM photometer and the histogram average (cloudless)

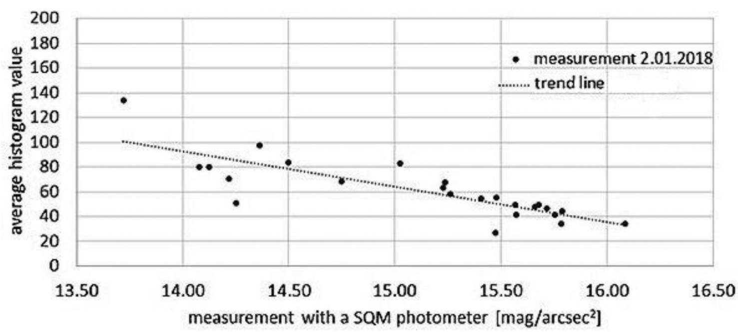

Fig. 5.11. Sky brightness measurement regression with SQM photometer and the histogram average (overcast sky)

According to the presented graphs, there is a significant correlation between the obtained data. The trend line is decreasing during both overcast and cloudless days.

Conclusions

An indisputable fact observed by an increasing number of people is that the excessive emission of light at night has become ubiquitous and is currently witnessed by the inhabitants of ever smaller human gatherings. Research groups from basically all parts of the world have begun to follow this phenomenon and its selected elements (Ścieżor et al. 2010; Pun et al. 2013, 90-108; Hánel et al. 2017; Karpińska and Kunz 2019, 91-100). Researchers from many institutions are increasingly often focusing their activities collaboratively to learn about the mechanisms of this phenomenon, the quick and universal method of its investigation and the determination of its negative effects upon living organisms and their functioning. For this purpose, existing measurement methods are used and furtherdeveloped to determine light emission in a given area. Measurements with a professional SQM photometer have been accepted as one of the main research methods (Zhang et al. 2007, 1292-1306; Kolláth 2010; Ściężor et al. 2010; Pun et al. 2013, 90-108; Hánel et al. 2017; Karpińska and Kunz 2019, 91-100). The data obtained as a result of measurements used for the project described in this paper are compatible with measurements performed by other research teams worldwide (Ściężor et al. 2010; Pun et al. 2013, 90-108; Hánel et al. 2017). The analysis of the obtained results shows that there is a significant correlation between the direct measurements made with the SQM photometer and those obtained with a digital camera. The spatial distribution of the results obtained from the analysis of the average histogram values of the photographs in the photographic method correspond to the distribution of the data obtained through the measurement performed with the SQM photometer. Both the correlation and linear regression are clear and prove the applicability of both methods in these types of studies.

The presented research shows that the photographic method is effective in the implementation of low-cost and repeatable measurement sessions in urban agglomerations. This method should be further developed and results obtained in test measurements should be correlated with quantitative methods. When conducting measurements with the use of the photographic method, it is necessary to maintain identical measurement conditions at each measured location. Minor discrepancies may generate errors that may be propagated to further stages of the research process and to the final conclusion.

6. LABORATORY FOR DARK SKY QUALITY MEASUREMENTS

Zoltán Kolláth[1], Dénes Száz[2], József Vanyó[3], Kai Pong Tong[4]

The recent development of commercial digital cameras provides a new opportunity to monitor the quality of the night sky and light pollution. We can calibrate cameras that are able to save images in a raw format to measure the radiance of the sky. We have been using this method routinely, see, for example, Kolláth 2010, Kolláth et al. 2016, 2017, Jechow et al. 2016, 2018. However, it transpires that the use of only the green channel in the measurements has some drawbacks. The colour information provides additional possibilities to distinguish different phenomena. To overcome the problems we have encountered, we also introduce a new metric and units.

We present our first results obtained in the Living Environmental Laboratory for Lighting (LELL) with the new measurement system (see Száz D. et al. 2019). LELL is a modernised and reconstructed public lighting system, in which the protection of the night sky and the environment are the primary goals. This system was first realised in the villages of Bárdudvarnok and Répáshuta, being within the dark-sky parks of Hungary. In these regions, the old CFL technology was changed to LED-based street lighting with a customised emission spectrum. Our motivation was twofold: i) change lighting according to the requirements of the International Dark-Sky Association (IDA); ii) observe the environmental impacts of new LED technology. We continue to perform sky quality surveys in the LELL and in other national parks in Hungary.

The national assessment of light pollution (e.g. through the determination of sky luminance distribution) is included in the National Landscape Strategy of Hungary for the years 2017-2026[5]. We have started the night sky quality survey required by the strategy with our mobile laboratory.

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5 https://www.kormany.hu/download/f/8f/11000/Hungarian%20National%20Landscape%20Strategy_2017-2026_webre.pdf

6.1. Calibration of the cameras

Digital camera-based measurement systems are usually calibrated with a device which has a different spectral sensitivity than the digital camera. For the evaluation of the measurements, we use the self-developed software, DiCaLum. Earlier versions of this software (before version 3.0) were calibrated with a photopic device with the standard CIE V(lambda) curve. It worked in a wide range of natural conditions. However, the spectral mismatch still resulted in non-negligible errors. Thus, we introduced a measurement metric which is better linked to the spectral sensitivity of the camera.

Complete information about sky brightness in a given direction is in the form of spectral radiance distribution. At low light-pollution levels, the spectral radiance is in the order of a few nW/m^2/sr/nm. Besides this relatively flat background, the spectral lines of the airglow (oxygen, hydroxyls) dominate the spectrum. However, devices which are able to make such measurements (e.g. spectroradiometers) are expensive and complicated to operate in field experiments. Moreover, it is not feasible to collect spectral information for the whole sky. We use these devices for calibration purposes and to provide additional data relating to whole sky images.

We can use the above unit of spectral radiance density not only in spectral measurements but also with finite-bandwidth measurements if we average the spectrum in a given wavelength range. When the mean is calculated by weighing with the spectral sensitivity of measurement equipment, we arrive at the band-averaged spectral radiance $\langle L_x \rangle$, where x = R, G or B indicates the selected colour channel. For simplification, when we apply the nW/m^2/sr/nm units for band-averaged radiance, we use the 'dsu' (dark sky unit) abbreviation. This metric provides an easily reproducible measurement unit. However, the calibration process becomes more complicated as the spectral sensitivity curves of the cameras have to be determined in the calibration process.

There are several methods to measure the spectral sensitivity of the cameras (e.g. Darrodi et al. 2015); most of these require particular types of laboratory equipment. To test several cameras in parallel, we developed a simplified measurement technique. We built a light source with thirteen LED sources with different central wavelengths and about 20 nm FWHM. A whiteboard with flat spectral reflexivity was illuminated by the LEDs separately. We then measured the spectral radiance of the target with a high precision spectroradiometer and took photos with a set of cameras. This procedure provides a method which can even be used in field conditions (e.g. in astronomy camps, where different cameras can be calibrated efficiently). For our standard cameras, we performed the calibration under laboratory conditions. Sample spectral sensitivity curves are presented in Fig. 6.1.

Based on the spectral sensitivity curves, it is possible to determine a calibration factor for each of the cameras and colour bands. We used a raw camera number based on the exposure parameters, and the black and saturation levels of the given camera, which represent the real exposure from different cameras with the required level of consistency. The band-averaged spectral radiance is given by the product of the calibration factor and the camera

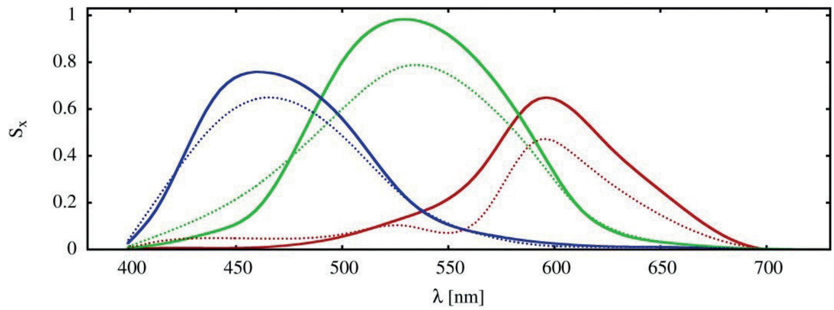

Fig. 6.1. Spectral sensitivity of two cameras: Sony ILCE A7SMII (dotted line) and Canon EOS 6D (solid line) for the three colour channels From left to right: B, G and R filters. The curves are normalised to the highest sensitivity, but the relative values represent the real differences of the filters

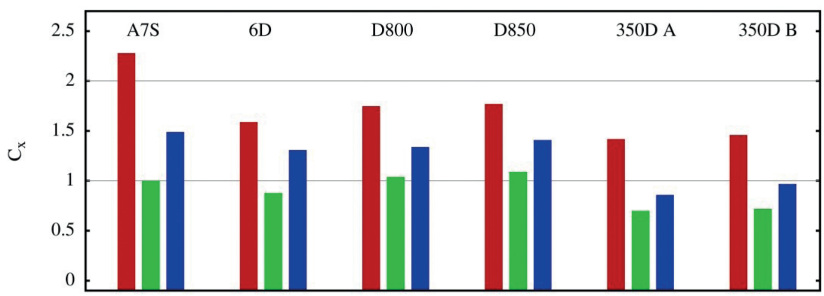

Fig. 6.2. Calibration coefficients of the R, G and B bands (from left to right for all models) for six different cameras. The values are normalised for the green (G) band of the Sony camera

raw exposure value. Figure 6.2. displays the calibration factors for six different cameras (Sony ILCE A7S, Canon EOS 6D, Nikon D800 and D850 and two Canon EOS 350 cameras).

The comparison of the cameras shows that the recent cameras match each other to within 10% level of accuracy. The older EOS 350 cameras are somehow different, but it is remarkable that two cameras that are more than ten years old and with different usage etc. match each other quite well. It demonstrates the stability of even the first generation of the DSLR cameras.

Our previous tests (Ribas et al. 2016) demonstrated that the new generation cameras of the same type are very similar to each other; thus, calibration data from one device can be used in other cameras.

6.2. "Real-colour" images of the night sky

The spectral calibration of the cameras makes it possible to convert the raw images to real colours. We have to note, however, that such colour processing is valid only to a given set of spectral distributions. Thus, we should select an appropriate learning set to fit the colour transformation matrix.

We selected a sequence of spectra during a specific night when we measured first with the setting moon then during a dark period and finally in the twilight. Thus, the learning set consists of the natural and slightly light-polluted spectra of the night sky.

For each spectrum, the CIE XYZ coordinates can easily be derived. We used the standard transformation matrix to calculate the Adobe (1998) RGB values from the CIE colour coordinates. We then used the camera sensitivity curves to derive the $<L_R>$, $<L_G>$ and $<L_B>$ band-averaged radiances from the spectra. We derived the colour transformation matrix 'M' by a linear least-squares fit to optimise the $[R,G,B] = M[<L_R>,<L_G>,<L_B>]$ formula. Please note that it is not necessary to take photos for this fitting procedure – we simulated the camera band-averaged radiances based on the camera sensitivity curves. This allowed us to build transformation matrices based on theoretically derived spectra.

Usually, the colour correction defined by the above process enhances the colours of the image; for example, the green shade of the airglow is easier to see. An example of such an image enhancement is presented in Fig. 6.3.

Fig. 6.3. Colour image based on the band-averaged spectral radiance (left) and the real-colour representation (right). The visibility of the airglow is enhanced

Note that the colour transformation is not valid for the partially saturated stars. It results in a pinkish hue as an artefact.

A similar transformation can be derived to convert the $[<L_R>,<L_G>,<L_B>]$ values to the correlated colour temperature (CCT). However, CCT is not defined well for particular colours; for example, such a conversion provides false values for green airglow dominated sky. Thus, we prefer to use real colours to distinguish between different phenomena.

Contrary to the bluish-greyish hint of the astrophotos, which is a result of subjective "artistic" colour processing, the colour of the natural night sky is slightly brownish in the absence of airglow.

6.3. The workflow of field measurements

We developed a standard workflow for the measurements and the post-processing of the obtained images. Although this method works for measurements with a single fish-eye lens, in our sky quality surveys, we prefer to use a robotic panorama head with a 24 mm lens on a full-frame camera. With such a set up, twenty-eight separate photos with different points of view cover the whole sky and some of the ground and environment at high resolution. Since the large aperture lenses and the sensitivity of the camera make it possible to use 6-10 seconds of exposure time, it is possible to perform all measurements in 10-15 minutes at a given location. This provides high resolution together with high accuracy and efficiency.

The processing pipeline consists of several independent steps. Where possible, we prefer to use an open-source or commercially available software to perform specific tasks, like the stitching of the individual images to form whole-sky panoramas.

As a first step, we use our software, DiCaLum, to convert the raw images to calibrated 24-bit-per-channel colour images. DiCaLum itself uses the open-source package '*dcraw*' to read the raw camera files and to save them as unprocessed ppm images. The colour channels of the output from DiCaLum contain the calibrated band-averaged radiances. In standard files, the 65535 maximum digital number represents 100 '*dsu*'; However, in special cases, other saturation values can be specified. It is important that the data are stored in a linear scale. These calibrated images contain all the necessary information for further processing and statistical analysis.

In our standard measurements, the calibrated images are then stitched together to provide a whole sky-image in a spherical projection. The processing guarantees that the calibration and the scale of the units are conserved during the processing. Another processing step with DiCaLum then provides the false colour representation of the band-averaged radiances in all the three channels. Additional smoothing of the images and statistical analysis is possible. Since DiCaLum is a GNU Octave library, the user can use all

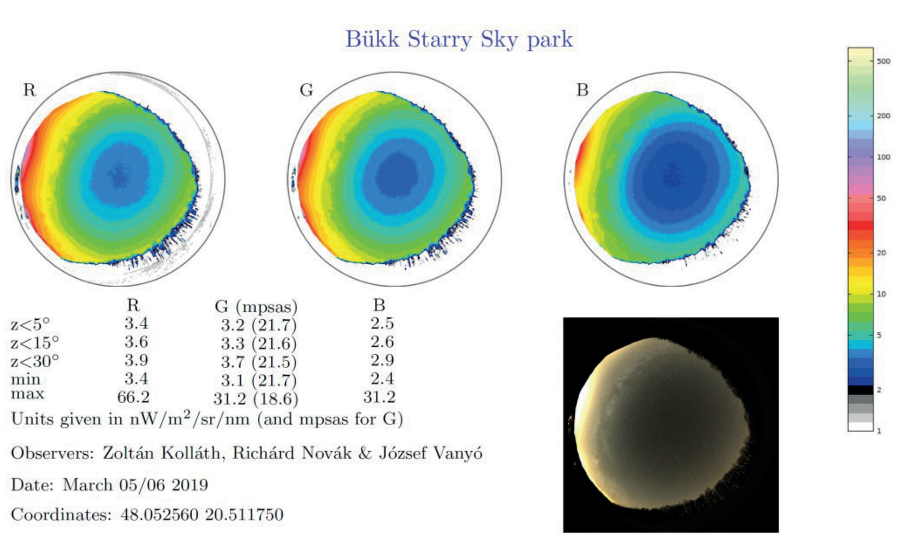

Fig. 6.4. Sample LaTex based measurement report close to the LELL in the Bükk Starry Sky Park

the processing and statistical packages available in GNU Octave. The most straightforward possible processing is to evaluate the mean band-averaged radiance at and around the zenith, to find the darkest and brightest locations.

There is no graphical output with a full summary provided by DiCaLum. It is possible to use additional GNU Octave or Matlab codes to generate such summary outputs. However, we prefer to use additional software to create a measurement report in a more flexible format. The results of the statistical analysis are saved in a script file that is 'GNU sed' compatible. It provides the possibility to use stream editors like 'sed' to put the data in text-based document files. We use LaTex, a standard publication-quality document processing system to make the final report of the measurements pipeline. A sample LaTex document can be used to generate the final report (see Fig. 6.4).

Conclusion

We present a new recommendation for a metric and its unit for measurements of dark sky quality. The system is SI traceable and can be implemented by using digital cameras.

Single-channel measurements do not provide important information about the quality of the night sky, especially in dark places and in the presence of airglow. Digital camera-based three-colour radiance measurements give an optimal way for sky brightness to be measured. DSLR and MILC cameras are also portable and easy to use in remote locations.

It is recommended to use band-averaged radiance as a primary measure of night-sky quality. The natural unit is $nW/m^2/sr/nm$, which can be shortened to '*dsu*'. The difference between the spectral sensitivity of different brands of cameras introduces some error, but it is acceptable when compared to natural changes of night-sky radiance.

Our calibration data and procedures are implemented in GNU Octave libraries which are going to be open-source software. In addition, we provide additional tools to create reports from digital-camera measurements in a freely modifiable format.

Acknowledgments

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7. LIGHT POLLUTION AT THE BOTANICAL GARDEN OF JAGIELLONIAN UNIVERSITY – PRELIMINARY ANALYSIS

Tomasz Ściężor[1]

The Botanical Garden of Jagiellonian University is located in the heart of Krakow, near important transport hubs. It is also a nature refuge in the middle of a large city. For reasons that will be presented later, it was chosen as an ideal place to study light pollution in such an environment, in particular, to analyse seasonal changes in one of the categories of this phenomenon, which is artificial sky glow. The roof terrace of the palace, located within the park, was chosen as the measuring point (hereinafter referred to as BOT). This palace houses the Field Research Station of the Climatology Department "Botanical Garden", belonging to the Institute of Geography and Spatial Management of Jagiellonian University in Krakow.

The period from 1 January to 31 December, 2019 was analysed, which made it possible to research the impact of variable atmospheric conditions during the year on the brightness of the Krakow sky glow.

7.1. History of the Botanical Garden

The Kraków botanical garden was created on the site of the garden of the Czartoryski family, bought in 1752 by the Jesuits (Rożek 1993). Originally, the Jurydyka[2] Wesoła, founded in 1639 by Katarzyna Zamoyska, stretched out in this place. There was probably already a large suburban estate with a small palace of the type "villa suburbana" in the Renaissance. After the dissolution of the order, it was handed over to the National Education Commission, which, as part of the reform of Krakow Academy (later Jagiellonian University), founded a botanical garden as an auxiliary plantation of the department of chemistry and natural history. The area, covering initially approx. 2.4 ha, was designed as a French baroque

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2 "Jurydyka" was a legal entity in the Polish legal system from bygone centuries (originating from Latin: iurisdictio, jurisdiction), denoting a privately owned tract of land within a larger municipality, often right outside the royal city, or as an autonomous enclave within it.

park, within which collections of medicinal and decorative plants were arranged. Preparatory works started in 1783 and the first greenhouses were built in 1787. The garden area was enlarged several times – it reached the current area of 9.6 ha in the 1950s.

In 1788-1792, the palace was rebuilt in the astronomical observatory. Reconstruction of the building for the needs of the observatory was made according to the design of the Warsaw architect Stanisław Zawadzki, and its implementation was supervised by Feliks Radwański. The spacious rooms on the ground floor were allocated to the needs of the botanical garden (including its directors' quarters). In 1858-1859, the former palace was rebuild in the style of classicism. The third floor was then constructed with observation domes on the roof (the so-called "postrzegalnie").

Jan Śniadecki, a well-known Krakow mathematician and astronomer, worked in this observatory, as did the astronomer Tadeusz Banachiewicz. It is worth mentioning that in the vicinity of the palace on April 1, 1784, the famous balloon flight took place, organised by J. Śniadecki and J. Jaśkiewicz (Piekiełko-Zemanek 1986).

Currently, the building known as Śniadecki's Collegium houses the Institute of Botany of Jagiellonian University. One of the oldest meteorological stations in Poland was established in the garden in 1792. It has an uninterrupted measuring series which began in 1825.

7.2. Apparatus

The brightness of the night sky at the measuring point was measured by the Unihedron SQM-LU-DL-R1 Sky Quality Meter, directed into the zenith with an accuracy of 5°. This meter is a microprocessor-based transmitter of a frequency signal from the TSL237 brightness sensor, produced by Texas Advanced Optoelectronic Solutions Inc. (TAOS).

The SQM measures the sky radiance in astronomical units of mag/arcsec^2 in a cone with a full-width half-maximum of 20°, in a single spectral channel, approximately resembling human photopic vision (Cinzano 2005).

The S_a unit is mag/arcsec^2. It is widely used in astronomy, as well as in works devoted to the issue of light pollution. When analysing measurement data, one should remember that this is a logarithmic and inverse measure. This means that a change in the S_a value of 1 mag/arcsec^2 means more than a double linear change in the surface brightness of the night sky. Moreover, the decreasing S_a values indicate the increasing surface brightness of the sky (Crawford 1997).

The SQM photometers have a quoted systematic uncertainty of 10% (0.1 mag/arcsec^2) (de Miguel et al. 2017). There is an additional 0.11 mag/arcsec^2 shift in the fixed SQM-LE readings due to the additional glass present on the waterproof housing. However, this correction is constant, so it does not matter in research of changes in night-sky brightness. In this chapter, all SQM readings are given without this correction.

The SQM used in the research, placed in a sealed casing with a glass entrance window, was mounted on the platform railing located in the middle of the roof of Śniadecki's Collegium, at altitude height of 17 m above the ground level. The meter measures the surface brightness of the sky at the zenith around the clock, every 10 minutes. The measured values, designated as S_a, are saved, along with the moment of measurement and temperature, in the meter's internal memory.

Throughout the described measuring period (from November 2018 to February 2020), the location of the meter did not change and the batteries supplying it were changed twice. The data were read initially every month and are now read every two to three months.

Averaged values of measurements taken between 23:00 and 1:00 local time (LMT) were used to analyse changes in the brightness of the night sky. This allows twilight effects to be avoided, which is especially significant in the summer.

