Artificial lighting at night

Position paper of the Tyrolean Environmental Ombudsoffice · **PART 1** · *March 2021 · 12 pages*

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Night lighting is an integral part of our lifestyle, and it is important that we handle artificial light responsibly. Sensible use of artificial light promotes health, safety and quality of life. It lowers energy and resource consumption and contributes to the preservation of biodiversity.

During the operating phase of artificial light, the following key factors must be taken into consideration:

⇒ Location – **WHERE**,
⇒ time period – **WHEN** and
⇒ light planning and technology – **HOW**.

This series of position papers provides information and proposes solutions for the following applications:

PART 2: lighting for roads, cycling paths, pavements and car parks

PART 3: sports facilities: lighting for natural toboggan runs, cross-country ski trails, ski slopes and football pitches.

PART 4: effect lighting: decorative lighting, illumination of objects, sky beamers, luminous advertising.

This first part of the series of position papers on artificial light is the general section containing information that is relevant to all lighting projects.

Light pollution refers to illumination of the night

Artificial light overlay and alter the natural lighting conditions at dusk and in the night. The brightness and expansion of lit spaces is on the rise: since 2012, light pollution has in creased by at least 2 per cent per annum.[1]

Undesired artificial light outdoors illuminates living spaces, the environment and the night sky, and it can dazzle. This has a negative impact on human health. Animals, plants and ecological systems are also affected.

Basic principles for all lighting projects

The necessity of outdoor lighting must be reviewed whenever relevant structures are renovated or newly built. Artificial light has a variety of functions, such as protection, orientation, signalling, advertising and artistic expression.[2] To find out whether a lighting system is genuinely necessary, it helps to examine its functions. **All further decisions must be made on the basis of a transparent needs assessment.**

No two lighting projects are alike. **Every project requires an assessment of detrimental effects and potential acceptable solutions.**

As a precaution, preventive and mitigating measures must be incorporated into the lighting plan.[3]

The ecosystem, biodiversity and the diversity of habitats, recreational value and natural beauty must be protected, safeguarded or restored. **Because lighting systems damage these conservation interests,[4] they require a permit when installed outside of built-up areas. Animals within residential areas must also be protected.[5]**

Once an **environmental permit has been granted, a limited operation period must be specified** for new lighting systems in order to facilitate any adaptations to the latest state of technology if required**.[6]**

Does light improve safety?

Artificial light is useful, modern and relatively economical. We use it as a matter of course. While it allows us to pursue a larger variety of leisure activities and gainful work, *safety* is another important consideration for the installation of artificial light. Road traffic safety and the prevention of violence and vandalism are all motivations for the increased use of artificial light.

Well-designed traffic lighting does contribute to a reduction in accident rates, although factors such as tiredness, alcohol consumption and speed are generally more significant.[7]On the other hand, artificial light can also introduce traffic risks, such as dazzle and distraction.[8]

There is no consensus as to whether artificial light reduces violence and vandalism. It has not been possible to determine a clear reduction in crime, but lighting does have the capacity to improve the subjective perception of safety.[7] Many people feel more comfortable in well-lit public spaces and are more likely to leave their own dwellings where such spaces are available. The feeling of safety is not related to the intensity of the available lighting. A survey has shown that young women prefer even levels of illumination, no dazzle, visibility of colours and shapes, and warm white light.[9, 10]

Negative effects on humans

Excessive artificial lighting at night is not just irritating, it directly influences our circadian rhythm. This compromises sleep, quiet and rest.[11] Artificial light might also be a risk factor for obesity,[12] heart attack,[13] diabetes[14] and depression[15]. The relationship between light pollution and cancer is controversial.[16] In many cases, it is a combination of factors causing the aforementioned diseases: lifestyle changes, an unhealthy diet, stimulant consumption and environmental pollution are often listed as triggers.

Excessive or improper consumption of artificial light has been linked to degeneration in eyesight, retinal damage,[17] age-related macular degeneration[18] and dangerous dazzle in traffic[8].

What level of brightness damages health?

Illuminance (lx) measures the luminous flux (lm) incident on a surface. Luminance (cd/m²) is a measure of the luminous intensity perceived on a surface by the human eye.

Exposure to high levels of illuminance or short wavelengths reaching the retina inhibits melatonin synthesis in the bodies of the affected organisms. The hormone is naturally released in the evening and at night. While it has a soporific effect on humans, it is a stimulant for nocturnal animals. Melatonin controls a variety of bodily functions and has antioxidant properties.