7.3. Measuring point

7.3.1. Location and description of the measuring point

The measuring point, designated as BOT, is located on the roof of Śniadecki's College, in a place with the following geographical coordinates (Meus 2019):

Lat = 50°03′49.26″N

Long = 19°57′21.20″E

Alt = 209 m

As mentioned above, the Jagiellonian University meteorological station has been operating at Śniadecki's College for over two hundred years and is currently part of the Geography and Spatial Management Institute of the University. In 2018, cooperation was established between the Light Pollution Monitoring Laboratory (LPML) of Cracow University of Technology and this Institute. Since then, LPML has received values of some meteorological elements such as air temperature T (measured at the roof level and the northern window located two meters below), relative humidity H (measured at the level of the north window), as well as values of the same elements and the amount of precipitation in the meteorological cage located in the garden. Only T and H values measured at the roof and window level were used for the analysis. These values are determined around the clock at ten-minute intervals. Additionally, horizontal visibility and cloud-cover assessments were also obtained, recorded by the weather forecaster five times a day: at 6, 9, 12, 15 and 18 UT (Universal Time). Unfortunately, there are no such ratings for night time; therefore, the latest visibility and cloudiness assessments from 18:00 UT (19:20 LMT for the longitude of BOT point) were used for the analysis. However, it should be remembered that to avoid the effect of twilight the S_a values measured near the local midnight were used to analyse changes in sky brightness. Almost four hours' time difference between S_a measurements and visibility/cloud cover assessments may sometimes be the reason for errors related to changes in meteorological conditions during this period. To definecloudless nights, only those cases were taken into account when the synoptic forecasts reported cloudless skies for both 18:00 UT and 6:00 UT the next day. Of course, also in this case, temporary cloud cover around midnight was possible. This problem should be kept in mind when analysing the received dependencies.

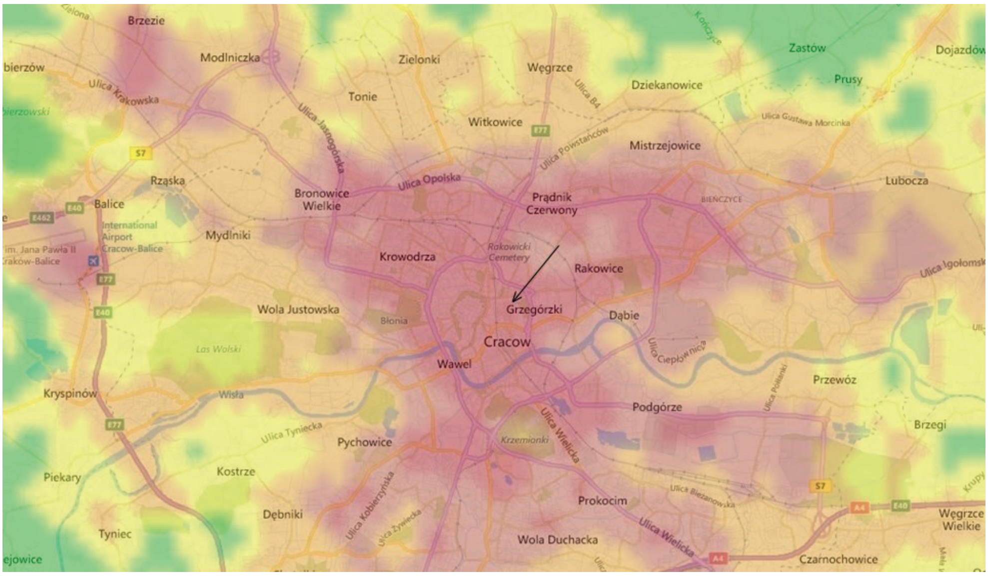

Fig. 7.1. Night-time Kraków observed by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument aboard the Suomi NPP spacecraft (VIIRS/DMSP Earth Observation Group, NOAA National Geophysical Data Center, https://www.lightpollutionmap.info). The BOT measuring point location is indicated by an arrow

Horizontal visibility was determined by the weather forecaster based on visual assessments on a scale of 0 to 9, where 0 to 3 usually means fog, 4-6 means mist, and 7 and 8 means good and very good visibility. Additionally, the level of cloud cover was rated on an oktas scale from 0 to 8, where 0 means sky completely clear, 4 – sky half cloudy and 8 – sky completely overcast.

7.3.2. Light pollution around the measuring point

The BOT measuring point has a very low level of local light pollution. There are no lamps installed in the park surrounding the palace itself, only a single lantern illuminates the nearby greenhouse. Additionally, Nicolaus Copernicus St., running next to the Śniadecki's College, is illuminated with low-intensity street lamps, mounted in such a way as to prevent light emission upwards. Furthermore, the location of the meter at a height of 17 m above the ground ensures that there is no risk of direct lighting by any artificial ground light source. At the same time, as mentioned in the introduction to this chapter, the park is located between the brightly lit traffic junctions such as Rondo Mogilskie and Rondo Grzegórzeckie. The brightly lit Powstania Warszawskiego Ave., connecting said roundabouts, runs along the park. As the VIIRS map shows (Fig. 7.1), the BOT measuring point is located in the very centre of the Krakow light island. This is also visible in photos of Krakow taken from the Jerzmanowice area, from a distance of around 20 km (Fig. 7.2). Such a location of the BOT point means that the brightness of the sky glow there is dominated by the surrounding

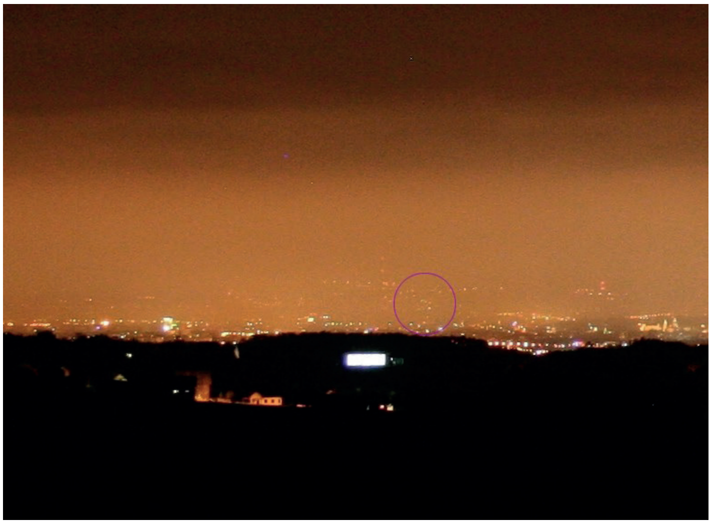

Fig. 7.2. Area of research immersed in the Kraków sky glow (photo: M. Filipek)

light sources and is disturbed by local factors only to a small extent. This makes this research a unique contribution to the study of this phenomenon in the centre of a large city.

7.4. Analysis of seasonal changes of selected meteorological elements at the BOT measuring point in 2019

As has been stated in previous studies, the scattering of light in the atmosphere is a very complex phenomenon (Ścieżor 2018). In simplified terms, it can be stated that clouds are he main reflecting factor in the sky. In the case of a cloudless sky, light scattering occurs on atmospheric aerosols of both natural and anthropogenic origin (Joseph et al. 1991; Cinzano 1998). The concentration of aerosols of natural origin, such as fog and mist, is affected by air temperature and humidity, particularly the dew point. Fog forms when the difference between air temperature and the dew point is less than 2.5°C (Aerobotica 2020). In turn, air temperature also has an indirect impact on the occurrence of anthropogenic aerosols in the atmosphere. It is associated with both the so-called low emissions from coal and wood burning in households for heating purposes, as well as with particles from power plants and combined heat and power plants. At low temperatures in winter, these emissions increase, contributing to an increase in the concentration of these types of aerosols in the atmosphere (Ścieżor 2018). When combined with natural aerosols (fogs), this results in smog in cities.

Due the effects of aerosols, a secondary dependence of the sky glow brightness on the temperature (T) and relative humidity of the air (H) can be expected. The changes in air temperature at the BOT measuring point were researched in 2019. It was found that during this period, the daily average air temperature changed from −7°C in January to +30°C at the beginning of July (Fig. 7.3). The amplitude of temperature changes during the week was on

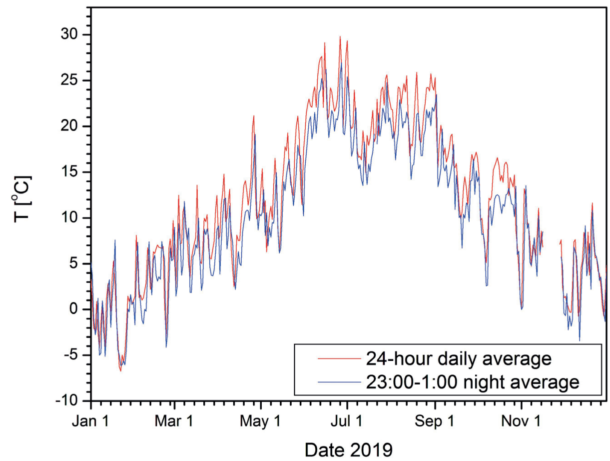

Fig. 7.3. Mean daily and night temperature on the roof of Śniadecki's College

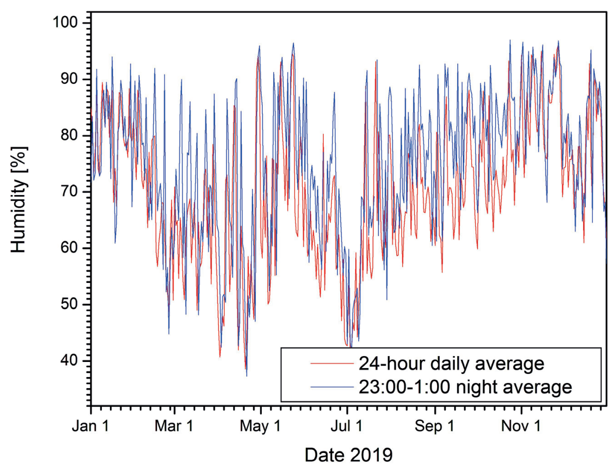

Fig. 7.4. Mean midnight humidity on the 2^{nd} floor of Śniadecki's College

average around 10°C. The subject of the presented research is the impact of meteorological elements on the brightness of the night sky, so changes in the average night temperature were also analysed. The period between 23:00 and 1:00 LMT was chosen for averaging the temperature. It was found that the mean night temperature determined in this way changed from –7°C in January to +27°C at the end of June, with a weekly amplitude of changes reaching 15°C (Fig. 7.3).

The average night value of relative humidity was independent of the season of the year. However, rapid (sometimes from night to night) changes of its value from 37% to 96% were observed. Attention should be drawn to the nights with exceptionally low relative humidity, occurring at the beginning of July when it remained below 50% for several days (Fig. 7.4).

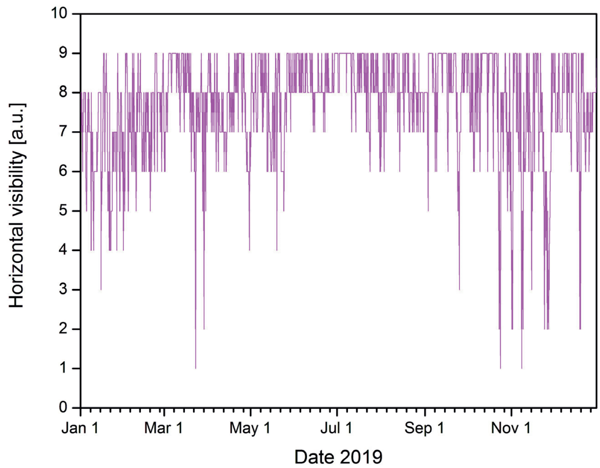

Fig. 7.5. Horizontal visibility on the 2nd floor of Śniadecki's College
(0-3: fog; 4-6: mist; 7-8: clear; 9: very clear)

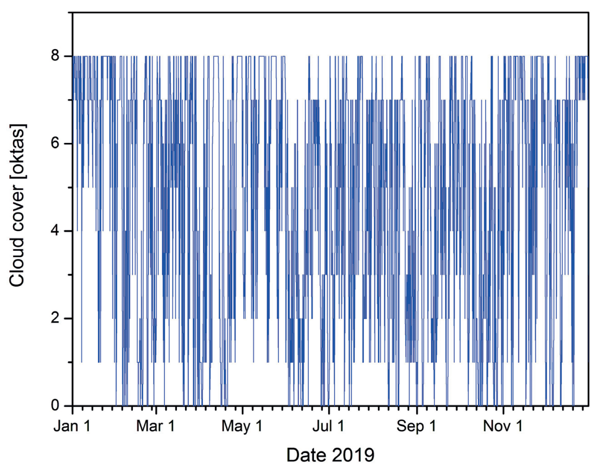

Fig. 7.6. Cloud cover registered at Śniadecki's College

Horizontal visibility can be considered a measure of the presence of fog or mist. On the nine-point scale described earlier, horizontal visibility ranged from 4 to 9 in the winter months, while in the summer months, it was estimated as very good, varying between 8 and 9 (Fig. 7.5). However, it should be remembered that the degree of mist determined for horizontal visibility may be different from vertical visibility. SQM measures the brightness of the night sky at the zenith, so the presence of the light scattering centres in the air column above the meter is important. Thus, low horizontal visibility can only be treated as an indicator of the possibility of the existence of such centres in the atmosphere.

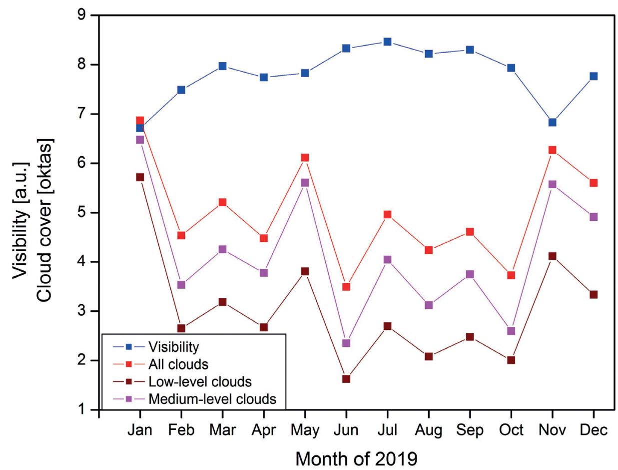

Fig. 7.7. Monthly averaged cloud cover and horizontal visibility, registered at Śniadecki's College

As has already been stated in literature on the subject, the main factor which brightens the night sky are clouds illuminated by the ground artificial light (Ścięzor et al. 2010; Kyba et al. 2011, 2012). At the BOT measuring point, the degree if cloud cover changed throughout the whole year from 0 to 8 oktas, with no significant differences between seasons (Fig. 7.6).

To state possible seasonal changes of the above quantities and to avoid the impact of their brief fluctuations on night-sky brightness, their monthly averaged values were determined (Fig. 7.7). It was found that the monthly averaged horizontal visibility changes to a small extent, between 7 in the winter months and about 9 in the summer months. In the case of cloud cover, it was found that regardless of the genus of clouds, the extent of cloud cover is the highest in the winter months and the lowest in the summer months. The increase in monthly averaged cloud cover is also visible in May.

7.5. Measurements of the brightness of the night sky

7.5.1. Night brightness statistics in 2019

An analysis of the annual distribution of nights with a given surface zenithal brightness averaged between 23:00 and 1:00 LMT was performed.

7.5.1.1. All nights

When all nights are taken into account, regardless of the presence of the moon in the sky or the state of the atmosphere, a distribution with a weakly expressed bimodal character was obtained (Fig. 7.8). Such a distribution is similar to the one previously recorded at other sites with a high level of light pollution (Ścięzor 2018). The first maximum (clear sky) can be seen for the S_a value of around 15.1-15.8 mag/arcsec^2 (79 nights). The second maximum (dark sky) can be seen for the S_a value of 18.0-18.6 mag/arcsec2 (92 nights).

A distinction was made between "winter" nights (December 22 to March 22, blue columns) and "summer" nights (June 22 to September 22, red columns). It was found that in the winter months, the above-mentioned first maximum can be distinguished, associated with nights with a greater surface brightness of the sky. In the summer months, a double, second maximum can be seen, associated with the nights with a lower surface brightness of the sky. It should be noticed, that in this season the first "winter" maximum completely disappears.

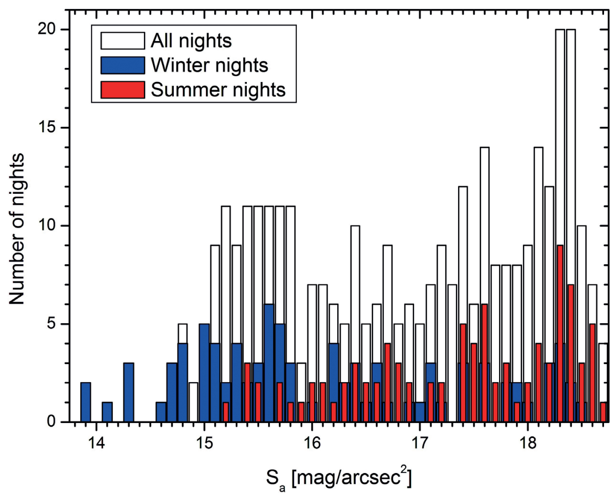

Fig. 7.8. The number of all nights with a specific mean surface brightness (11 pm – 1 am LMT)

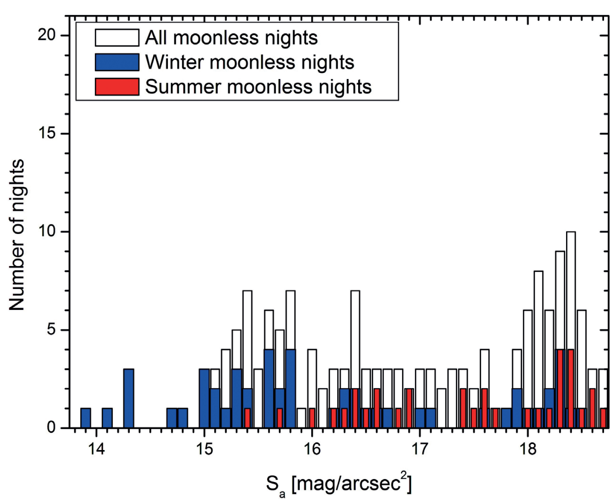

Fig. 7.9. The number of moonless nights with a specific mean surface brightness (11 pm – 1 am LMT)

7.5.1.2. Moonless nights

Comparable histograms were made taking into account only moonless nights. As was stated earlier (Ścieżor et al. 2010), in the analysed time period (23:00-1:00 LMT) the moon is not visible in the sky near midnight, if its phase, measured linearly, is less than 40%. Therefore, only selected nights meet this condition. The obtained distribution (Fig. 7.9) does not significantly differ from the one previously presented.

7.5.1.3. Cloudless and moonless nights

Histograms made for both cloudless and moonless nights (Fig. 7.10) show the disappearance of the first of the above-described maxima (the one associated with a sky of high surface brightness). Additionally, in the summer months, the S_a value changes between 17.5-18.7 mag/arcsec^2. In these months, the sky is never brighter than the value specified by S_a = 17.5 mag/arcsec^2. However, in the winter months, the S_a value varies within the range of 15.0 to 18.3 mag/arcsec^2.

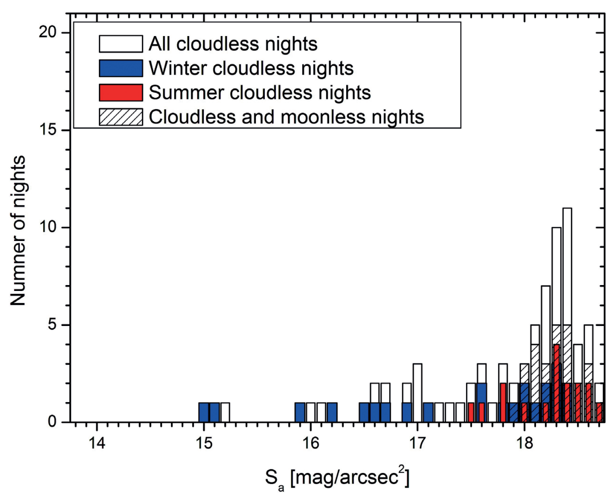

Fig. 7.10. Number of cloudless nights, including cloudless and moonless nights, with a specific mean surface brightness (11 pm – 1 am LMT)

7.5.2. The dependence of the brightness of the night sky on the values of selected meteorological elements

The relationship between the S_a value averaged for the period of 23:00-1:00 LMT and the values of selected meteorological elements were analysed. Air temperature (T) and relative humidity (H) were also subjected to similar averaging. With regard to horizontal visibility and cloud cover, only the estimations made at 18:00 UT were taken into account due to the lack of data from the midnight period. In this case, it should be remembered that changes in both cloud cover and relative humidity could occur, and this probably did happen sometimes between the time of assessing these quantities and the period of averaging the S_a values. This phenomenon could be one of the factors increasing the distribution of points in the presented graphs.

7.5.2.1. The dependence of the brightness of the night sky on air temperature

The presented plot (Fig. 7.11) shows the measured S_a values for all measured nights, as well as for moonless and cloudless nights, as a function of air temperature T. The observed distribution of points for all nights and moonless nights should be explained primarily by variable levels of cloud cover. This is proven by a practically constant S_a value for cloudless and moonless nights of around 18.2 mag/arcsec^2 in these conditions. Interestingly, the pronounced sky brightening is visible at 0°C. By analysing the distribution of points representing moonless nights, two border lines can be drawn. The first of these, limiting the set of points from the side of larger S_a values (sky with low surface brightness) of 18.7 mag/arcsec^2, has a constant value independent of temperature. The second border line, limiting the set of measuring points from the side of lower S_a values (sky with high surface brightness), changes from 16.3 mag/arcsec^2 at a temperature of around 2°C, to around 14.0 mag/arcsec^2 at temperatures of 0°C and lower. At the same time, there are no measuring points representing S_a values in the range 15.2-18.2 mag/arcsec^2 at temperatures below 0°C. This means that a temperature of 0°C is a temperature somehow distinguished both in the case of a cloudless sky (increase in the brightness of the sky at this temperature), as well as in the case of an overcast sky (sky much brighter than in temperatures higher than 0°C).

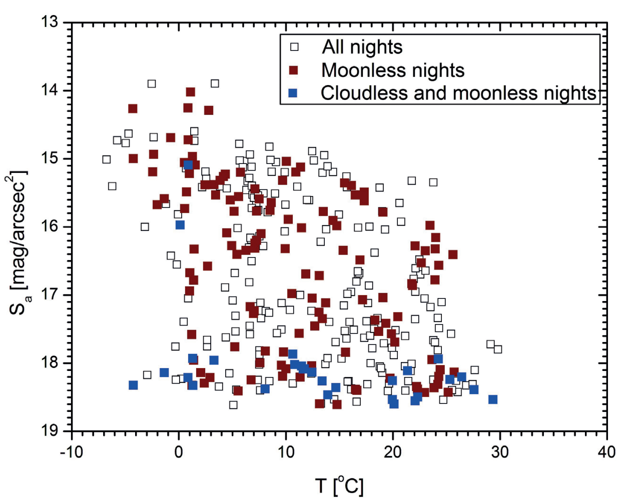

Fig. 7.11. The surface sky brightness S_a vs. air temperature T, determined in 2019 for all nights at Śniadecki's College

7.5.2.2. The dependence of the brightness of the night sky on the relative humidity of the air

The presented plot (Fig. 7.12) shows the S_a values for all measurement nights, as well as moonless and cloudless nights, as a function of relative humidity H. The observed distribution of points for all nights and for moonless nights should be explained again by changing levels of cloud cover. In the case of cloudless and moonless skies, the S_a value remains constant at approx. 18.2 mag/arcsec^2 in the relative humidity range of 40-85%, while above 85% humidity, it sometimes reaches a value of approx. 15 mag/arcsec^2. The logarithmic nature of the mag/arcsec^2 scale indicates a nearly twentyfold linear increase in the brightness of the sky at a relative humidity exceeding 85%, compared to conditions with lower humidity.

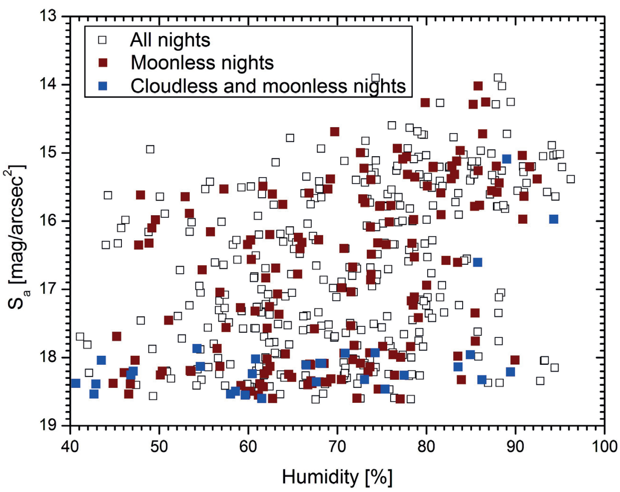

Fig. 7.12. The surface sky brightness S_a vs. relative humidity H, determined in 2019 for all nights at Śniadecki's College

On the plot of S_a vs. relative humidity for moonless nights, one can also distinguish two border lines, similar to those observed on the S_a vs. temperature plot. The first of these, limiting the set of points from the side of larger S_a values (dark sky), at 18.7 mag/arcsec^2, has a constant value, independent of humidity. The second border line, limiting the set of points from the side of smaller S_a values (bright sky), changes from approx. 18 mag/arcsec^2 for 40% humidity, to approx. 14 mag/arcsec^2 for 90% humidity.

7.5.2.3. The dependence of the brightness of the night sky on the level of cloud cover

As was mentioned before, the analysis of the effects of cloud cover on the brightness of the night sky is hindered by the fact that the last cloud cover assessments during the day are carried out at 18:00 UT, which precedes the analysed measurement period of the S_a value by several hours. Two ways have been proposed to solve this problem and enable at least an approximate analysis:

1. Analysis of the monthly averaged S_a values (determined during moonless nights) as a function of similarly averaged cloud cover assessments (Fig. 7.13). This averaging makes it possible to reduce the weight of such nights during which there was a change in cloud cover between the time of its assessment and measurements of the brightness of the sky.

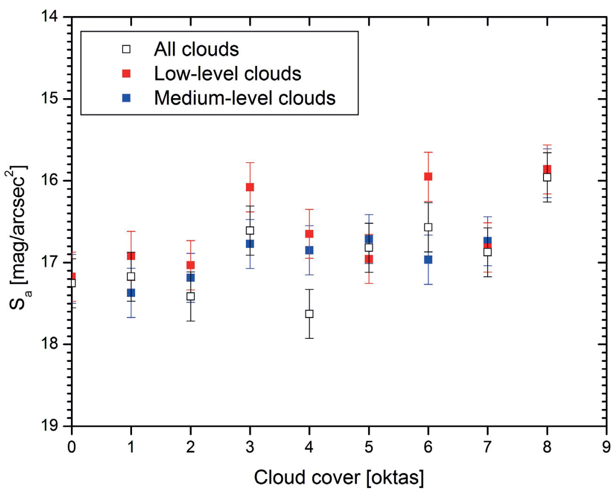

Fig. 7.13. The monthly averaged surface sky brightness S_a vs. monthly averaged cloud cover determined in 2019 for all nights at Śniadecki's College

It can be seen that as the cloud cover increases from 0 to 8 oktas, the monthly averaged S_a value decreases from approx. 17.3 mag/arcsec^2 to 16.0 mag/arcsec^2, which means more than a triple linear increase in the brightness of the night sky. A similar increase is visible when only low clouds are taken into consideration. In the case of medium clouds, up to a level of cloud cover of 7 oktas, the S_a value remains constant within the limit of the measurement error and amounts to approx. 17 mag/arcsec^2, while it decreases rapidly for 8 oktas, reaching 16 mag/arcsec^2.

2. Using only S_a measurements taken at 18:00 UT for the analysis, i.e. when the level of cloud cover was assessed (Fig. 7.14). However, the period of the astronomical night changes during the year, during which the twilight sky brightening effect no longer occurs. This means that in the latitude of the BOT measuring point, only measurements taken between October 1 and the end of February are suitable for this type of analysis.

In this case, a generally large dispersion of the S_a values at medium levels of cloud cover was found. A low dispersion of these values with cloud cover of around 5 oktas can be seen. In the case of low-level clouds, it seems that an increase in the brightness of the sky (i.e. a decrease in the value of Sa) is visible as the level of cloud cover increases.

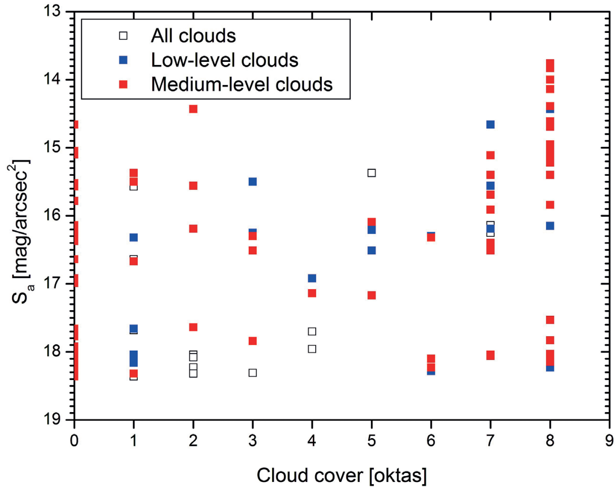

Fig. 7.14. The surface sky brightness S_a vs. cloud cover, both measured at 18:00 UT, determined in 2019 for all nights at Śniadecki's College

7.5.2.4. Dependence of the night sky brightness on horizontal visibility

This analysis was performed in a similar manner as the analysis concerning cloud cover but this time only for cloudless nights. Analysis of the monthly averaged S_a values vs. visibility showed that the S_a value did not depend on horizontal visibility and was equal to 17.2 mag/arcsec^2 (Fig. 7.15). Analysis of measurements taken in the winter months, on cloudless and moonless nights at 18:00 UT, also showed that the measured S_a value was then equal to 18

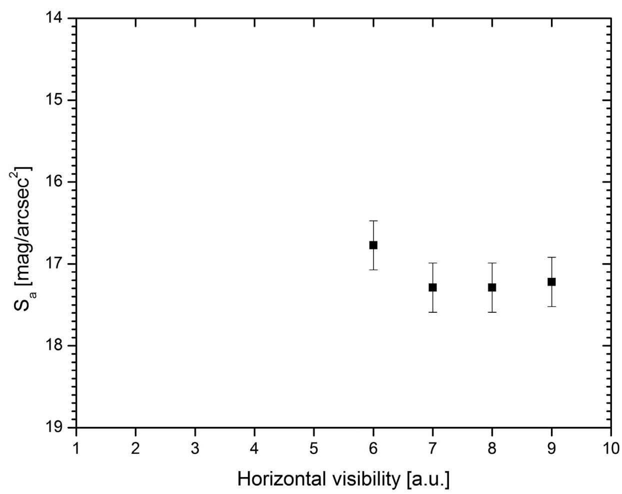

Fig. 7.15. The monthly averaged surface sky brightness S_a vs. monthly averaged horizontal visibility, determined in 2019 for all nights at Śniadecki's College

mag/arcsec^2 and did not depend on the degree of horizontal visibility in the range of 6 to 9. A single point at the visibility level of 2 (S_a = 16.3 mag/arcsec^2) does not allow drawing any generalised conclusions.

Conclusions

The botanical garden in Krakow is located practically in the centre of the city light island, where, based on remote photographs as well as satellite maps, the highest values of the night sky glow brightness should be expected. In 2019, at the BOT site, the darkest sky near the local midnight was found in October, when the maximum S_a = 18.8 mag/arcsec^2 was measured at the zenith in a cloudless and moonless sky. The same or very similar S_a values was found during the year-round monitoring of the brightness of the night sky in 2009 at other measuring points operating then in the centre of Krakow (surroundings of the Wawel Hill – 18.5 mag/arcsec^2; Podwawelskie residential area – 18.7 mag/arcsec^2; Prądnik Czerwony residential area – 18.8 mag/arcsec^2; Bronowice-Osiedle Widok residential area – 18.9 mag/arcsec^2). Significantly higher values were measured in peripheral estates (Łagiewniki – 19.2 mag/arcsec^2; Nowy Bieżanów – 19.3 mag/arcsec^2) (Ściężor et al. 2010).

The smallest S_a value (meaning the brightest sky) measured in 2019 at the BOT measuring point was equal to 13.8 mag/arcsec^2. Research conducted in 2010-2016 (Ściężor 2018) showed that with this value S_a the illuminance of the ground under an overcast sky reached 1 lux, which is close to the illuminance at the end of civil twilight (3.41 lux) (Schlyter 2019).

The maximum S_a value measured at the BOT measuring point in the case of a cloudless, moonless and clear sky was constant throughout the year, except for January and February, when it did not reach values greater than 18.0 mag/arcsec^2, which means a brighter sky in these months compared to others. The highest surface brightness of the sky glow, corresponding to a value of S_a = 13.9 mag/arcsec^2, was found at the beginning of January. As early as the end of February, the S_a value increased to around 15 mag/arcsec^2 and remained constant at this value until the end of the year.

Clouds were found to be the main scattering factors for artificial ground lights and brightening the sky glow. The difference between S_a values for cloudless and overcast skies was 4.4 mag/arcsec^2. Keeping in mind that the mag/arcsec^2 scale is an inverse and logarithmic scale, this difference means a near sixtyfold linear increase in the brightness of the overcast sky relative to the cloudless sky.

The histograms of night distribution throughout the year presented in the work enable a detailed analysis of the impact of clouds on the brightness of the sky glow. If all nights are taken into account, regardless of the level of cloud cover, it can be seen that at the BOT measuring point, throughout the analysed year, the S_a value fluctuated between approx. 15 and approx. 19 mag/arcsec^2, with two brightness dominants occurring at approx. 15.5 mag/arcsec^2 and approx. 18.4 mag/arcsec^2. In the winter months, there were also single nights with a S_a value of around 14 mag/arcsec^2, which relates to a very bright sky. It can be seen that the first of the abovementioned dominants is associated with the winter months, while in the summer months, only the second dominant can be distinguished, which in turn may be separated into two subdominants: S_a = 17.5 mag/arcsec^2 and 18.3 mag/arcsec^2. The shape of the histogram, except for the smaller total number of nights, remains the same when only moonless nights are considered. This means that the presence of the moon in the sky does not affect the brightness of the night sky in the area of research. In the case of a cloudless sky, S_a = 18.1 mag/arcsec^2 was measured during the full-moon period. This means that in the BOT position, the full-moon sky is only twice as bright as the clear, cloudless and moonless sky. Furthermore, comparing this value with the highest brightness of an overcast sky found in the examined site, it can be seen that the full-moon sky has a brightness more than fifty times lower than a completely overcast sky. This means that at the BOT measuring point, the natural light source, which is the moon, has a negligible effect on the brightness of the sky glow.

The importance of clouds in the brightening of the night sky at the BOT measuring point is evident when only cloudless nights are included in the analysis. It was found that the first of the above-mentioned dominants disappears, leaving only scattered single nights with S_a values varying in the range from 15.0 to 17.5 mag/arcsec^2 (hereinafter referred to as the "first dominant"). This "scattered dominant" does not occur in the summer months. However, a clear dominant is visible at S_a = 18.4 mag/arcsec^2. Also, if only cloudless and moonless nights are taken into account, only the second dominant remains, in the range S_a = 17.9-18.7 mag/arcsec^2. This means that the first dominant (i.e. the "scattered" dominant) is probably associated with the scattering of moonlight on atmospheric aerosols or high clouds, not recorded by the weather forecaster.

Based on the above observations, it can be concluded that at the BOT measuring point, the main source of brightening the night sky are clouds, especially in the winter. This can be associated with the already established dependence of sky brightness on the altitude of the cloud base (Ściężor 2018) together with low clouds of the Stratus type dominating in winter very effectively reflecting ground lights. The brightening of the sky glow in the summer months can also be associated with the reflection of light by the clouds, as well as with the dispersion of it on atmospheric aerosols in the case of a cloudless sky.

Analysing the dependence of S_a on the level of cloud cover, it was found that a decrease in the value of the former (i.e. an increase in the brightness of the sky) is visible in the case of both low-level and medium-level clouds. An increase in the level of cloud cover from 0 to 8 oktas causes a decrease in the S_a value from about 17.3 to 16.0 mag/arcsec^2, which means an over threefold increase in the brightness of the night sky.

Analysis of the dependence of the brightness of the sky glow on the selected meteorological elements did not give unequivocal results. Based on the dependence of the S_a value on temperature and relative humidity, it can be stated that the maximum brightness of the overcast sky changes from S_a = 14 mag/arcsec^2 at an air temperature of around 0°C and a relative humidity of around 90%, to 16.5 mag/arcsec^2 at an air temperature of 25°C and a relative humidity of approx. 45%. Analysis of the described histograms allows us to state that these relationships are not the real relationships. They are associated with various types of clouds dominating in the summer and winter months, but not directly with temperature or relative humidity. However, there is an interesting effect, noted when only cloudless and moonless nights are taken into account, of a narrow maximum of S_a = 15 mag/arcsec^2 at exactly 0°C and a corresponding relative humidity of 90%. This is probably related to the scattering of light on the mists and hazes appearing under these conditions. This is important because the influence of fog on the brightness of the night sky is an effect that is difficult to investigate and poorly described in the literature on the subject, or even sometimes negated. However, in the case of the described research, it was not possible to show the relationship between horizontal visibility and the brightness of the night sky.

Summary

Throughout 2019, the surface brightness of the night sky (sky glow) was monitored at the Botanical Garden of Jagiellonian University in Krakow. This garden is located in the city centre, deep inside its light island. At the same time, several meteorological elements were measured and evaluated at the Field Research Station of the Climatology Department. The analysis of the obtained data particularly allowed us to state that the dominant sources of the night sky glow are artificial lights scattered on clouds, particularly low-level clouds. The natural source of light, which is the moon, makes an insignificant contribution to the brightness of the sky glow here. Even in the absence of clouds, artificial lights disperse into various types of atmospheric aerosols, both natural (like fog) as well as anthropogenic (particulate matter), brightening even the cloudless sky to a level comparable to the brightness measured in the presence of a full moon. As a result, the illumination of the ground by the sky brightened in this way reaches values similar to those of illumination by a full moon (with a cloudless sky) or even approaching the intensity of illumination during the twilight (with an overcast sky, especially in winter). This means that in the Botanical Garden the natural circadian cycle is completely disturbed, which must have an impact on the often unique plants, as well as on night animals.

Acknowledgements

The author would like to thank employees of the Institute of Geography and Spatial Management of Jagiellonian University, Krakow, especially Sebastian Wypych for supervision of measurements of the night sky brightness at the Field Research Station of the Climatology Department "Botanical Garden" in Kraków, Katarzyna Piotrowicz for sharing the meteorological data from this station and Zbigniew Ustrnul for the coordination of the cooperation of all people related to the researched issue.

8. LIGHTING SYSTEMS IN RESIDENTIAL DEVELOPMENTS IN THE CITY OF WROCŁAW. THE LATEST LIGHTING AND LIGHT POLLUTION ISSUES ON AN URBAN SCALE

Agata Łopuszyńska[1], Dominik Gronkiewicz[2]

Modern lighting installations are an essential element of the urban tissue after dusk. They closely follow the dynamic development in urban engineering and in global trends. In the past, the highest levels of luminosity would be reserved for major thoroughfares, busy public spaces and facilities of local importance or touristic attractions (Wejchert 1984, 185-204). Recently, increased illumination of architectural objects, trade, office and even residential areas has been observed. Time sprawl, construed as unnatural 'extension' of the daytime (Rozwadowski 2007), in the cities has blurred the border between day and night, identified by their inherent characteristics of lightness and darkness, respectively.

This is of significant importance in the case of residential areas, regardless of the urban zone in which they are located. While generous illumination of trade objects, historical monuments or other strategical entities can be explained by the need for exposure, identification, aesthetics or marketing of urban space in the night time (Martyniuk-Pęczek 2014, 29-102), it remains highly controversial in the case of residential areas. The primary and inalienable function of housing is to provide optimal and comfortable conditions for humans to live and rest. While on the one hand, the visual comfort and feeling of safety after dusk remains an important factor, on the other, the essential requirement for effective rest and the regeneration of the human body during the night is darkness (Wehr 1992). Particularly in multi-apartment complexes, the greater the number of inhabitants, the larger the impact of artificial lighting. The influence becomes even wider when we take into account how easily stray light can travel large distances (Schreuder 2008, 373-377). With the popularity and affordability of lighting installations steadily growing, the introduced light pollution disturbs the nocturnal spatial order and might become an

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annoyance or even a disabling factor, lowering the quality of life for inhabitants and other users of urban spaces.

Currently, this field remains largely unregulated. Additionally, due to the lack of unanimous sociocultural norms regarding artificial illumination, there is huge variety with regard to lighting design across new investments. Although new residential estates that are not muncipal property constitute isolated lighting environments, in terms of illumination design, they still influence the common urban space (Łopuszyńska 2019, 88-89). The power to freely shape the residential environment and choose how it functions after dusk is completely in the hands of the investor. This is in contrast to communal investments that are burdened with greater bureaucracy but also have more uniformity in lighting design choices. Therefore, private investments give the potential for improvements and overall better quality in the applied solutions.

We have reviewed the current lighting solutions for multi-apartment estate investments and searched for any commonalities or differences. We performed in-situ inspections in selected recent investments and analysed them using our criteria that we adopted on the basis of recent research developments in light pollution. We then attempted to recognise the motivation behind the design choices that were made and point out areas that are potentially problematic.

8.1. Methodology and scope of the research

We consider the quality of the lighting environment in contemporary residential areas, based on our investigation of several of the most recent investments in the city of Wrocław, Poland. Being completely independent of the city, they might be considered as isolated cases, which allows us to draw interesting conclusions in confrontation with the overall trend of increasing artificial illumination in the urban area. The characteristics of the applied lighting reflects the preference of the investor and is customised for the need of the particular building, while at the same time being limited by still imperfect technical norms and energetic efficiency of the technical solutions.

We selected nine multi-apartment buildings located in the city of Wrocław that were completed, fitted with lighting systems and utilised independently in the years 2018-2019 (Fig. 8.1). Each of the investments is located in a different part of the city, spanning from the centre to the suburbs, and freely accessible from the street (not fenced). All of the analysed investments used LED (light-emitting diode) lighting solutions.

During the in-situ investigations performed in September 2019 and January 2020, we documented the illumination solutions in each of the investments using a digital camera. We selected spots in each residential areas which we considered to be representative of the lighting conditions in that particular area (no direct illumination from artificial light sources) and measured zenith sky brightness expressed in mag/arcsec^2 using a Unihedron SQM-L meter during clear, moonless nights, between 23:00 and 02:00 hours local time. Each value was obtained as an average of five consecutive measurements, which is the standard methodology for that instrument (Globe at Night, n.d.). This should be therefore considered a measure of the average, above-the-line-of-sight brightness of the night time space, as observed at ten metres or less from the apartment windows.

In the analysis, we noted the type, geometry and mounting of the lighting fixtures, the colour temperature of the light, the spatial direction and distribution of the light cone, the occurrence of undesirable effects such as light escape or visual glare, and the presence of other light sources: facade illuminations, advertisements, banners or neons. The above factors are considered the criteria for sutainable lighting and light pollution prevention.

Fig. 8.1. Locations of selected housing development in Wrocław together with average values of sky brightness in the zenith (in mag/arcsec^2 unit) coming from representative points located not more than 10 m from the windows of apartments. In accordance with the scale (Dark Sky Awareness, n.d.), the value of 22 mag/arcsec^2 corresponds to an excellent dark sky; below the value of 19 mag/arcsec^2 the Milky Way ceases to be visible, and values lower than 18 mag/arcsec^2 are considered a typical, polluted urban sky (own study based on OpenStreetMap map data)

We abstained from judging the aesthetics and composition of the lighting system, particularly how it shapes the night time landscape of the city or how it is applied for the exposure of architecture. We included a bibliography on the topic of urban lighting, with greatest focus on visual comfort, light pollution and sustainable lighting recommendations. The conclusion section was divided into different topics of interest, depending on the characteristics of the analysed solution.

8.2. A look at the balanced illumination in residential areas

Polish law leaves a lot of leeway with regard to the requirements for newly installed lighting systems, not imposing any particular restrictions or recommendations. Light is also not considered by environmental law as a possible pollutant (Ustawa 2001). Thus, the responsibility for the quality of lighting installations is dissipated, which increases the difficulty of conscious planning of lighting conditions for different urban zones. While technical norms contain guidelines for the illumination of roads, outdoor workplaces and sport fields (Pracki 2014), these are exceptions and the entire range of other urban functions remains unregulated. A turning tide in the industry was initiated by the European Union regulation (European Commission 2009) that allowed the domination of LED lighting technology. While this directive draws attention to the problem of light pollution and introduces the concept of burdensome lighting, the main goal has been the pursuit of energy savings and maintaining appropriate levels of the colour rendering index. As a consequence, light sources characterised by high luminosity and cold colour temperatures have become dominant in urban engineering, particularly in street lights. Simultaneously, in 2009 a provision was added to Polish law that mentions the possibility of light as a burdensome factor for living conditions in residential areas (Rozporządzenie 2009). This provision limits the intensity of the light that is directed towards building facades that have windows and enables light to be considered as a burden if emitted by incorrectly placed or designed lights or banners. According to the bill, the limit for the intensity of light directed towards residential building is 5 lux for white light and 3 lux for coloured or variable light. Unfortunately, the awareness of this law update seems to be rather low, as developers and designers do not respect it, and inhabitants are unaware they have a basis for fighting against intrusive lighting.

As the legal regulations are weak, the postulative recommendations for designers and econo-technical norms are lacking and social awareness is low, questions arise concerning the humanistic view on light in urban space. Aesthetic values should be considered too subjective, thus difficult to characterise. The composition of the night landscape is a very complex topic and requires a strategic approach to lighting. We can, however, isolate the rules and characteristics of quality lighting, depending on the different needs and limitations of the users of the analysed urban spaces.

The urban perspective on lighting places the human as the centre of interest, taking into account their relationship with the urban space and the natural environment. Following the trend of sustainable development, fields of human activity must maintain balance in the social, economic and environmental realms (Mensah 2019). Applying this rule to the topic of artificial lighting, it is not sufficient to only attend to the energy-saving properties of lighting to consider it "eco-friendly" or "green", which is often used to market products, as the other two factors could still be neglected. In an ideal case, a balanced lighting solution should fulfill the human needs (both evolutionary – for rest, and civilisational – for maintaining activity), environmental sustainability (protecting fauna, flora and the lanscape) and economic (minimising both the cost and the carbon footprint).

The problem of light pollution and the need to protect the dark sky have been known in the astronomical community for many years, and recently these have inspired a change in the understanding of light and darkness. The increased awareness has driven steadily developed research on this truly cross-disciplinary problem. Since it has become clear that the scope of influence of light pollution reaches far beyond astronomy and includes a burden and negative effects on humans and wildlife, numerous guidelines and rules have been founded to help limit these effects. The most important publications have been released by, among other bodies, the International Commision on Illumination (CIE 2017), the International Astronomical Union (IAU/CIE 1980), the Dark-Sky Association (IDA/IES 2011), the Institution of Lighting Professionals (ILP 2011) and the Illuminating Engineering Society (IES 2014). Many of these guidelines have found their application in the construction of lighting policies in countries all over the world, both due to sharply rising electric energy costs and to increasingly problematic illumination intensity in urban areas. That being said, despite the guidelines in place, conflicts are unavoidable, especially with the spatial proximity of contrasting functionalities. In such cases, the means and solutions minimising the impact of light can become helpful in resolving this type of interest clash.

The greatest challenge that remains is how to maintain healthy proportions of light and darkness during the night. These proportions will certainly vary; in muncipal areas, they will depend on the characteristics of the area, the distance from the centre, the local communication points, the functionality of the area, the number of users of the space and their typical time of activity. On this basis, it is fair to state that it is not the intensity but the type of the lighting that is essential to provide a good quality of illumination to fit the requirements. Finely selected and adjusted lighting fixtures can provide good lighting and a feeling of safety in the street while simultaneously preventing light from entering the building and disrupting the rest cycle of inhabitants. At the same time, the light sources must be chosen wisely so that they are not irritating to the human eye and are neutral to the environment.

8.3. Lighting quality criteria: light pollution and housing development

With consideration to the aforementioned requirements and limitations, we selected several criteria to judge the quality of illumination infrastructure. We made this selection in order to provide a balance between the limitation of light pollution and the quality of life. The following conditions occur when excessive or unsuitable lighting is designed or lighting fixtures are installed erroneously, decreasing the comfort of users of the space or having other kinds of negative influence.

Visual discomfort

This includes glare and lighting chaos, perceived as eyesight fatigue, temporary dazzle, blinding or irritation caused by bright light sources or by strong brightness contrast in the visual field (Rea 2010, chapter 10; Iacomussi et al. 2015).

Direct upward light emission above the horizon plane or in the vertical direction

This unutilised light is not confined by any surface, so it escapes, and is subsequently scattered in the lower atmosphere (light trespass) becoming the main contribution to skyglow observed in the proximity of populated areas (ILP 2011; Narisada and Schreuder 2013, 79-114). Currently, the majority of guidelines for sustainable lighting require 0% ULOR (upward light output ratio) and recommend limiting the light to only illuminate surfaces that are required. This recommendation also applies to architectural and landscape illuminations, which is very reluctantly received in the designer community and presents technical challenges when it needs to be applied to historic buildings under protection.

Correlated colour temperature (CCT)

In the inspected properties, illumination was mostly implemented by white colour LEDs. The hue or CCT for different white LED lamps can vary, however, spanning from warm and yellowish (low CCT) through neutral to cold, bluish-white (high CCT). Warm hues cause the least impact on the human sleep cycle and also are characterised by lesser scattering in the atmosphere in contrast to the colder hues that are more prone to causing "light smog" and provide less than optimal visibility if fog or mist is present (IDA 2010; Hecht 2016). Cold hues are also very unnatural for the human eye in nocturnal conditions (Stevens and Zhu 2015) and, similarly, they impact upon flora and fauna (particularly the insects). There has been a lot of development in LED lighting technology focused on obtaining warmer light (lesser CCT) without the penalty of lower energy efficiency or decreased color rendering index.

Lighting of facades and residential windows

Also referred to as light trespass, this primarily occurs due to direct illumination by light sources that are improperly chosen so that the cone of the light extends beyond the desired surfaces. Due to the intensity it is perharps one of the most prevalent reasons of light nuisance by interfering with one's use of property or is prejudicial to one's health (Cheltenham Borough Council, n.d.), typically due to direct intense light entering and brightening the building interior interfering with residents' sleep.

Influence on greenery and the environment

Lighting fixtures may expose surroundings of residential areas to excessive and unnecessary light. Muncipal green areas, parks, forests and riverside banks or other water reservoirs are particularly fragile, since they are sub-components of a larger ecosystem.

Lighting advertisements, intense decorative illuminations, pulsating lights

Typical for the centers and downtowns of large cities, these can cause additional light nuisance for the residents, very often due to illuminated banners and signs that remain switched on even outside of the working hours of the businesses they advertise.

We grouped the conclusions from observations and comparative analysis according to the most important issues, exposing the strengths and weaknesses of the lighting infrastructure, using the criteria defined above. Additionally, the list can also be read as a review of the characteristics of the latest illumination projects in multi-apartment housing in Wrocław.

8.4. Day immitation: current awareness and importance to residential function

The fundamental dissonance in the modern perception of night time urban space is caused by blurring the border between day and night. There are two possible approaches: one that strives to extend the daytime using artificial lighting, and the opposing one, preserving the night time by limiting the use of such lighting. The former is a response to the need of a modern human to establish an individual lifestyle isolated from biological rhythm and keeping pace with the busy pulse of urban life, while the latter is in peace with nature, providing only as much light as is required for basic safety conditions within a given space (Fig. 8.2).

This urban "daytime imitation" is expressed by brightness, frequently in excessive magnitude, and creates high contrast with the dark night time surroundings of the illuminated zone. This is particularly perceivable in combination with a cool, day-like colour of the light. We took measurements in different housing estates and showed that in addition to the lighting installation in the area, ambient lights from the surroundings impact the perceived and measured brightness in the residential area (Fig. 8.1). This is most evident in the proximity of the city center, where the estate is within an area of high overall lightness, and in other areas where illumination is accumulated.

Fig. 8.2. Examples of residential complexes of high brightness and lighting evenness (top) and of more dimmed lighting (bottom) (photo: D. Gronkiewicz)

Fig. 8.3. Sample light colour (colour temperature) of white LED luminaires.
From left to right: warm, neutral and cool shade (photo: D. Gronkiewicz)

Fig. 8.4. Differentiation in the color of lighting fixtures: warmer shade in the housing site, cooler in the vehicle and pedestrian area (photo: D. Gronkiewicz)

High colour temperatures corresponding to cool hues of light are another way to imitate day in the illuminated space (Fig. 8.3). Similarly to sunlight, this hue of light results in very good colour rendering properties, even at low brightness. It should be noted that this kind of cool light has often been chosen by designers in order to satisfy technical requirements for lighting levels at the lowest possible cost. Recently, however, it has been a conscious choice for reasons other than financial: blue light has stimulating effects, and a cool hue of high intensity illumination can be used for the enlivening of busy spaces or for security reasons. It remains a controversial debate whether users of residential zones need stimulation in their housing areas, or maybe only in workplaces and spots known to be busy after dusk or those hosting night-time activities.

Fig. 8.5. Example of a light control system used in a residential area. Illumination level increases when a pedestrian passes by (photo: D. Gronkiewicz)

Night vision is different from daytime vision, however, from an evolutionary standpoint it does not tolerate well this wavelength range. The peak sensitivity of scotopic vision is within the blue-green range; during the night time, warmer hues close to the colour of wood fire are the most comforting for the eye (Luginbuhl et al. 2014). The primary function of residential zones is to provide sensory conditions that enable good sleep and recovery for its inhabitants by calming the hue and intensity of the lights, comparable to night time quiet hours. For some estates, the lighting system differentiates between pedestrian traffic and the housing zone, and uses cooler colour temperatures for the former zones and warmer for the latter (Fig. 8.4). The effectiveness of this solution is often decreased by excessive power of the used light sources, which causes blurring of the borders and a loss of isolation between spaces of different functionalities. Smart solutions have recently appeared that modulate the intensity of the light, depending on the presence of pedestrian traffic or the time of night (Fig. 8.5). This introduces the additional benefit of energy savings. These solutions, however, have thus far been applied only in a few investments.

8.5. Lights-out time

The inappropriate positioning of the artificial light sources causes light trespass and the illumination of surfaces where it is undesirable. The issue of facades and windows in residential buildings being exposed to intrusive light prevails in areas adjacent to streets with

Fig. 8.6. Examples of the residential facades lit up by the light trespass from nearby lamps (top). Facades and windows remain relatively dark despite the lighting of the passageways (below) (photo: D. Gronkiewicz)

Fig. 8.7. Facades lit up by the upward light installations: located directly on the facade (left) and on the ground (right) (photo: D. Gronkiewicz)

higher technical and functional parameters and it is also an acute problem inside residential estates (Fig. 8.6).

In most cases, this is an undesired side effect of unsuitable lighting used along traffic routes or parking areas. However, lighting fixtures directed upwards can also be seen (Fig. 8.7). They are typically used to illuminate building facades or surrounding greenery for visual exposure. Continuing the idea of the division into day and night using artificial light, the colour of the used light sources is also important, as it contributes to the degree of light nuisance and its effects.

8.6. Visual comfort

The issue of visual comfort in the context of housing estate lighting primarily concerns users of common spaces, such as entrance areas, paths, pavements, internal roads and parking spaces. The experienced comfort not only depends on the light source itself but also on the mounting method and the height and direction of the lighting fixtures. When lighting urban interiors such as residential estates or streets, the designer should be mostly guided by the principle of visibility of the illuminated surface, not the light source itself, similarly to how an architect designs the lighting of interiors such as rooms or apartments. Practical experience shows that when bare LEDs are used, the pedestrian is subjected to a blinding visual sensation, similar to looking at the sun.

Due to intense and point-like light, LEDs are much more aggressive to eyesight than traditional incandescent bulbs. In addition, most of the luminaires leave them uncovered, even if they are positioned horizontally. Due to the height of the LEDs installed in street lighting, users are exposed to the glare effect when they pass along a row of such lamps (Fig. 8.8). This also applies to fixtures mounted at an inclination, which directly exposes the bare LEDs.

We have observed several solutions that are used to cover the diodes (Fig. 8.9) bringing significant improvement to visual comfort, but they often involve the lateral spread of the light. Spot lighting is also appearing more often, accenting elements of night time yard furnishings. Due to this, the emitted light has no defined boundaries in space, but thoughtful solutions allow its containment within the spaces that require it.

Fig. 8.8. Examples of lamps that create glare by 'bare', unshielded light-emmiting diodes, regardless of how well the lighting suits the space – whether in a very bright or dimmed environment (photo: D. Gronkiewicz)

Fig. 8.9. Fixture solutions that shield direct light sources and accenting lights of the yard's furnishing elements (photo: D. Gronkiewicz)

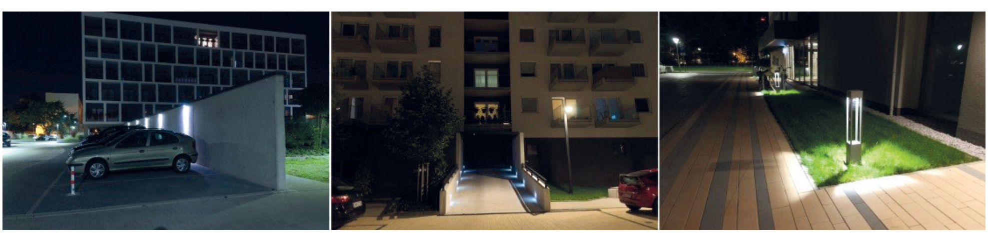

Fig. 8.10. Light installations located at ground level not only directly contribute to the formation of light smog, but are unpleasant to the eyes of space users and cause intrusive light spill on the facades (photo: D. Gronkiewicz)

Unpleasant visual impressions may also be a result of lighting installations located directly in the ground, used to highlight trees or facades. They cause the upper escape of light and dazzle pedestrians without making a significant contribution to the brightening of the space (Fig. 8.10). The same category includes chaotic lighting, a combination of different types of lamps with different directions of light distribution at different heights. A similar issue is caused by light from banners and advertising, usually at the ground floor level of residential buildings, although light nuisance has become an issue even on upper floors of tall buildings (Fig. 8.11).

Fig. 8.11. Lighting advertisement located on the ground floors of residential buildings are on through the whole night (left) and an obtrusive light from the illumination of tall buildings (pointing downwards) (photo: D. Gronkiewicz)

Fig. 8.12. Horizontal illumination of the elevations of a residential building (photo: A. Łopuszyńska)

LED technology is also used to illuminate residential buildings, not only in the form of spotlights but also as horizontal stripes. Like the previous examples, this does not significantly affect the brightness of the residential space, but may cause discomfort and light trespass into the environment. Such installations are often associated with the central, prestigious location of the investment and adjustment to the already illuminated environment (Fig. 8.12).

8.7. Light smog and environmental impact

In all the forementioned examples, one can find elements classified as sources of light pollution, affecting mainly residents and users of the shared space of housing estates. The impact of inadequate lighting, however, does not remain only within its neighbourhood because the light affects the entire city.

Emission above the horizon plane is the largest contribution to light smog, mostly due to improper fixtures, inclined lantern arms, reflections of excessively intense light or upward emission. This light smog is also a threat to the environment being particularly harmful in the case of animal habitats, urban greenery and areas that are part of larger ecosystems. Excessive light around waterfronts (Fig. 8.13) is reflected in the water surface, amplifying its negative impact. In winter, the negative effects can be compounded by snow cover.

Fig. 8.13. Housing lights located affecting the waterfronts and greenery illuminations (photos: D. Gronkiewicz and A. Łopuszyńska)

Conclusions

All of the analysed residential estates stand out from their surroundings by their higher illumination intensities and cooler temperatures of the light. Each of them also exhibits some elements of light pollution, be it in terms of light nuisance, light trespass causing sleep disturbance or light smog. However, fixtures that are parallel to the ground plane, thus preventing light emission to the upper hermisphere, are becoming more common. There is also a tendency to choose spotlights over broad-angle fixtures. This is a positive trend because it allows for greater customisation and control over light distribution, provided that it is not obtrusive. We observed no close link between brightness or the choice of specific illumination solutions with location, urban zone or the presence of small businesses. Peripheral estates can be as bright as those located in the center. Quite the opposite is possible – settlements located closer to the center may be illuminated relatively well due to the influence of the surrounding city lights and require less of their own lighting.

We consider light trespass, glare and too high lighting colour temperatures as the main current problems. To minimise light pollution and create a comfortable lighting environment, several basic conditions must be met. Therefore, it cannot be unequivocally said that the examined estates are illuminated in a sustainable way. Investors still prefer energy efficiency over visual comfort. Unlike the traditional technical approach, as in the case of road lighting, residential lights also perform decorative functions or are an expression of the desire to extend the daytime conditions.

Field studies also show that LEDs perform no worse than traditional sources when their use is well thought out and suited to the given space and its users. It is worth considering why, despite the potential for better quality and sustainability than existing muncipal lighting, lighting installations in the new estates are still intrusive or contribute to the city glow. Facing the increasing prevalency of spatial conflicts, rethinking, reconsideration and development of solid principles of the use of artificial light will be necessary sooner than we anticipate. Modern lighting technology has a chance to help in this, but whether LEDs, in the fashion that they are used nowadays, are the future of urban lighting, still remains a controversy.

Paradoxically, greater brightness drew attention to the need for darkness, which has been forgotten by modern civilisation. Maybe it forecasts a paradigm shift from keeping cities alive 24/7 to the appreciation of the night time as a requirement for a productive society. It is necessary to keep in mind that the urban darkness need not be ominous or pitch black, as qualitative lighting strives to achieve satisfying compromises, depending on the function of the given area. An analysis of urban space also shows that lighting investments cannot be treated as isolated islands, and light pollution is much more expansive than it might seem at first. For this reason, lighting may soon become a permanent element of spatial planning. The effects of artificial light on urban areas are being treated increasingly holistically and studied interdisciplinarily following the recent rapid development of technology and the introduction of restrictions arising from concerns related to climate change.

9. PROTECTING THE NIGHT SKY IN HISTORICAL CITIES

Anna Czaplicka[1], Bogdan Siedlecki[2]

Groups of proponents of environmental protection have been active in recent years, drawing attention to the detrimental consequences that light pollution has on the natural environment (note that their activities should not be confused with "ecoterrorism"). However, artificial lighting is an essential element of the environment of human life, affecting our sense of safety and prolonging our activity well into the night. Due to technological progress in the production of light sources, which have become more cost-effective and durable, light is used not only for utilitarian but also for aesthetic purposes. One example of the decorative role of lighting is the illumination of historically significant buildings. When done correctly, they highlight a given structure's architectural assets and help create the image of historical cities. However, when improperly selected and placed, lighting can cause light pollution. Knowledge of the use of light on an urban scale has a significant impact on human physical and psychological health.

9.1. Legal regulations

Due to the worsening problem of light pollution, appropriate legal solutions are being created all around the world at local, regional and national levels. Polish legislation does not feature regulations that limit light pollution and does not mandate that standards that feature such regulations be followed. One exception is a provision stipulated in the Ordinance of the Minister of Infrastructure concerning the technical conditions to be met by buildings and their placement (Dz.U. 2015, pos. 142), which states: "Lighting fixtures, including advertisements, placed on the exterior of a building or in its vicinity, cannot inconvenience its users, passersby and drivers. If the light is directed at a building's windowed facade, the light intensity on said facade's surface cannot exceed 5 lux in the case of white light and 3 lux in the case of coloured light or light with variable intensity, which flashe or pulse". This provision

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indirectly constrains light pollution, primarily focusing on matters associated with traffic safety and the comfort and health of building users (Kubala 2017). It should be noted that where this provision is concerned, the essence of lighting standards is not the intention to directly limit light pollution but merely to ensure safety and meet user needs.

Of particular note is the so-called "Lombard law", which came into force in Lombardy, Italy, on the 27th of March 2000, and which mentions the problem of excessive lighting and methods of effectively limiting it so as to conserve energy and combat light pollution. It is a model case of legal solutions, set as an example to private and public entities by organisations and associations that focus on protecting the dark sky. The provisions of this law define, among other things, the obligations of individual government institutions, the supervision of newly designed and built lighting, the funding mechanisms for applying the law and the penalties for failing to adhere to it. The proceeds from fines are used to improve illumination quality. The primary objectives of the act concerning the obligation to ensure proper exterior illumination by communal authorities enable the stopping of harmful solutions at the design stage. Contractors who install external lighting must possess proper permits issued by the commune. The commune issues permits based on a design prepared by a specialist, which is to be compliant with the act's provisions. Furthermore, after completing their work, the contractor is obligated to deliver a certificate confirming the compliance of the completed external illumination with the design and applicable regulations to the client (Kubala 2017).

9.2. Phenomena associated with light pollution

The human eye is not perfect; under conditions present in the natural environment, it takes several dozen minutes for the eye to adapt to lower light intensities (darkness, night). This is why it is important to avoid numerous effects such as glare (blinding by light) and excessive illumination (i.e. illuminating a space that is not the target of the lighting fixtures, e.g. windows). Furthermore, the use of excessive illumination (when it is unneeded) and focusing too many light sources at a particular target is associated with wasting energy and contributes to sky glow above cities.

9.3. The impact of light pollution on animate nature and humans

The organisms that live on Earth had to evolve an internal biological clock, capable of sensing the day/night cycle, and adapt their own physiologies to it. Disruptions in the operation of the biological clock are typically caused by external factors, such as being exposed to too much light during the night, which has an adverse effect on flora, fauna and humans. As much as 81.9% of the Earth's continental area is at risk of excessive illumination (Cinzano et al. 2001) due to the improper illumination of structures. Excessive light that is directed upwards can be scattered by aerosols and/or dust particles present in the atmosphere and reflected back by clouds, causing distant areas to be polluted by light (Kyba et al. 2011). It is generally known that light regulates the biological functions of living organisms throughout the day/night cycle.

Solar radiation that reaches plants is subjected to reflection, absorption and transmission processes, which leads to changes in its spectral composition. This radiation affects their development. It determines not only the course and performance of photochemical processes, but also provides plants with information about the environment, e.g. the season of the year, allowing plants to adapt to current conditions (Kostecka 2017). Plant growth, blooming and maturing disorders have been observed in areas with excessive sky glow. Furthermore, plants observed to suffer from day/night cycle disruptions often have poorer immunological responses and are more susceptible to disease (Solecka 2015; Ziółkowska and Dobiesz 2015). Ścieżor and Balcerzak (2015) suggested that the excessive illumination of water bodies can lead to algae biomass growth, which is associated with an increase in water trophy and pollution of the aquatic environment. They have demonstrated a significant correlation between chlorophyll content in the water layers closest to the surface and the brightness of the night sky. Moore et al. (2000), when studying suburban lakes affected by light pollution, observed that *Daphnia* (which is a part of zooplankton) shows a lower migration amplitude in such conditions and its night-time algae consumption is less intense.

Excessive night-time illumination affects the feeding, communication, reproductive and migratory behaviours of animals (Moore et al. 2000; Longcore and Rich 2004; Rich and Longcore 2005; Tałanda 2015). Ecological balance can also be disrupted within an ecosystem as a result of excessive illumination, e.g. by causing predator populations and activity to rise, or can disrupt the feeding behaviours of nocturnal animals (Gliwicz 1999; Gotthard 2000; Kateta 2007). Artificial lighting has a considerable impact on firefly populations as they communicate by light flashes during their reproductive season. These flashes are disrupted by anthropogenic light sources – when artificial light intensity is in the range of 0.3-0.18 lux at night, no firefly male was able to locate a female (Bird and Parker 2014). Adverse effects of artificial lights on migratory bird populations were also seen, as hundreds of thousands of specimens were observed to die each day (Dobiesz and Ziółkowska 2015). Light pollution disrupts the natural magnetic compass of migratory birds and many of them die in collisions with brightly lit tall buildings. Another occasional type of illumination which is dangerous to birds and insects that enter its impact range are light structures (sculptures), which combine artistic illumination and art (Bartnicka 2015). Birds and insects become trapped in light beams and are unable to get out, moving inside until they collapse from exhaustion.

Long-term night-time light exposure negatively affects the proper functioning of the human organism. Examples of reactions to night-time artificial illumination include lower amounts of melatonin produced in the pineal gland, which is released into the bloodstream only when it is dark, and the associated disruptions of the day/night cycle, increased secretion of hormones such as cortisol, testosterone and oestrogen, as well as the triggering of immune system disorders (Janosik 2015; Jurkowlaniec 2017). The consequences of such disruptions include sleeping disorders, metabolism disorders that lead to conditions like obesity and diabetes, cardiovascular diseases, depression and increased risk of breast and prostate cancers (Skwarło-Sońta 2015; Kostecka 2017; Kucharczyk and Gąsek 2017). The biological reaction to artificial light is dependent on its spectral distribution, the amount of absorbed radiation and the time and frequency of exposure. Studies have shown that light sources that produce significant quantities of blue light in their radiation spectra, such as LED diodes, directly affect the human body, preventing the secretion of melatonin (Tabaka and Fryc 2019).

9.4. Examples of correct and incorrect illumination of historical cities

The aforementioned natural phenomena are directly affected by the type, intensity and location of light sources. Keeping the above in mind, it is necessary to design them correctly. This paper focuses on examples of correctly designed building illumination systems located in selected cities that have development zones of high historical value.

As in any case, there are exceptions to the rule – the northern edges of Europe, America and Asia do not go dark at night during summer, which means that their local ecosystems are forced to adapt to the atypical day/night cycle and significantly differ from those that comprise our climate zone. The long months without natural sunlight experienced in these areas have inspired many to pay greater attention to the role and potential of artificial light. There is a scientifically proven link between deficiencies in light exposure and a negative impact on human psychology.

Every building or complex needs to be treated individuallyin a manner appropriate to its character, function or form. In some cases, all that is necessary is to highlight the spatial form of the building by only illuminating its interior. This enables one to underscore the essence

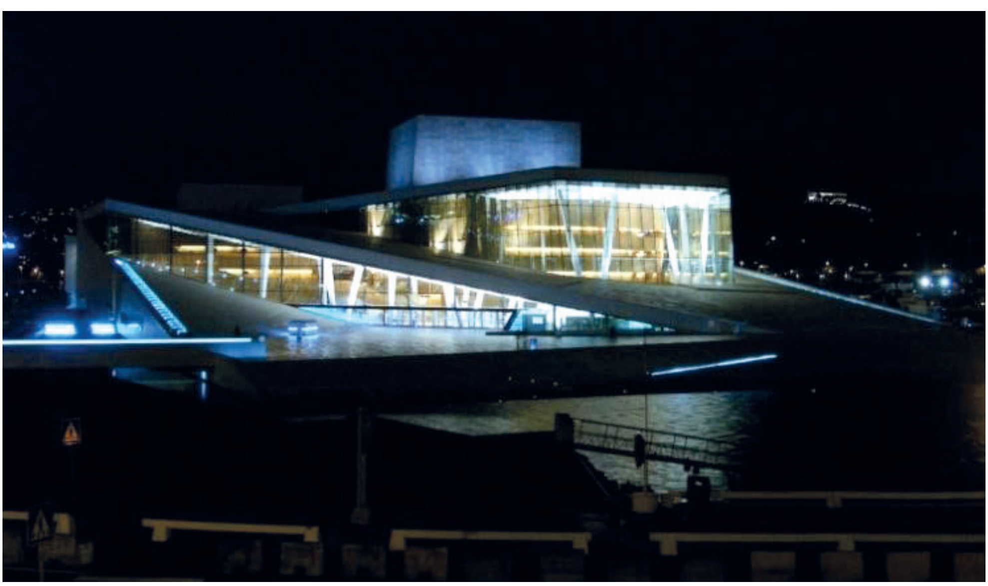

Fig. 9.1. Oslo, opera house. Original photograph

of a building's massing, structure and original material pairing. In order to maintain control over the effect both at night and during the day, the entire illumination system should be comprehensively designed and applied by the architect (Fig. 9.1). In April 2009, the Opera building by Snøhetta received The European Union Prize for Contemporary Architecture – the Mies van der Rohe Award.

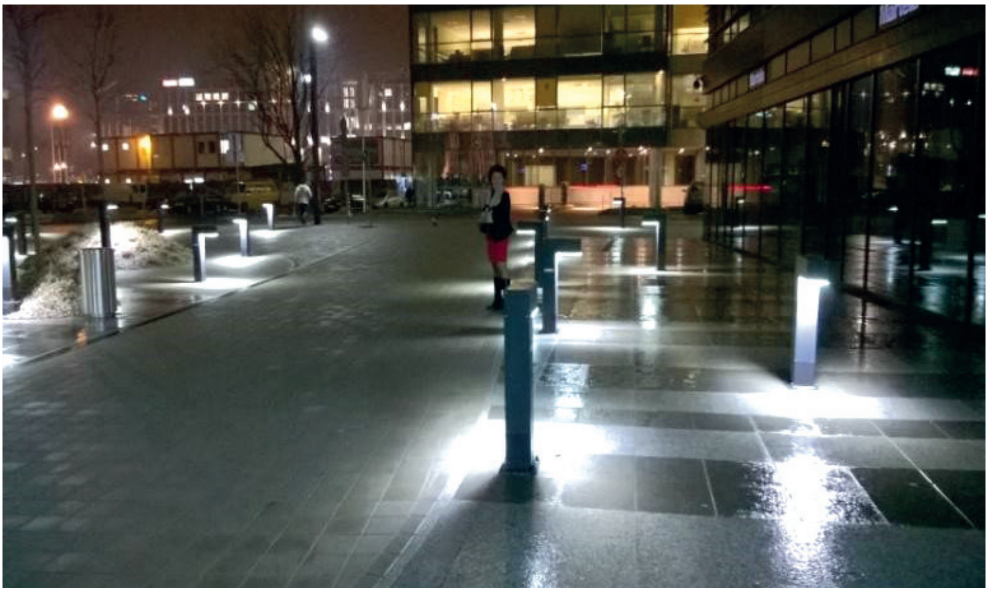

Fig. 9.2. Warsaw, the vicinity of the Stefan Kuryłowicz Foundation building. Original photograph

Fig. 9.3. Valetta – the capital of Malta – parliament building. Original photograph

Fig. 9.4. Malta, Valetta, historical buildings near the square in front of the parliament. Original photograph

However, merely illuminating a building and its surroundings is not always enough to properly present it. At times, even a properly selected illumination system can be completely invisible as it is directed entirely at the surface of the sidewalk, forming a zone without tall street lamps. Such a lighting system is completely sufficient to maintain legibility of both pedestrian walkways and the safety of vehicular transport (Fig. 9.2). Regardless, such a system creates a remarkably friendly atmosphere within the entire urban interior.

In Malta, the illumination of both buildings and the entire space has been limited to illuminating only the pedestrian-only zone in the direct vicinity of the building. Architect Renzo Piano did not use any light sources to illuminate the building's facade from the outside. This measure limits glare and prevents light scattering towards the sky (Fig. 9.3). The opposite frontage of the square features a historical building in which its user decided to highlight the entire wealth of its architectural detail through bright illumination. Despite the glaring light, it is worth mentioning that the fixtures were aimed downwards, illuminating individual elements of the building while interfering very little with the darkness of the sky (Fig. 9.4).

9.5. Toronto city centre

When analysing contemporary projects within areas of historical urban tissue, one cannot ignore the negative examples of impact on a structure's surroundings. Many structures, particularly those that are extensively glazed, despite the cost-effective use of street illumination, emit significant amounts of light into their surroundings. This is a direct result of the use of intense office lighting technology on each storey (Fig. 9.5). Unfortunately, erroneous approaches to highlighting the night-time surroundings of the world's most famous sites are

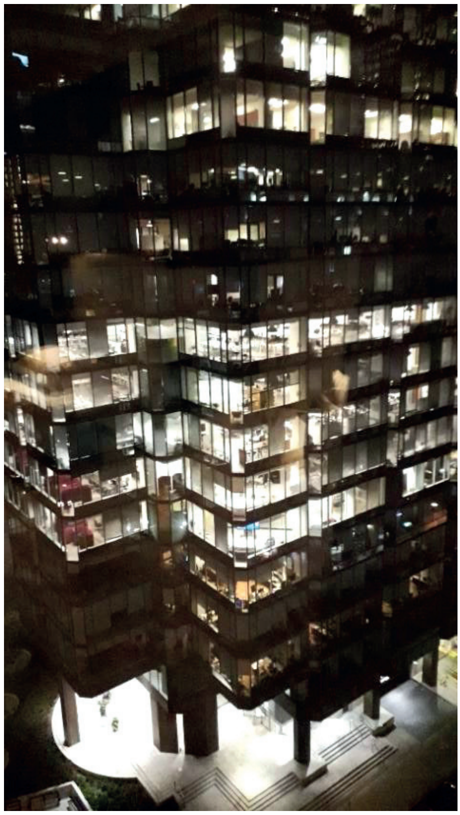

Fig. 9.5. Toronto city centre. Original photograph

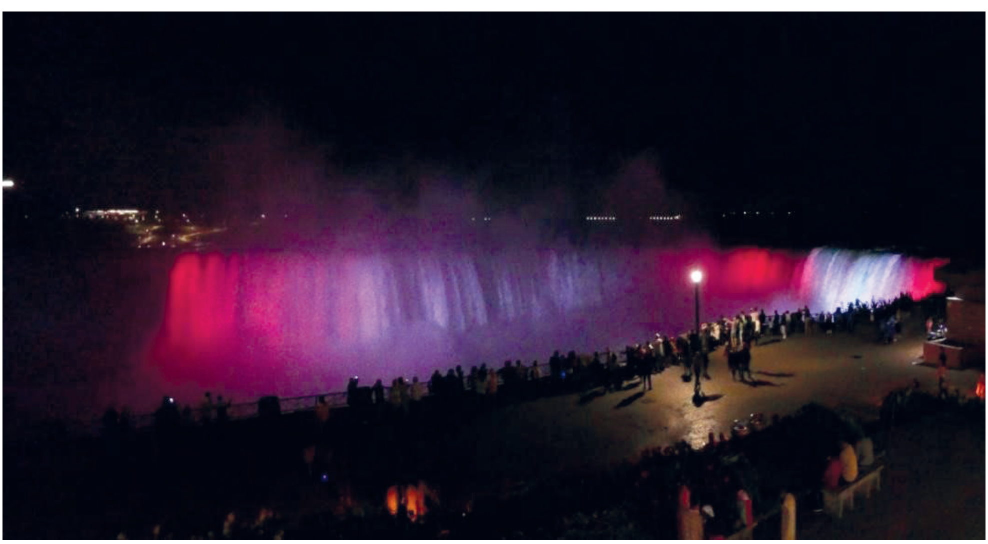

Fig. 9.6. Niagara Falls, Canadian side. Original photograph

far from rare. The Canadian side of Niagara Falls is one such case. Some natural phenomena should be considered to be equally precious and worthy of protection as the greatest monuments of man-made architecture. Acting without proper care can limit or completely erase the natural perception of unique natural phenomena. The waterfalls, illuminated by a full spectrum of changing colours, have completely lost their natural beauty and power. Most probably, the author of their illumination systems had a wealth of experience in designing night club and disco lighting (Fig. 9.6). This phenomenon can be considered as an instance of significant environmental pollution.

9.6. Contemporary technologies and environmental protection

In Times Square, New York, ever-present LED screens practically cover the facades of buildings that form the frontages of this part of the city. Observations, analyses and spectrum studies have indicated that LED screens generate light that is so focused and polarised that this technology does not cause sky glow above this area of the city (Fig. 9.7). Limiting night-time sky glow can also be achieved by properly building lamp posts. The Power Need SLL12 street lamp was developed using contemporary photovoltaic and LED technologies. The photovoltaic panel forms the cover, generating a power output of 18.5 W, feeding the in-built lithium-ion battery that powers a 2000 lm light source. An in-built motion sensor activates the light only when someone is nearby. ALS2.0+TCS technology improves performance on cloudy and rainy days (Fig. 9.8).

Fig. 9.7. Times Square, New York, USA. Original photograph

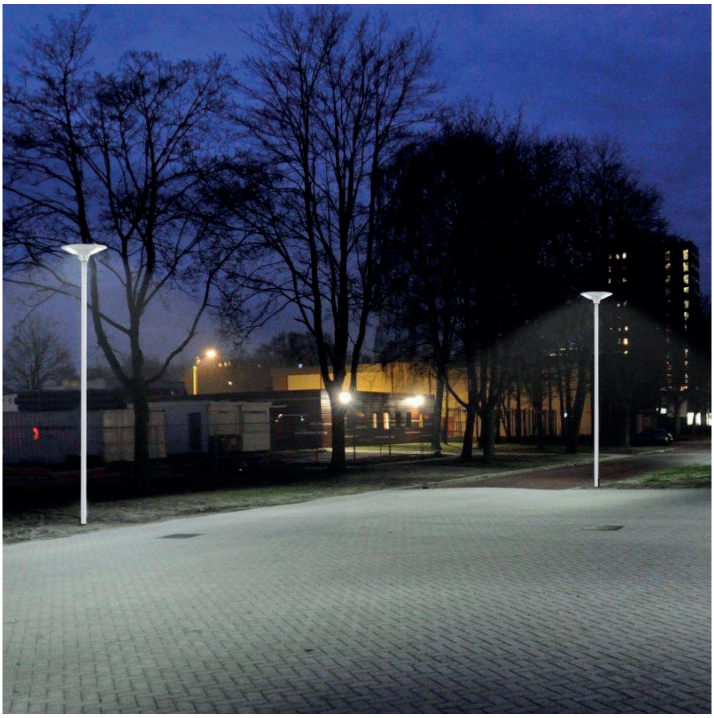

Fig. 9.8. PowerNeed SLL12 lampposts. Source: www.domenasportowa.pl/product-pol-230600-Solarna-lampa-uliczna

One positive technology that is considered for introduction into protected historical urban areas is smart light control, with light intensity constantly adapted to weather conditions and the scale to which a specific local traffic zone is externally illuminated.

9.7. "Ground Zero", New York

As an urban and architectural complex commemorating the victims of the 9/11 terrorist attacks, Ground Zero is, of course, perfectly acceptable. However, the effect of the aggressive night-time illumination produced by the beams of light that imitate the outline of the twin towers is unfortunately extremely dangerous to migratory birds, causing their complete disorientation. The effect changes depending on meteorological conditions, but during cloudy weather, the illumination of the area is almost as bright as daylight (Fig. 9.9).

Proper lighting on the urban scale is necessary to ensure both road safety and the personal safety of residents, in addition to creating an appropriate atmosphere within the city. Street lights enable drivers, cyclists and pedestrians to see better after dark, which helps to reduce the number of road accidents. Furthermore, street lighting indirectly contributes to preventing crime by increasing personal safety. In recent years, intensive work has gone into utilising renewable energy sources to power street and road illumination (Fig. 9.10).

Fig. 9.9. Ground Zero, New York, USA, monument to the victims of the 9/11 attacks, https://www.dailymail.co.uk/news/article-2034608/9-11-anniversary-Twin-towers-light-waterfall-remembrance-NYC

Fig. 9.10. Hybrid street illumination, http://elektrykbialogard.pl/oswietlenie_ulic.php

Conclusion

Numerous factors affect the proper selection of illumination systems: both external systems used on the scale of individual buildings and those used for entire building complexes and their interiors. The factors are follows:

1. The economic factor – reconciling the best possible effect with the lowest possible cost.
2. The aesthetic factor – the need to produce the planned effect of highlighting the essential characteristics of a building or creating an appropriate atmosphere in an architectural or urban interior.
3. The factor of human physiology – ensuring that requirements for creating good conditions for vision are met. The importance of appropriate light source control in highlighting architectural or landscape elements and even creating architecture through light is demonstrated by the fact that two independent ticket types are offered during World EXPOs: daytime and night-time tickets.

Summary

How should we design systems for the illumination of works of architecture and other essential urban zones so as not to waste energy and prevent light pollution, which contributes to sky glow? Numerous solutions exist, but we only need to focus our attention on some, including:

- installing fixtures that provide top-down building illumination, highlighting their architectural assets;
- using reflector masks, particularly in the case of some structures, such as towers, or ensure that light only falls on the dedicated structure;
- using short LED lamps that reach a maximum height of a single storey to illuminate areas. These lamps should have appropriately pitched fixtures and have their light sources directed so that excessive illumination and light emission into space is avoided;
- avoiding the placement of brightly lit billboards, particularly close to streets, so as to reduce glare (which is a primary traffic hazard).

It is noteworthy that individual countries introduce legal regulations concerning lighting systems and technologies that ensure energy efficiency and thus limit excessive light emission into the environment.

In addition, in terms of global warming, it is worth paying attention to the fact that (based on representative measurements for over 50% of the northern hemisphere continents in 1000 measurement stations from 1951-1990), a more pronounced increase in night-time temperatures as opposed to the maximum daily temperatures. It appears that the warming of the northern hemisphere that has been recorded since the period of the Second World War is largely the result of increases in night-time temperatures (Kukla and Karl 1993). Light pollution can potentially affect the current process of climate change, which is why it should become another reason to consider proper city illumination, alongside the economic, health-related and ecological factors.

10. POSSIBILITIES REGARDING THE IMPLEMENTATION OF NIGHT-TIME ARTIFICIAL LIGHT IN ENVIRONMENTAL PLANNING PROCESSES

Maria Zschorn[1]

Artificial lighting and the resulting illumination of the night landscape has increased considerably in the recent past (Kyba et al. 2017). As a consequence, a lot of literature is concerned with the question of what (negative) effects light pollution has on different species, on humans and on their environment (Böttcher 2001; Rich and Longcore et al. 2006; Held, Hölker, Jessel (eds.) 2013; Posch et al. 2013; Adams et al. 2019). Biologists, astronomers and medical experts worldwide underline the relevance of the topic. Thus, scientists and activists as well as planners have been looking for ways to avoid the negative environmental impact of artificial light (Frank, Isermann, Hänel 2013; Lang 2013; Walking and Stockmar et al. 2013; Förderverein Sternenpark Westhavelland e.V. 2018).

The avoidance or minimisation of light-related impairments is possible by means of measures that are usually easy to implement, such as the timing or dimming of lighting, shielding and focusing of the light beam or replacement of the lamp. However, like most other countries, Germany currently has no applicable law regulating the use of artificial lighting in outdoor areas. This means that "good professional practice" is not necessarily implemented.

The task of environmental planning in Germany is given in Section 1 of the Federal Nature Conservation Act (BNatSchG):

"[…] Nature and landscape […] are to be protected, so as to permanently safeguard

1. biological diversity,
2. the performance and functioning of the natural balance, including the ability of natural resources to regenerate and lend themselves to sustainable use, and
3. the diversity, characteristic features and beauty of nature and landscape, as well as their recreational value.

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Such protection shall include management, development and, as necessary, restoration of nature and landscape".

This goal should be achieved by using various environmental planning instruments, such as Preventive Landscape Planning (BNatSchG 2009, sect. 34) or Environmental Assessment (UVPG 2010, sect. 3).

10.1. Possibilities of environmental instruments to influence light pollution

Preventive Landscape Planning has the task of presenting objectives, requirements and measures relating to the environment for a specific area in maps and explanatory text in order to integrate the concerns of nature and landscape into the overall spatial planning (Auhagen, Ermer, Mohrmann 2002, 14; BNatSchG 2009, sect. 9). A wide variety of competing demands are made on space and landscape, which must be weighed up and brought to a compromise. Preventive Landscape Planning should ensure that the manner in which the environment is used does not exceed the capacity of the natural balance (SMUL 2005, 4, 9). This particularly concerns environmental pollution such as pollutants, noise or light.

The wide range of subjects under investigation in landscape planning as well as their action on different levels contribute to the fact that light impacts can be determined and prevented to a comprehensive extent. As the name suggests, this is an opportunity to take preventative measures and protect the environment from the harmful effects of light before they occur.

The preperation of landscape plans is stipulated by law and thus law and thus it is not linked to a specific building project. This shows great potential for a comprehensive preventive approach to the topic. In this way, the planning of light-intensive uses in light-sensitive areas and low-light areas (that are worthy of protection) can be ruled out in advance. Alternatively, guidelines for the use of artificial lighting can be established. In order for these to be integrated into the respective spatial plan, it is necessary to precisely substantiate these definitions in a well-founded and comprehensive analysis. Without the adoption of the objectives and measures in spatial planning, no binding effect develops and environmental protection cannot be achieved (BNatSchG 2009, sect. 11, para. 1, 3).

In addition to the direct protection of the environment from harmful light influences, Preventive Landscape Planning also offers the opportunity to raise awareness and educational opportunities of the population with regard to the topic (BfN 2012, 8). Offers such as guided star-tours or information events help to ensure that individuals can also develop a greater awareness of how to use light (Frank, Isermann, Hänel 2013, 119 ff.). This is necessary to legitimise night protection measures and to remove hindrances such as the subjective feeling of security and the purely positive connotation of light as a sign of prosperity and wealth (Held, Hölker, Jessel 2013, 13). Also, private outdoor lighting can be influenced in this way, which is currently not possible by other means.

The Environmental Assessment as a further instrument of environmental planning is intended to identify, describe and evaluate significant impacts of a plan or programme on protected features of the environment in accordance with the Environmental Impact Assessment Act (UVPG). It shall ensure effective environmental precautions and is to use uniform principles and guarantee public participation (UVPG 2010, sect. 3). The identified impacts on the environment are to be considered as part of the planning process and included in the decision on planning approval proceedings (Gassner, Winkelbrandt, Bernotat 2010, 3).

As the Environmental Assessment is process oriented and starts early in the planning procedure, it can accompany the process and contribute to the environmental optimisation of the associated (lighting) planning (Gassner, Winkelbrandt, Bernotat 2010, 1). Since the Environmental Assessment is carried out when a specific project is planned, in urban land use the assessment is only established for the affected area. The early approach and the processual nature of the project pose a major difficulty for the integration of night protection concerns. At the time of preparing the environmental report and the environmental impact study, the project planning is relatively provisional. As a result, the lighting design in particular often remains to be finalised (Zschorn 2018, 291). This makes it difficult to identify project-related light effects on the environment.

Furthermore, the evaluation of light effects on the objects of protection proves to be a challenge. As the results of the Environmental Assessment are to be only considered rather than included in the authorisation decision, it is necessary to make clear statements on the severity of the adverse effects. In future, evaluation methods will have to be developed so that the Environmental Assessment can fulfil its task of outlining the significance of the impacts at an early stage.

The advantage of the Environmental Assessment lies in its large scope of assessment, which, in addition to the items of protection of preventive landscape planning, also includes the items (impaired by light emissions) “human and human health”, “cultural and other material goods” and “interactions between the protected goods” (UVPG 2010, sect. 2).

The Habitats Directive aims to permanently safeguard and protect the biodiversity of wild fauna and flora, their habitats and the European network of these (Habitats Directive 1992, Art. 2, para. 1). If a planned project affects one of the protected areas designated for this purpose, its compatibility with the conservation objectives of the Natura 2000-site must be examined as part of a Habitats Directive Assessment (BNatSchG 2009, sect. 34, para. 1). This assessment is only drawn up if a project or plan affects a Natura 2000-site or a bird reserve. Unlike the Environmental Assessment, the result of the Habitats Directive Assessment may lead to the plan not being implemented (BNatSchG 2009, sect. 34, para. 2), so that harmful effects of light on sensitive areas can be eliminated. Thus, a legally binding, effective protection of the environment from the adverse effects of artificial lighting can be achieved. However, this always raises the question of the significance of the effects, which often cannot be assessed due to inadequate research into the severity of impairments caused by light and insufficient knowledge amongst planners. Furthermore, the Habitats Directive Assessment only aims at the protection of species and habitats and thus has a rather limited scope of investigation.

Conclusion

If properly implemented, all three named instruments can be used to ensure environmental protection against impairments caused by light. The prevention-oriented and comprehensive approach of Preventive Landscape Planning can create protected areas and determine standards for the environmentally optimised use of light. Moreover, it can be the basis for other planning processes and the use of subsidies. The Environmental Assessment has the advantage of being involved in such concrete planning processes that it can influence the handling of light in projects or plans within this process. With the help of the Habitats Directive Assessment, it is even possible to prevent a plan or project if it is causing significant effects due to its light emissions.

Although it has been shown that the mentioned instruments are able to interfere regulatively, a number of problems are apparent in their implementation. Among planners, there remains a lack of awareness of the problem and knowledge of how the issue can be integrated into environmental planning processes. There is a lack of methods for analysing and evaluating light-related impairments and for assessing their significance; these should be developed in the future.

11. THE IMPORTANCE OF THE BÜKK AND HORTOBÁGY DARK-SKY PARKS AND THEIR EDUCATIONAL BENEFITS

Anna Apró[1], István Gyarmathy[1], Richárd Novák[1]

11.1. Hortobágy National Park

The Hortobágy National Park is situated on the former floodplain of the Tisza river (the park's area is 82,000 hectares, the nearest city is Debrecen, 35 km East of the park's border, see Fig. 11.7). The park is the first proclaimed and the largest Hungarian national park; it is also a World Heritage site, a Ramsar site, a Natura 2000-site and a UNESCO Biosphere reserve.

Fig. 11.1. The obtrusive light-free environment at night is essential for the protection of migratory birds and wildlife such as insects (Longcore and Rich 2006) (photo: A. Szilágyi)

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Fig. 11.2. Traditional shepherd building with the Milky Way (photo: T. Ladányi)

Hortobágy is an almost flat plain landscape, a great and continuous grassland area with wetland mosaics, the most extended in its category in Europe. It is occupied by alkaline marshes, meadows, dry alkaline pastures and remnant loess-steppe vegetation (Tardy 1999).

Hortobágy is most famous for its rich avi-fauna. The number of nesting species is 159 and there are an additional 178 species which are regular or irregular visitors. It is generally the best bird-watching place in Hungary (possibly in the whole Karpathian Basin) and also the most important IBA (important bird area) too. Migration is particularly significant (Fig. 11.1).

Hortobágy is one of the last guardians of the living shepherd tradition. Shepherd culture has a deep interrelation and interdependence with the natural environment. Pastures of Hortobágy are scattered with traditional buildings of ancient pastoral activity. There are many pieces of evidence of ethnographical works of the starry-sky knowledge of the shepherds (Fig. 11.2).

11.2. Hortobágy as a dark-sky park, public access and outreach

Hortobágy is one of the largest unpopulated and darkest areas in Hungary. Hortobágy got its international dark-sky park (or Starry Sky Park – SSP) status from the International Dark Sky Association in 2011 according to the nomination submitted in 2010 (Fig. 11.3).

Both maps show that the area is as intact and undisturbed at night time as it is in the daytime. The lack of light-pollution can be viewed as one of the measures of naturalness.

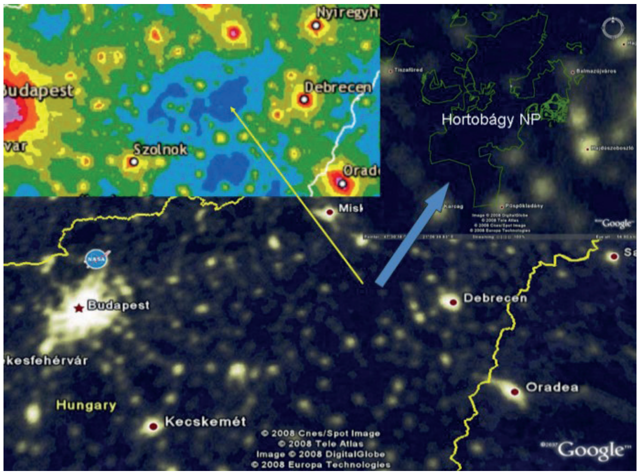

Fig. 11.3. Hortobágy National Park on the Google Earth night-time satellite map and on the new World Atlas of artificial sky brightness (Fabio et al. 2016)

The starry sky park's significance is mostly related to the undisturbed night-time landscape, the shepherd tradition related to the starry sky and the protection of the high biodiversity, especially the great number of migrating bird species and special nocturnal insect species. It is notable that many of the important breeding and nesting bird species (geese, cranes, spoonbills, etc.) and other species, especially many rare insect species, are sensitive to light pollution (Longcore and Rich 2006).

Being a starry sky park is important for the protection of the nocturnal wildlife habitats as well as the landscape values of Hortobágy as an outstanding and an unaltered wilderness

Fig. 11.4. The park's new public observatory (photo: T. Ladányi)

area in the Great Hungarian Plain, in the middle of Europe. Now, the dark-sky values also provide a new attraction to the area – the park has become an astro-tourism destination.

The astro-tourist travels for the purpose of astronomy or simply to enjoy the beauty of the pristine starry sky. Starry sky parks can be the main places for developing astro-tourism and amateur astronomy.

These darkest corners of the planet where the environment is not disturbed at night by artificial light have not only ecological functions but also educational and touristic values.

Hortobágy Starry Sky Park organises night-time walks, special interpretive programs related to dark-sky values and good lighting practices. There is a high level of interest demonstrated by the general public to attend these night adventures. The park has different programs designed to show the values of the park, and is planning a new visitor centre with an exhibition dedicated to the dark-sky park.

Astronomy has become part of the park's Field Study Centre's curriculum. The park has recently established a public astronomical observatory as part of the development of the centre (Fig. 11.4). It is also equipped with all-sky cameras and permanent SQM.

11.2.1. Lighting regulations in Hortobágy Dark-Sky Park

According to the Park's regulations, the following conditions should be satisfied by any outdoor lighting in Hortobágy (Lighting Plan of the Hortobágy Starry Sky Park 2011):

- Only fully shielded fixtures can be used, and they should be installed and serviced so that no light should be emitted above the horizontal plane.
- Colour temperature cannot exceed 3,000 K.
- The maximum allowable light output (luminous flux) per fixture is 1,800 lumens.

If the total luminous flux of a premises or property exceeds 10,000 lumens, a detailed lighting permit plan should be prepared.

- Any construction should be started only after approval by the Hortobagy National Park Directorate as the competent nature conservation management organisation, and by IDA Hungary.
- The illumination levels cannot exceed the minimum norms available for the given purpose.
- Outdoor lights can only be used when pedestrian or considerable vehicular traffic is expected. Motion sensors or time switches are preferred in locations with infrequent traffic.
- The use the most energy efficient lamps is preferred.

The park included the articles of the lighting plan of the starry sky park to its management plan to protect the natural and scenic values of the undisturbed night-time environment. The lighting regulation and zoning policy provide the possibility to control artificial lights within the park.

The park has cooperation agreements with local and national conservation and astronomy NGOs to protect the area's dark sky values as well as with the local stakeholders.

11.3. Bükk National Park

In the Bükk Mountains of Northern Hungary, near Miskolc, there is a national park called Bükk National Park. It was founded in 1976 as the third national park in Hungary. Its area is 431.3 km^2. It contains important karst formations, caves, ravines and swallow-holes (Fig. 11.5 and 11.6).

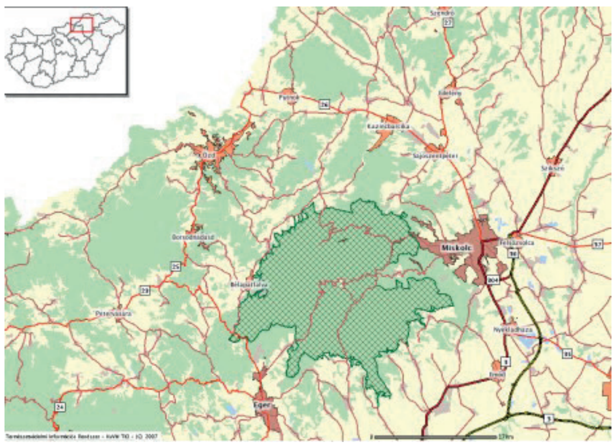

Fig. 11.5. Location and boundary of the Bükki Starry Sky Park (source: TIR & Google Maps)

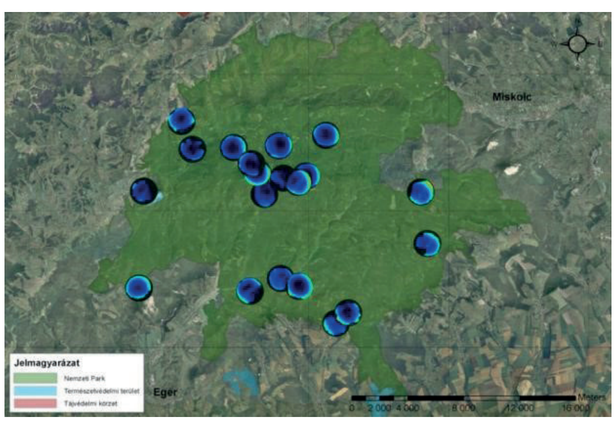

Fig. 11.6. False coloured fish-eye images from the Bükk National Park

Articles from the Management Plan of the Bükk National Park

1. Nature Conservation Objectives: preserving the natural view of the natural dark starry sky.
2. Nature Conservation Strategies: preserving the natural dark sky conditions in the national park; the establishment of a light pollution-free zone (dark sky park) for the benefit of light-sensitive ecosystems and for public outreach.

3. Nature Management Methods, Restrictions and Prohibitions:
   - In outskirt areas (protected areas), the illumination of objects is forbidden. To establish new outdoor lighting, it is necessary to have permission of the nature conservation authority involving the Bükk National Park Directorate.
   - Lighting for non-residential buildings in the outlying targets is to be revised. For establishing new outdoor lighting, it is necessary to obtain the permission of the nature conservation authority involving the Bükk National park. In the case of unavoidable outside lighting, their environment must be designed in such a way as to not reduce the value of the night landscape.
   - If all the lumen volume of a suburban real estate are in excess of 10,000 lumens, a detailed lighting plan shall be prepared by the owner and must first be consulted with Bükk National Park Directorate for the prupose of authorisation.
   - The periphery exposure should not exceed the values of current uses lowest values.
   - The use of upward lighting devices is prohibited.

11.3.1. Public access and outreach

Throughout the whole year we are conducting several stargazing episodes, night shows and presentations together with the Bükk National Park Directorate. It was reamarkably observable that people were very much interested in night shows and observations. The area of the national park is easy to access by anyone by car or on foot. Actually, there are no regulations for limiting public access, except some forestry activities and some scattered strictly protected areas, for instance, when there are birds nesting.

Informing people of the sights of the starry sky is sometimes achieved using astronomical presentations near to urban areas. The Bükk National Park Directorate's forest school/field education centre in Felsőtárkány accepted 2012 students in 2016. The national park is highly committed to field education and fighting against light pollution. Over the last two years, we have replaced eight outdoor lighting fixtures in our forest school in order to consume less energy and show a good example to our students/visitors. We led twenty star parties and nocturnal hiking events for these groups in 2016, and also intended to reach or exceed this amount in 2017. Firefly observing, bat catching, and night-time hikes on study trails are also regularly done almost twice per month in high season.

When the national park or the association's workers are showing a presentation to educate student or adult groups, light pollution monitoring and a light pollution map is always shown and interpreted in order to raise awareness of the National Park's current light pollution state. During nocturnal activities (observing of wildlife, night-time study trail walks) a SQM-L device is used to show the values between populated areas and light-pollution-free protected areas. On night-time walks, we often lead our visitors as far as 10 km from settlements in order to make them understand the difference between the sky conditions of settlements and uninhabited areas.

The following two images are always shown in presentations about Bükk National Park for a comparison (Fig. 11.7).

Fig. 11.7. Eger centre and Bükk National Park

11.3.2. Lighting fixture replacements

On completion of the surveys, we wanted to replace some light fixtures that generated light pollution. This activity was conducted not only to decrease light pollution but also for educational purposes.

As shown on the following photos, we have reduced the light pollution in certain areas. The replaced lighting fixtures can be found in the Szalajka-valley (replaced lighting fixtures in the Szalajka-valley), Kisgyőr (village), St. Stephen Cave (old and new lighting fixtures, replaced at the entrance of the St. Stephen's Cave – Bükk National Park) and Felsőtárkány (The National Park Directorate's field education centre). During nocturnal activities in our forest school, we direct our student's attention to the replaced lighting fixtures: why we did it, why it is important, and who benefits from this (the connection between us and nature).

During guided tours to St. Stephen's Cave, outdoor lighting and the colour temperature of the new lighting system is also demonstrated by the collegues of the Bükk National Park Directorate. Light pollution was also an issue at our partner association's visitor center (Rónaörző Nature Conservation Assocation); old road lights were replaced there in order to prevent light pollution and gain the effectivity of their nocturnal presentations and star parties.

We also would like to replace the entire light system of Répáshuta in two years so as to comply with the IDA's regulations (Fig. 11.8). The Mayor of Répáshuta is highly committed to comply with the rules of the IDA regulations, the starry sky park and the national park

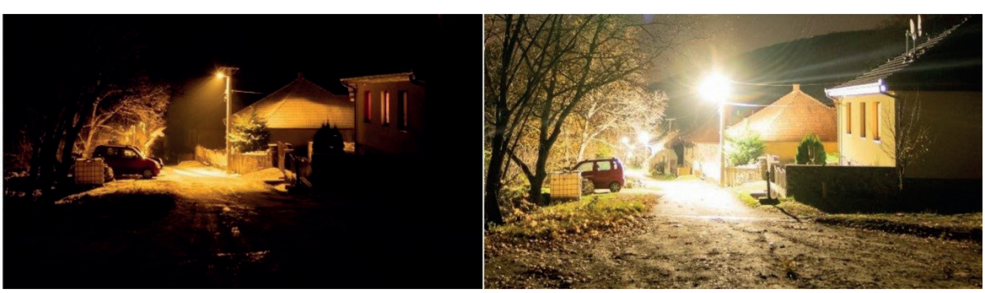

Fig. 11.8. Lighting fixtures replacements in Répáshuta

management plan. They also would like to make it a pilot project in order to show the right direction and serve as an example for similar actions in the future. His expressed pledge is that within one and a half years, all lighting fixtures will be replaced in the village. This commitment can also be found in his letter of support above.

11.4. Awareness of light pollution in educational institutions

The social and educational issues of light pollution also need to be addressed. In the following section, we will look at emerging issues in environmental science and geography.

In the lower part of the class, you will find subject matter that is related to light pollution in the Environmental Knowledge module. They are aimed at recognising the relationship between the Earth, the sun and the moon, and studying the alternation of the seasons and its characteristics. Developmental requirements include the discovery of the beauty of celestial bodies, which must be an important part of astronomical education. In daytime astronomy, we can help students to create their own star map. We learn to use it in the classroom so they can apply their newly acquired knowledge at home during the evenings (Percy 2001). However, the professional development of teacher education in astronomy is essential for this. In the upper part of the class, students will learn about the structure, lifestyle and significance of animals living in and around the house. The Nature Study subject is supplemented by basic bird protection knowledge, and learning and practicing bird protection with season-related activities. In teaching about the Earth and the universe, the goal is to develop causal thinking by explaining the causal relationships between the natural environment and the underlying atmospheric processes. These include the evolution of the moon's light, the seasons, and the climate zones. Students get answers to questions about how to determine the northern light without a compass at night, why we see the starry sky in different seasons, and about orbs, stars, planets, moons and constellations. It is also important to raise awareness of the presence of light pollution in this area. We examine the individual and social impacts of large areas of our country and ways of recognising and solving the resulting problems in relation to the environment. The natural values of the national parks are also mentioned.

Acknowledgements

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12. ARE DARK-SKY PARKS RECOGNISABLE IN SOCIETY? THE EXAMPLE OF IZERA DARK-SKY PARK

Grzegorz Iwanicki[1]

Dark-sky parks are established to minimise the effects of excessive artificial light at night in areas of natural, cultural or recreational value. They are characterised by the good quality of the dark sky, which is protected and often promoted as a sustainable and astronomical tourism product (Rodrigues et al. 2015). The first such protected areas, unrelated with astronomical observatories, were established in the 1990s in the Lake Hudson Recreation Area Dark Sky Preserve and Torrance Barrens Dark Sky Preserve, located in the US state of Michigan and the Canadian province of Ontario, respectively (DSAG 2020).

Currently (data for February 2020), there are over 180 such parks in nearly thirty countries on six continents. Most have been established under the auspices of the International Dark-Sky Association (IDA), a global non-profit organisation dedicated to the fight against light pollution. The remaining parks have been sanctioned by Fundaçión Starlight (Starlight Initiative, a foundation operating mainly in Spanish-speaking countries), the Royal Astronomical Society of Canada (over twenty-five parks exclusively in Canada) and local institutions or consortia (e.g. parks in Poland, the Czech Republic and Slovakia) (DSAG 2020).

Despite the large number of functioning starry parks, there is a lack of detailed analyses concerning their recognition among local communities. One of the objectives for which dark-sky parks are established is to promote knowledge about the negative effects of light pollution by means of various events and activities organised there. Research shows that this knowledge is not common. According to the results of the online survey (n = 2053) conducted by J. Lyytimäki and J. Rinne (2013), mainly among educated Finns from the circle of those potentially interested in the subject of light pollution (including astronomy enthusiasts and members of NGOs), the perception of light pollution sources and the degree of nuisance of the phenomenon itself may vary depending on gender, age, interests or place of residence.

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Knowledge about the existence and activities of dark-sky parks is also not common. In a survey conducted in 2015 among Zagreb residents (n = 191), only 6% of respondents answered that they had heard about dark-sky parks but could not indicate the name or location of any of them (Iwanicki et al. 2018). The respondents had also never heard of the Zselic Dark-Sky Park in Hungary, located 200 km from Zagreb. This park is the oldest international area of its kind in Europe on a par with Galloway Forest in the UK (Kollath 2010). Even lower results in terms of knowledge of dark-sky parks were recorded during a survey (n = 132) conducted among randomly selected respondents from Poland (residents of the municipality of Jabłonna near Lublin), where only 2.2% had previously heard of dark-sky parks (Iwanicki 2014).

Organised dark sky protection carried out in dark-sky parks is an exception in most countries. The lack of nationwide regulations limiting the excessive use of outdoor night-time lighting may result from underestimating the issue of dark sky protection in relation to other environmental problems. This underestimation may have its origin in the low awareness within society about the negative effects of light pollution, which may also translate into a lack of knowledge among the members of local governments and state administration.

The mere number of created dark-sky parks, which is growing every year, does not necessarily have to be correlated with the increase in awareness of the objectives of the existence of dark sky preservation areas. Such areas are created mainly on the initiative of astronomy enthusiasts or people involved in nature conservation, and are usually located in the areas of previously functioning sites with varying degrees of nature conservation (from landscape parks to national parks) (DSAG 2019). Therefore, tourists visiting these areas for some reasons have the opportunity to learn about the dark sky and increase their awareness of the effects of light pollution. They can apply their knowledge in practice by introducing dark sky friendly solutions in their homes and on their property.

Examples of introducing such solutions are the international dark sky communities established under the auspices of the IDA, where a group of people who know the dangers of excessive lighting push certain legal regulations on a local scale. On a national scale, stronger lobbies from circles, mainly related to astronomy, have led to stricter legal regulations in a few countries aimed at minimising the effects of light pollution (Ściężor et al. 2010; SR 2019).

To what extent do the activities of dark-sky parks contribute to the dissemination of knowledge on the sustainable use of outdoor lighting? Thus far, there has been no analysis in this area, and this article is an attempt to answer the question: do tourists visiting dark-sky park know they are visiting a dark sky preservation area? An additional purpose of the article is to answer the question: do residents living in the vicinity of dark-sky parks know that there is a dark sky protection area close to their homes?

The survey was conducted in August 2019 in the Izera Dark-Sky Park (IDSP) among 124 tourists visiting the park, and 178 people living in the communities where the IDSP is located.

The choice of the research area was motivated by two factors. The first is the long period of activity of this park, which is one of the longest functioning areas of this type in Europe and celebrated its 10th anniversary in 2019. It is also the oldest cross-border dark-sky park in the world – the second part is on the Czech side (Mrozek and Kołomański 2014). An additional reason for choosing the Polish park is the low awareness of the problems of light pollution among Poles. Research carried out a few years earlier shows that knowledge about the very existence of the problem of artificial light pollution is low. Only 5% of respondents have heard the term of light pollution (Iwanicki 2014; TNS 2015), while as many as 83% could not say what they associate it with (TNS 2015). Additionally, only 2.2% have ever heard of dark-sky parks (Iwanicki 2014).

12.1. Materials and methods

This article describes the first part of the wider research project *The impact of dark-sky parks on regional socio-economic development* partly financed by the Polish Ministry of Science and Higher Education. Two stages of this first part have been conducted, the results of which are described in this article.

The first stage was the analysis of the activities of the IDSP in terms of promoting knowledge about the dark sky and light pollution in the period 2009-2019. The information was collected from the official website of the IDSP and other websites displayed on the first two result pages after entering the phrases *Izerski Park Ciemnego Nieba* (in Polish) in the Google Chrome browser which is the most popular in the world and also in Poland (StatCounter 2019a; StatCounter 2019b).

The second stage was to conduct individual interviews in August 2019 with 124 randomly selected tourists on the tourist trails in the IDSP (57.3% were females, and the average age of respondents was 39.2 years) and with 178 residents of the municipalities where the park is located (66 respondents from Szklarska Poręba, 70 from Świeradów-Zdrój and 42 from Mirsk; 59.0% were females, and the average age of all respondents was 41.3 years). The chosen method was a structured interview based on the "random tourist" interview scenario. Each of the respondents was asked a question "How can I get to the Izera Dark-Sky Park?". If the respondent had never heard of the IDSP, then additional information was given: "This park was established in 2009 somewhere in the Izera Mountains, but I don't have it on my map and I don't know how to get there – some astronomical events are organised there". In cases where the respondent knew about the existence of the IDSP, questions were asked about the exact location of the park (and a request to point it out on the tourist map of the Izera Mountains) and interesting attractions or events related to the park.

The selected research method, the limited number of questions and the form of asking them were aimed at preserving the natural behaviour of the respondents and avoiding negative aspects associated with standard questionnaires.

12.2. IDSP popularisation activities

The beginnings of the IDSP date back to 2007 and are connected with the *Projekty Izerskie* (Izera Projects) whose founders were, among others, Sylwester Kołomański and Tomasz

Mrozek from the Astronomical Institute of the University of Wrocław and Grzegorz Żakowicz from one of the high schools in Wrocław. The initiators received support from local institutions: Towarzystwo Izerskie (Izery Society), the Forest District in Świeradów and Szklarska Poręba, as well as the Gondola Railway in Świeradów-Zdrój (Mrozek et al. 2012; Kołomański et al. 2014).

As part of the projects, annual meetings of astronomy enthusiasts were held under the name of Ogólnopolskie Spotkania Astronomiczne (All-Poland Astronomy Meetings, the last edition took place in 2015) and twice a year, School Astronomical Workshops started to be organised in Izera Mountains (Table 12.1), which continued in subsequent years, after the establishment of the IDSP. Both closed events (limited number of participants, required reservation), were complemented by mass events, aimed at a larger number of participants, including the flagship event Astronomical Day at the IDSP, which has been held twice a year since 2010 in the most popular places in the park: Jizerka (on the Czech side), Szklarska Poręba (Jakuszyce and Orle), and Świeradów-Zdrój (most often at the gondola station on Stóg Izerski).

Table 12.1. Events and atractions related to Izera Dark-Sky Park

NAME	SUMMARY DESCRIPTION
Regular events	
Szkolne Warsztaty Astronomiczne (School Astronomical Workshops)	These have been organised for secondary school students twice a year, in spring and autumn, since 2007. On the website dedicated to workshops (www.swa.edu.pl), only one "news" tab has been updated since 2018.
Izerskie Długie Ekspozycje (Izera Long Expositions)	Astrophotographic workshops for a limited number of people (20-30 participants), organised every year from 2016 at the Tourist Station Orle.
Former regular events	
Astronomiczny Dzień w IDSP (Astronomical Day in IDSP)	Free entrance. Organised twice a year, in spring and autumn, since 2010. Last edition was in 2017. Event venues: Jizerka (on the Czech side), Szklarska Poręba (Jakuszyce and Orle) and Świeradów-Zdrój (gondola station on Stog Izerski, and near the seat of the Świeradów Forest District).
Ogólnopolskie Spotkania Astronomiczne (All-Poland Astronomy Meetings)	Annual meetings of astronomy enthusiasts organised once a year, last held in 2015.
Astronomiczna majówka w IDSP (Astronomical May Day in IDSP)	Open meetings in Świeradow-Zdrój (Stóg Izerski), e.g. sky observations, portable planetarium, organised in 2012-2014.
Warsztaty Astronomiczne dla nauczycieli (Astronomical workshops for teachers)	Organised in 2013-2014.
Permanent sites and atractions	

NAME	SUMMARY DESCRIPTION
Model Układu Słonecznego "Ścieżka planetarna" ("planetary path" model of Solar System)	Medium-sized stones representing each of the planets, located at the main tourist route (starts in the Orle settlement), opened in 2010.
Gnomon i zegar słoneczny (gnomon and sundial)	The sundial has been functioning on the wall of the Orle Tourist Station since 2009, and the gnomon was erected in 2010 in the Orle settlement.
Centrum Edukacji Ekologicznej „Izerska Łąka" (Izerska Meadow Ecological Educational Center)	Institution operating in Świeradów-Zdrój since 2015. It organises various science and educational events in the field of ecology, including issues of light pollution (weekends with astronomy, evenings with astronomy, sky observations).
Irregular events	
e.g. Polish-Czech astronomical picnics, sky observations, Perseid observations, Polish European Association for Astronomy Education Summer Schools	

Source: www.izera-darksky.eu, www.astro.uni.wroc.pl/astroizery

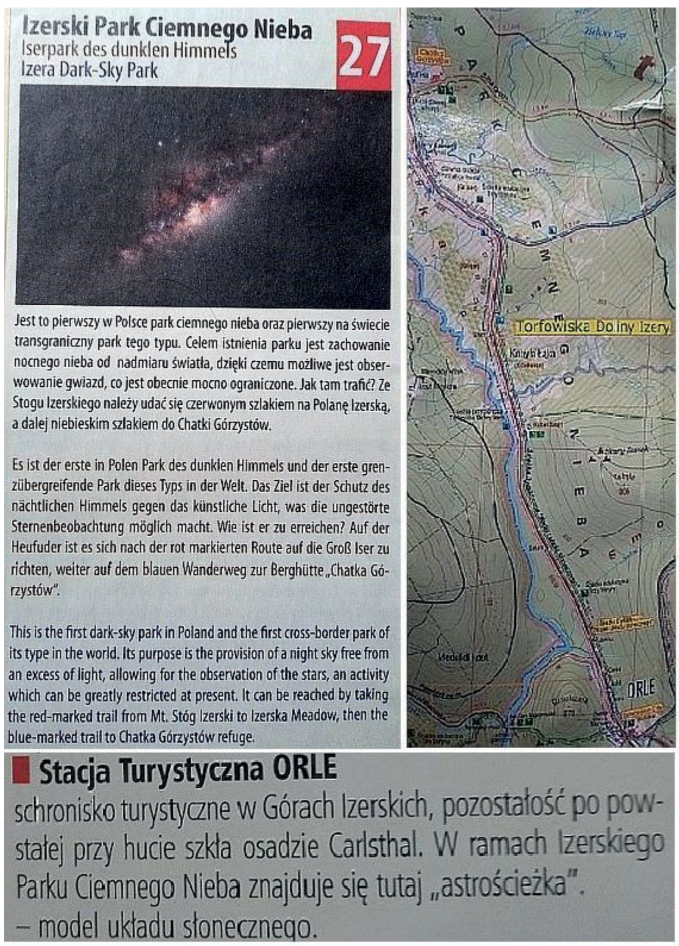
Among the regular events, only closed workshops for a limited number of participants are still organised in the park: the aforementioned School Astronomical Workshops, and the Izera Long Expositions, organised since 2016, which are astrophotographical workshops. Free entry events are organised mainly in the Izerska Meadow Ecological Educational Center located in the suburbs of Świeradów-Zdrój. In addition to the occasional night sky shows and science lectures for school students, the basic offer for visitors to the centre includes shows in the planetarium and presentations on the problems of light pollution, together with information about the nearby functioning dark-sky park.

Tourists and others can also learn about the IDSP and its activities from dedicated websites. The most important is the official website of the park (www.izera-darksky.eu), which is in three languages: Polish, Czech and English. It contains detailed information on the history of the park, activities and issues related to light pollution, as well as information on organised events and the presence of the IDSP in various media. The latter type of information, however, has not been updated since 2011, and the tab on events in the park only contains information of events held until 2017. A similar range of information, but only in Polish, can be found on the official website of Astro Izera, run by the Astronomical Institute of the University of Wrocław. The information there is as detailed as in the previous website but unfortunately, the degree of update is also similar. Information about the presence of the park in the media reaches only 2013, and the list of events ends in 2016. Currently, although rather sparse, information about later events can be found on Astro Izera's Facebook page, officially followed by approx. 1100 people.

Other websites that offer basic information about the IPCN and some of the astronomical events organised in its area are the official website of the town of Świeradów-Zdrój and the Izera Mountains (Góry Izerskie) portal dealing with tourism in this mountain range. Other sites from the analysed results where we can find a lot of information about the park include: one of the travel blogs – zbierajsie.pl (a report of the visit to the park with a lot of information about it); the portal of the largest organisation in Poland focused on the fight against light pollution – ciemneniebo.pl; one of the largest astronomical portals – urania.edu.pl; the Czech portal dedicated to tourism in the Izera Mountains region – www.jizerky.cz.

It should be added that one of the pages that first appears after typing in the searched phrase is the Polish Wikipedia, but it contains very little information about IDSP (there is also a Czech version available, with more information), and at the beginning, the location of the park is indicated in Mirsk, which is actually more than 10 km away from the park's border.

Information about the activities of IPCN has also been announced in a lot of local and national media. Not counting the representatives of media from Lower Silesia, examples



Izerski Park Ciemnego Nieba
Iserpark des dunklen Himmels
Izera Dark-Sky Park
27

Jest to pierwszy w Polsce park ciemnego nieba oraz pierwszy na świecie transgraniczny park tego typu. Celem istnienia parku jest zachowanie nocnego nieba od nadmiaru światła, dzięki czemu możliwe jest obserwowanie gwiazd, co jest obecnie mocno ograniczone. Jak tam trafić? Ze Stogu Izerskiego należy udać się czerwonym szlakiem na Polanę Izerską, a dalej niebieskim szlakiem do Chatki Górzystów.

Es ist der erste in Polen Park des dunklen Himmels und der erste grenzübergreifende Park dieses Typs in der Welt. Das Ziel ist der Schutz des nächtlichen Himmels gegen das künstliche Licht, was die ungestörte Sternenbeobachtung möglich macht. Wie ist er zu erreichen? Auf der Heufuder ist es sich nach der rot markierten Route auf die Groß Iser zu richten, weiter auf dem blauen Wanderweg zur Berghütte „Chatka Górzystów".

This is the first dark-sky park in Poland and the first cross-border park of its type in the world. Its purpose is the provision of a night sky free from an excess of light, allowing for the observation of the stars, an activity which can be greatly restricted at present. It can be reached by taking the red-marked trail from Mt. Stóg Izerski to Izerska Meadow, then the blue-marked trail to Chatka Górzystów refuge.

Stacja Turystyczna ORLE
schronisko turystyczne w Górach Izerskich, pozostałość po powstałej przy hucie szkła osadzie Carlsthal. W ramach Izerskiego Parku Ciemnego Nieba znajduje się tutaj „astrościeżka". – model układu słonecznego.

Fig. 12.1. Examples of information on IDSP: tourist guide published in Świeradów-Zdrój (left), Izera Mountain tourist map (right), practical guide published by Szklarska Poręba (bottom).
Source: author's own photographs of publications

of such "advertising" were articles published in national newspapers, e.g. in Polityka, Rzeczpospolita and Gazeta Wyborcza, broadcasts on the radio, e.g. in the First Program of the Polish Radio, as well as reports about the park on nationwide television, e.g. TVP (in one of the episodes of the programme Astronarium), TVN Meteo and TVN 24. Materials about IDSP have also been published on You Tube, including material on the channels of the University of Wroclaw, Urania TV, Hunter of Adventures, and Astronarium, with the total number of views exceeding fifty thousand.

For those who prefer paper publications, maps and tourist guides on the attractions of the Izera Mountains and its surroundings have been prepared. The most information about the IDSP is contained in the tourist guide prepared by the Municipal Centre for Culture, Activity and Promotion of the Commune "Culture Station" in Świeradów-Zdrój. In this near 50-page publication, one page is devoted to several sentences about the IPCN, together with one small mention of it on one of the maps placed there, as well as half a page for the Izerska Meadow Ecological Educational Center. In the practical guide published by the Municipal Office in Szklarska Poręba, there is only a short mention of the IDSP when describing the tourist station in Orle. Much more information, mainly about the problems of light pollution, can be obtained from a dozen-page brochure on the state of the Izerska Meadow Center. On the detailed tourist map of the Izera Mountains published by Wydawnictwo Turystyczne Plan, the place where the IDSP approximately stretches (on the map between Chatka Górzystów and Orle settlement) is marked; however, on the back of the map with the mentioned attractions there is no room for even one sentence about the park. The only mention related to IDSP is a short sentence about the model of the solar system in Orle (Fig. 12.1).

12.3. Interviews

Only twenty people out of 124 tourists (16.1%) met on the tourist trails inside the park knew about the existence of IDSP. Out of these people, four respondents (3.2%) answered positively about the existence of the IDSP after an additional question.

Knowledge about the territory of the park and its borders was not common. Only three respondents (2.4%) were able to indicate that the IDSP stretches on both sides of the Polish-Czech border and covers several dozen square kilometers. The remaining respondents, as the location of the park, indicated Orle (10 respondents), Hala Izerska (3), Chatka Górzystów (2) and Stóg Izerski (1). One person indicated that the IDSP is located only on the Czech side of the Izera Mountains.

Among the attractions included in the park, the respondents mentioned the sundial (12 respondents), which judging from the description is often confused with the gnomon (Fig. 12.2), the planetary path (10 respondents) and the dark sky view in general and astronomical shows (8).

Of the 178 inhabitants of the three neighbouring municipalities 13.5% were aware of the existence of IDSP. However, significant differences were observed in particular communes. The largest number of respondents who knew about the IDSP lived in Świeradów-Zdrój

Fig. 12.2. Touristic elements in IDSP: sundial (upper left), gnomon (upper right), planetary path – Mercury (lower left), information board with IDSP-related information in Jakuszyce at the entrance to the trail (lower right). Source: author's own photographs

(21.4%), much fewer lived in Szklarska Poręba (13.6%), and the smallest amount lived in Mirsk, where no one had ever heard of IDSP.

In Świeradów-Zdrój, only two people knew that the park lies on both sides of the border and stretches over many kilometers. The remaining respondents most often pointed to Hala Izerska and/or Orle (five respondents), Stóg Izerski (four) and Izerska Meadow Centre (three). One person replied that the park is in the Czech Republic. Among the attractions, the most often indicated were night observations (eleven respondents), the planetary path (six) and the planetarium and telescopes (four).

The answers were slight different in Szklarska Poręba, where only one person could correctly indicate the range of the IDSP. The remaining respondents located the park near Orle and Hala Izerska (six) and Jakuszyce (two). Among the answers about attractions were the planetary path (five), the sundial (three) and the dark sky and observations of night sky (three respondents).

Discussion and conclusions

IDSP is the first park of this type in Poland and the first cross-border park in the world. It celebrated its tenth anniversary in the year of the research (Mrozek and Kołomański 2014); however, the promotion of the related events was not widely present in the national or local media. There was also no mention of it on the official website of the park, in the events section. When analysing the popularisation activities relating to the park, one can get the impression that their intensity peaked in 2009-2016. In recent years, interest in the organisation of cyclical events in the park has significantly decreased. This may be related to the opening of Izerska Łąka Meadow Center in 2015, which in its daily activities, has an educational offer on the issue of artificial light pollution. It also hosts occasional sky shows and astronomical lectures.

Among the investments made as part of the Astro Izera project, the most popular, according to the interviewees, are the planetary path and the sundial, as well as the gnomon, which is often mistaken for the sundial by tourists. However, the very knowledge about the existence of the IDSP is lower than could be expected from a 10-year-old tourist attraction. Low knowledge among tourists can be explained by different tourist preferences – not everyone is interested in astronomy, especially since astronomy as a subject is almost absent in Polish schools. Additionally, information about entering the IDSP area could be more emphasised, so tourists would have no doubt that they were in the area of night landscape protection. Maybe it would be worthwhile, in addition to the current information boards containing other tourist information, to put special signs at each entrance to the trail, similar to those standing at the entrances to the international dark sky places designated by International Dark Sky Association. Furthermore, merely getting the International Dark-sky park name would certainly make the park more recognisable, but for organisational and legal reasons, it is certainly a big challenge in the current situation.

The low level of knowledge about the park among the inhabitants of the surrounding municipalities is certainly surprising. Especially since the local community should be proud of an unusual tourist attraction on a national scale. Perhaps the local authorities should promote the park more, which after all, makes the Izera Mountains and its surroundings clearly different from other tourist regions. The dark sky could become a brand with more promotion, but the situation is made difficult by the fact that a large part of the park is located in a nature conservation area, which makes any investment in infrastructure very difficult. Even reaching the settlement of Orle by car requires a special permit from foresters. This has also undoubted advantages. The Jizera Mountains have the chance to remain an almost untouched oasis in an increasingly lightened world for a long time to come.

The popularisation of knowledge about the park and light pollution is likely to remain in the hands of few enthusiasts, such as the founders of the IDSP, because astrotourism seems to be a niche activity among tourists and the general society. The results of the interviews clearly indicate that the places most often associated with the location of IDSP are those where night sky shows were most often held in the past. Nevertheless, it should be noted that results due to the small number of respondents do not represent a sample of the tourists visiting the IDSP and residents of communes adjacent to the park. However, the results can give important insights into this issue and allow preliminary comparisons with future surveys in other dark-sky parks.

Acknowledgement

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13. THE TENTH ANNIVERSARY OF THE IZERA DARK-SKY PARK

Sylwester Kołomański[1], Ewa Niemczura[1], Joanna Molenda-Żakowicz[1]

Our night landscape has changed dramatically over the past 100-200 years. Our ancestors lived under the dark skies, surrounded by wild nature and starlight. We live surrounded by the products of our civilisation, including artificial light. The amount of this light has been growing rapidly since the mid-twentieth century. Artificial light at night (ALAN) has many positive sides, e.g. ensuring safety, enabling 24/7 activity, creating aesthetics. It is seen as luxury and progress. However, artificial light has also a "darker" side. ALAN exerts pressure on living organisms, including humans, and degrades the night sky. This sky is our cultural heritage and crucial scientific resource. Without the night sky we, humankind, would not be able to determine that we are a part of something much bigger than our planet – the Universe.

Satellite observations, like those delivered by the VIIRS instrument (Miller et al. 2012) on board the Suomi NPP satellite, show us the scale of the ALAN problem. The night side of the Earth is spotted with bright islands of cities, towns, and smaller settlements. Naturally dark areas on land shrink year by year, especially in the highly populated areas of fast developing and developed countries. Europe is a quite densely populated and developed continent with high level of light pollution (Bennie et al. 2014). Based on satellite images, Falchi et al. (2016) estimated that almost 60% of European Union citizens live in areas where the night sky is so heavily degraded that the Milky Way, for example, is never visible. There is a similar situation among other places, North America, South and East Asia. Thus, it's clear that light pollution is a common problem. Moreover, the level of the pollution is still increasing (Kyba et al. 2017) while public awareness of the effects of light pollution is insufficient.

Artificial light scatters in the atmosphere, increasing the brightness of the night sky. As a result of this, the sky over the largest cities is so heavily degraded that only the Moon and the brightest planets and stars can be seen. Unfortunately, the problem is not limited to big cities. Each settlement with outdoor lighting creates a kind of "island of light" – an area where the night sky is degraded. The size of this "island" is always greater than the size of its respective settlement, due to the diffusion of artificial light. Consequently, this process reduces the

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expanse of areas of natural or close to natural dark sky and makes it much more difficult for urban residents to experience starry skies. It seems unbelievable, but a lot of people have never seen the Milky Way and often they are unaware of its existence. This is not a trivial problem. The night sky is important not only for astronomers. The sky has shaped our culture and had a great impact on many areas of human activity in the past. It has helped us to understand our place in the Universe and has been the cause of many discoveries and inventions. It is said that the sky is the limit, but now, the night sky becomes off limits to humankind.

Many activities are undertaken around the world to overcome the light pollution problem. One such activity is the designation of dark-sky parks, preserves and sanctuaries. These areas, like typical nature reserves, aim not only at conservation but also at education, supporting making society aware of how serious the problem of light pollution is. The history of dark-sky parks started in Canada in 1999. The first three such parks in Europe were designated in 2009. Among them there is a Polish-Czech dark-sky park in the Izera Mountains.

13.1. Izera Dark-Sky Park – basic facts

Izera Dark-Sky Park (IDSP) was established on 4th November 2009 as part of the celebration of the International Year of Astronomy 2009. It was the first dark-sky park in Poland and the Czech Republic, and the first trans-boundry dark-sky park in the world. The IDSP is located on both sides of the Polish-Czech border, in the eastern, environmentally valuable part of the Izera Mountains (see Fig. 13.1).

Fig. 13.1. Night satellite photo of the Izera Mountains and surroundings. Selected towns, state border (dashed line), and boundary of the Izera Dark-Sky Park (yellow line) are marked. At night, the towns are seen from space as bright spots because of outdoor lighting (visualization: S. Kołomański based on the National Geophysical Data Center data)

The IDSP covers the area of seventy-five square kilometres at an altitude from 680 up to 1126 m asl. Two wide river valleys (Izera and Jizerka) with neighbouring mountain ridges are within the Park. Most of the IDSP is forested. Meadows and peatbogs cover a smaller area. Only three very small settlements are located within the Park: Orle and Chatka Górzystów (on the Polish side), and Jizerka (on the Czech side). The climate of the IDSP, like of the whole of the Izera Mountains is cold and wet. The annual average temperature above 800 m asl is only 4.5°C, while annual precipitation exceeds 1200 mm. Winters are harsh and snowy. In the Izera and Jizerka valleys, temperatures may drop to −30°C, and snow cover in some years is present until the beginning of May. Summer is short and cool. The average temperature of the warmest month (July) is around 15°C. Thus, the local climate is more like the climate in Scandinavia than in Central Europe.

The fact that the area of the park is sparsely populated and well sheltered by mountain ridges from the artificial lights of nearby villages and towns makes it a good place for dark-sky protection. Moreover, there is no street lighting. The low level of light pollution allows seeing almost 2000 stars with the naked eye. During clear, moonless nights, the sky brightness at zenith can achieve 21.5 mag/arcsec^2, while the natural zenith sky brightness is 21.9 mag/arcsec^2 (Patat, n.d.). Thus, the night sky in the IDSP is only 1.5 times brighter than a pristine night sky.

The establishing of the Izera DSP was possible thanks to the collaboration of six Polish and Czech institutions:

- Astronomical Institute of the University of Wrocław (the initiator),
- Forestry Commission Świeradów,
- Forestry Commission Szklarska Poręba,
- Astronomical Institute of the Czech Academy of Sciences,
- Protected Landscape Area Jizerské Hory,
- Liberec Regional Directorate of Czech Republic Forests.

The park has no legal basis but is the result of an agreement between the mentioned institutions in consultation with local municipal authorities.

The main purpose of creating the IDSP was to increase public awareness of light pollution and to build understanding of the need for preserving dark skies and the nocturnal environment. Actions to achieve these goals include workshops, hands-on activities, stargazing events, and public lectures targeting all types of audience. Furthermore, the park offers permanent astronomical attractions. The Izera Dark-Sky Park is easily accessible for tourists by public and private transport, giving many people the opportunity to take advantage of the environmental and educational values of this place.

13.2. Astronomical attractions

The Izera DSP is not only a place on a map or some area deep in a forest with a starry sky. Our aim was to create an astrotourist destination. For this purpose, we designed and constructed three astronomical attractions: a sundial, a gnomon and a planetary path.

13.2.1. Sundial

A sundial is one of the oldest instruments for measuring time. The rotation of the Earth and its movement around the Sun causes the apparent motion of the Sun across the sky during the day and the year. This changing position of the Sun in the sky is the mechanism that drives the sundial. A shadow of the sundial gnomon changes its position and length as the Sun moves. We read the time using the scale on the dial of the sundial. A properly constructed sundial can also show the date. The advantage of sundials is their simple, time-resistant construction. The disadvantage is that they do not work on cloudy days and at night.

The sundial in Orle is a vertical one, i.e. its dial is aligned vertically (see Fig. 13.2). The sundial is mounted on the walls of a building which is not oriented with a cardinal direction (like true north). Due to this fact, two dials are needed on two adjacent walls. One dial faces the south-east and reads time from sunrise until the early afternoon. The second faces the south-west and reads time from noon until sunset. In addition to hours, both dials indicate a date with an accuracy of up to one or two weeks.

Fig. 13.2. The sundial in Orle. Due to the building's orientation in relation to south, two sundials are mounted on two adjacent walls. One reads time from sunrise to the early afternoon, the other from noon to the sunset (photo: S. Kołomański)

13.2.2. Gnomon

A gnomon is the simplest and probably the oldest astronomical instrument, which was used thousands of years ago. A pole of any size, or even a regular stick mounted vertically in the ground, can be a gnomon. The principle of a gnomon is also simple. Illuminated by the Sun, a gnomon casts a shadow. Its direction and length changes with the diurnal and annual

Fig. 13.3. The gnomon in Orle. It is a granite pillar about 2 m high, embedded in an ellipse made of coloured granite cubes. On sunny days, the gnomon shows the exact time of the local true solar noon. The yellowish circle at the base of the gnomon is the model of the Sun (photo: S. Kołomański)

movements of the Sun across the sky. This simple phenomenon allows us to use a vertical gnomon as a solar calendar or a simpler, less accurate version of a sundial. A gnomon also allows measuring the position of the Sun in the sky; we can calculate the elevation of the Sun above the horizon and the azimuth – the angle between the direction of the Sun and a reference direction (south or north).

The gnomon in Orle is an irregular granite pillar about two metres high, embedded in an ellipse made of coloured granite cubes (Fig. 13.3). At the base of the gnomon is a circle representing the Sun – the first point of the planetary trail. In the gnomon, there is a narrow-slit pointing towards the south. Close to the local true solar noon, the Sun shines through the slit and casts a small bright spot in the gnomon's shadow. The spot is visible only for fifteen minutes around noon. Thus, tourists who wants to see this phenomenon must come at exactly the right time of a day.

Observing both the sundial and the gnomon, is an opportunity to learn about the diurnal and annual movement of the Sun across the sky, and that the time measured by the Sun does not flow steadily like the time we use every day. This in turn provides basic astronomical knowledge about the Earth's motions, which still shape our everyday modern 24/7 life.

13.2.3. Planetary trail

The Solar System model is a popular way to imagine the true size and scale of the Solar System and the Universe in general. Such models, in various scales, can be found all around the world. Thanks to them, we can see how tiny planets are compared to the Sun and compared to the distances between them. The Solar System model not only makes it easier to imagine the scale of distances and sizes in the Universe but also makes it possible to get to know the nearest cosmic neighbourhood of the Earth.

Fig. 13.4. The planetary trail in the Izera DSP. The Sun is represented by a 1.4 m circle placed at the base of the gnomon. Models of planets and dwarf planets (not presented here) are shown as round holes on metal plates placed on small boulders. Each point on the trail is made of a different type of rock (photo: S. Kołomański)

Planetary educational trail in the IDSP leads from Orle settlement to the top of Stóg Izerski mountain via picturesque meadows and peatbogs in the Izera valley. The planetary trail is 11 km long and consists of the Sun, eight planets, and five dwarf planets reproduced on a scale of 1:1 000 000 000. Both the sizes of all objects and the distances between them are shown on this one scale.

The Sun is represented by a 1.4 m circle placed at the base of the gnomon and is made of yellowish granite cubes (Fig. 13.4). Models of planets and dwarf planets are shown as round holes on metal plates placed on small boulders. On each metal plate a name of the planet and its symbol are given. Sizes of the holes range from 1 mm (dwarf planet Ceres) to 143 mm (planet Jupiter). In this scale the Earth is 13 mm in diameter, and it is located 150 m from the model of the Sun.

Each point on the trail is made of a different type of rock. All these rocks come from the mountain region of Sudetes and thanks to this, the trail also shows the geological diversity of this region. The middle part of the trail runs through the valley of the upper Izera river, which is one of the most valuable natural places in Poland and Czech Republic. Thus, tourists hiking or bicycling along the planetary trail can make an interesting trip through the Solar System and local nature.

13.3. Activities

We want to attract public attention to the problem of light pollution. To do so, cyclic astronomical events targeting all types of audience are held in the Izera DSP every year. These events include workshops, hands-on activities, stargazing, night walks, and public talks. They are not focused only on light pollution. They are rather astronomical events and ALAN is one of the broached topics.

13.3.1. School Workshops on Astronomy

The School Workshops on Astronomy (SWA), which are a bi-annual event popularising astronomy and other sciences, are addressed to the pupils of the age range 15-18. The SWA have been organised at the Orle since 2009. Since the beginning, the SWA have been organised and coordinated by Grzegorz Żakowicz, who is a teacher of physics at the XIII Lyceum in Wrocław. There have been already twenty-three of these workshops. The total number of pupils who have taken part in them exceeds 500. Since 2014, there has been a school astronomical laboratory in Orle, created by the Astronomical Institute of the University of

Fig. 13.5. Assembling the telescope – hands-on activity during School Workshops on Astronomy. The pupils work in small groups and learn how to assemble the telescope from a kit. Later in the night, they use that equipment to observe night sky objects (photo: G. Żakowicz)

Fig. 13.6. Learning the night sky and constellations – the pupils participating in SWA learn how a planisphere, which shows the look of the sky at different times, can be used to find constellations, planets, and other objects at any time the user chooses (photo: G. Żakowicz)

Wrocław and the Izera Society. The laboratory is equipped with telescopes, cameras, sky--quality meters, sky maps, computers, and other hardware that is needed for astronomical educational activities.

The program of the SWA consists of talks given by astronomers and other scientists, various hands-on activities, observations of the astronomical and meteorological phenomena, and dedicated exhibitions. In the basics of the astronomy course, the pupils learn how to assemble the telescope (see Fig. 13.5), how to find targets on the sky (first, they learn the orientation on the night sky with the use of the sky maps and planispheres, see Fig. 13.6), how to use their equipment to carry out visual or astrophotograpic observations, and how to document them. Objects which the pupils observe include the Moon, planets, stars, planetary nebulae, galaxies, meteor showers, lunar eclipses, the occultation of Jupiter, and various atmospheric phenomena. The pupils learn how to measure the darkness of the sky and estimate the level of light pollution. They work in groups, which is another new skill gained as a result of the SWA. Finally, the pupils learn how to present the results of their work in a concise and interesting way in the form of a multimedia presentation. The main goal of the SWA is to help the pupils find their genuine interests, which they may develop in their future education and career plans.

13.3.2. Izera Long Exposures

Izera Long Exposures meetings take place once a year in August. The event is organised by professional and amateur astronomers for amateur astronomers. Participants can start their adventure with astronomy or broaden their knowledge and skills in this field. The meetings offer activities like stargazing, lectures and practical classes in astrophotography. Beginners learn the basics of astronomical observations and astrophotography. More advanced participants study techniques of reduction and analysis of observations. Lectures on interesting astronomical issues are presented to all participants.

Izera Long Exposures meetings are held in Orle. There are only four buildings in the settlement ("Orle Tourist Station" hostel) and no street lighting. The settlement is located in a wide river valley. Thanks to this, the sky is not obscured above 15° above the horizon. Thus, the place provides excellent conditions for amateur astronomical observations and photography.

13.3.3. Astronomical events for the public

Open events, like the Astronomical Day, are the Polish-Czech way of astrotourism – a way to bring the dark starry sky closer to everyone. Attractions like talks, stargazings, and guided night walks under starry skies for a wide audience are offered. Since 2010, fifteen Astonomical Days have been organised. Besides the Astronomical Day, other cyclical and occasional events are held on the Polish and Czech side, e.g. Starry night in the Museum of the Izera Mountains, Night with Persids, Asteroid Day, total lunar eclipse, and Venus transit events.

Stargazings and guided night walks are the most popular events, of course. Such events give a perfect occasion to talk about the beauty and importance of the night sky and its degradation by light pollution.

Fig. 13.7. Stargazing during Izera Long Exposures meeting in August 2019 (photo: D. Koszela)

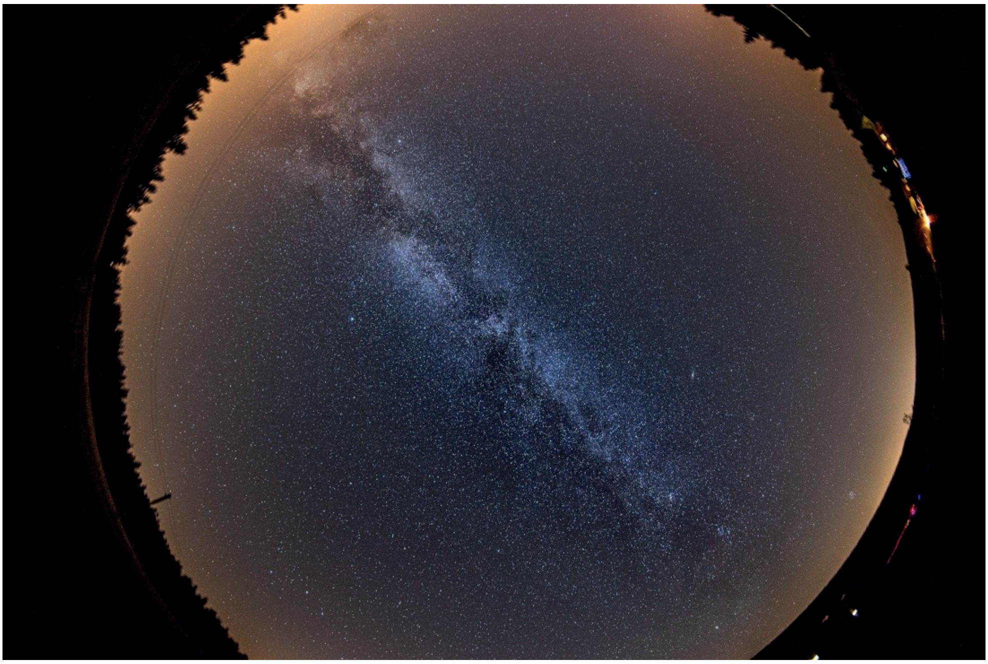

Fig. 13.8. Photography of the night sky in the Izera DSP taken during Izera Long Exposures meeting in August 2019 (photo: K. Siwa)

Summary

The level of light pollution in Poland and the Czech Republic is high. About half of the population lives in areas where the night sky is highly degraded (Falchi et al. 2016). Unfortunately, in both countries the awareness of this form of pollution is low. Therefore, any effort to reduce light pollution must be preceded by raising public awareness. It can be achieved by education and public outreach projects, like the Izera Dark-Sky Park.

The Izera Mountains are not the place with the darkest night sky in Poland or the Czech Republic. Despite this, there are several factors which enabled us to start and develop the project of the dark-sky park right there. Firstly, the low level of light pollution. The area of the Izera DSP is sparsely populated and has no street lighting. Moreover, the park is located in two valleys which give additional protection against light from surrounding villages and towns. Consequently, the night sky is only 1.5 times brighter than a pristine night sky and is a substantial natural resource for the local community.

Secondly, the Izera Mountains are attractive for tourists because of their wonderful nature, beautiful landscapes, and interesting history. This region is easily accessible for everyone by public and private transport and offers different kinds of accommodation. The dark sky combined with touristic popularity, makes the Izera Mountains an ideal place to develop astrotourism.

Thirdly, it should be emphasised that the establishment of the Izera Dark-Sky Park and the development of astrotourism is the result of collaboration of several entities from both countries, including professional and amateur astronomers, foresters, local activists and authorities, and private persons. Such broad collaboration was possible thanks to the openness of many people. Moreover, the sundial, gnomon, and planetary trail were made thanks to individual and institutional founders.

The dark-sky park and the astronomical activities in the Izera Mountains have inspired others to take action. The forestry commission in Świeradów-Zdrój equipped their educational garden "Izera of the Tree Elements" with two telescopes. The forestry commission organizes many educational events, including astronomical ones. The town of Świeradów-Zdrój operates the Centre for Ecological Education. In the centre, there is a cinema hall with a large interactive sky map on the ceiling. The map enables learning of the constellations and becoming acquainted with knowledge about light pollution.

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EKOLOGICZNE I ASTRONOMICZNE ASPEKTY ZANIECZYSZCZENIA ŚWIETLNEGO

Streszczenie

Monografia w sposób wszechstronny prezentuje zagadnienie zanieczyszczenia świetlnego zarówno pod kątem jego wpływu na środowisko naturalne czy zdrowie człowieka, jak też na możliwość prowadzenia obserwacji astronomicznych. Przedstawiono również, rzadko opisywany w literaturze, wpływ zanieczyszczenia świetlnego na rośliny. Zostało opisane oddziaływanie tego rodzaju zanieczyszczenia środowiska na ekosystemy nocne, ze szczególnym uwzględnieniem nietoperzy. Opisano mechanizmy zaburzania cyklu dobowego oraz jego skutki dla zdrowia człowieka. W monografii zaprezentowano również wiele metod pomiarowych, uwzględniających zarówno samo zjawisko, jak też powiązane z nim warunki środowiskowe, takie jak np. elementy meteorologiczne. Zwrócono też uwagę na wpływ urbanizacji na wielkość zanieczyszczenia świetlnego, uwzględniając również problematykę architektoniczną. W pracy przedstawiono także sposoby ochrony środowiska przed zanieczyszczeniem świetlnym, zwłaszcza przez tworzenie dedykowanych temu celowi obszarów chronionych, tzw. parków ciemnego nieba.

ECOLOGICAL AND ASTRONOMICAL ASPECTS OF LIGHT POLLUTION

Summary

This monograph presents the problem of light pollution in a comprehensive manner, both in terms of its impact on the natural environment and human health, as well as on the possibility of conducting astronomical observations. The effect of light pollution on plants, which is rarely described in literature, is also presented. The impact of this type of environmental pollution on nocturnal ecosystems has been described, with a particular emphasis on bats. The mechanisms of disturbing the circadian cycle and its effects on human health have been also described. The monograph presents a number of measurement methods, taking into account both the phenomenon itself and related environmental conditions, such as meteorological elements. Attention was also paid to the influence of urbanisation on the level of light pollution, also taking into account architectural issues. The monograph also presents ways to protect the environment against light pollution, in particular, by creating protected areas dedicated to this purpose – so-called dark sky parks.

ÖKOLOGISCHE UND ASTRONOMISCHE ASPEKTE DER LICHTVERUNREINIGUNG

Zusammenfassung

In der Monographie wird das Problem der Lichtverschmutzung umfassend dargestellt, sowohl hinsichtlich ihrer Auswirkungen auf die natürliche Umwelt und die menschliche Gesundheit als auch hinsichtlich der Möglichkeit, astronomische Beobachtungen durchzuführen. Die in der Literatur selten beschriebene Auswirkung der Lichtverschmutzung auf Pflanzen wird ebenfalls vorgestellt. Die Auswirkungen dieser Art von Umweltverschmutzung auf nächtliche Ökosysteme mit besonderem Schwerpunkt auf Fledermäusen wurden beschrieben. Die Mechanismen zur Störung des Tageszyklus und seine Auswirkungen auf die menschliche Gesundheit wurden ebenfalls beschrieben. Die Monographie präsentiert eine Reihe von Messmethoden, die sowohl das Phänomen selbst als auch verwandte Umgebungsbedingungen berücksichtigen, wie z. meteorologische Elemente. Es wurde auch auf den Einfluss der Urbanisierung auf die Lichtverschmutzung unter Berücksichtigung architektonischer Aspekte geachtet. Die Monographie zeigt auch Möglichkeiten zum Schutz der Umwelt vor Lichtverschmutzung auf, insbesondere durch die Schaffung von Schutzgebieten, die diesem Zweck gewidmet sind, den sogenannten Dark Sky Parks.

ЭКОЛОГИЧЕСКИЕ И АСТРОНОМИЧЕСКИЕ АСПЕКТЫ СВЕТОВОГО ЗАГРЯЗНЕНИЯ

Резюме

В монографии комплексно представлена проблема светового загрязнения, как с точки зрения его воздействия на окружающую среду и здоровье человека, так и с точки зрения возможности проведения астрономических наблюдений. Также представлено влияние светового загрязнения на растения, которое редко описывается в литературе. Описано влияние этого типа загрязнения окружающей среды на ночные экосистемы, особенно на летучих мышей. Также описаны механизмы нарушения циркадного цикла и его влияние на здоровье человека. В монографии представлен ряд методов измерения, учитывающих как само явление, так и связанные с ним условия окружающей среды, такие как, например, метеорологические элементы. Также было уделено внимание влиянию урбанизации на уровень светового загрязнения, в том числе с учетом архитектурных аспектов. В монографии также представлены способы защиты окружающей среды от светового загрязнения, в частности, путем создания специально отведенных для этого охраняемых территорий, так называемых парков темного неба.