Illuminance levels of 0.01–0.03 lx in non-human mammals and fish and up to 6 lx in sensitive humans are sufficient to suppress natural melatonin production. Depending on wavelengths, even lower levels of illuminance can influence organisms.[19] For reference: the maximal illuminance of the moon is 0.3 lx. In the long term, continuous levels of 0.3 lx during the night affect male blackbirds to the extent that they can no longer breed.[20]

As little as 3 lx before bed time is enough to increase human blood pressure over night.[13] As per ÖNORM O 1052[21], this level is permissible until 10:00 pm when measured at the window level in a residential section of a small community. High streets and mixed-use areas may be lit at 10 lx until 8:00 pm. The limits only apply to light pollution produced for non-traffic purposes (effect lighting and lighting of sports facilities); the relevant standard excludes traffic lighting for its informative function.

Which colour temperatures and spectral ranges are harmful?

Colour temperature is the colour of light as perceived by the human eye. It is measured in kelvin. Pleasant indoor lighting has 2700 kelvin, while moonlight has a colour temperature of 4000 kelvin. The spectral graph provides greater detail: it displays the range of radiation emitted by a light source.

Generally speaking, organisms react differently to various spectral ranges. There is greater evidence, however, of detrimental effects from short-wave visible light (up to 490 nm) and from neutral to cool white colour temperatures (more than 3000 kelvin).[22] Our own research into the effects of various light sources on the attraction of insects in Völs (Tyrol) has shown that LEDs with a low colour temperature (max. 3000 kelvin) are less attractive to insects.[23]

Ultraviolet light (UV < 380 nm) and infrared light (IR > 780 nm) are irrelevant to human visual perception. Light sources should not emit radiation at those wavelengths, as some organisms that are capable of perceiving it may be affected negatively by it.

For reasons of health, environmental protection and even astronomy, low colour temperatures are recommended: in particular, amber LEDs (max. 2200 kelvin) and warm white LEDs (max. 3000 kelvin). The radiation range emitted by a light source is closely linked to its colour temperature, but the spectral composition of warm white LEDs varies. Choosing a light source of no more than 3000 kelvin ensures that the amount of radiation under 490 nm is low and limits the potential of detrimental health and environmental effects.

Adverse effects on animals, plants and habitats

Light pollution also plays a role in the global loss of biodiversity. It has the potential further to disrupt ecosystems that are already suffering from multiple weakening factors.[24] When artificial light affects animals, plants, habitats or even ecosystem services (such as pollination), it also has an impact on the basis of human existence.

Light-dependent rhythms, such as the day/night cycle, seasonal changes in daytime lengths, and the lunar phases reliably inform the circadian rhythms of many organisms. Over the history of the Earth, their vital functions and processes adapted to them. Apart from physiological processes, light pollution also alters the behaviour of living beings: they may be unnaturally attracted to or repulsed by artificial light or lose their orientation.

Nightly artificial light affects insects,[25] birds,[26] mammals,[27] amphibians,[28] fish,[29] aquatic microorganisms[30] and plants.[31] There is also evidence of far-reaching environmental effects, such as changes in species composition[32] and reduced pollination.[33]

Nocturnal animals

A nocturnal animal experiencing a brightly lit night is like a seal released in the Alps – this apt comment on the situation of nocturnal animals in artificially illuminated habitats was made by the author of *Licht aus!?*[34].

Natural light regimes and predictable activity periods are vital. **Nocturnal animals depend on darkness and natural light from the moon and stars for orientation, movement, breeding, hunting or foraging, and avoiding predators and food competitors.**

Around two thirds of all species are nocturnal, including around half of all insect species.[35] Approximately 2700 butterfly species have been found in Tyrol alone, and around 85 per cent of them are exclusively or predominantly active at night.[36] Owls, bats, dormice, hedgehogs, martens, European polecats, foxes, badgers, frogs and toads also depend on the night for their activities. Roe deer and red deer are generalists: they are often seen around dusk.

Negative effects on the restorative value of the night landscape

In today's world, everything is bright. Real darkness becomes a positive contrast; it has value. Darkness enhances the mysterious, and our imagination takes the place of that which becomes invisible. When we observe the night sky, we contemplate the infinity of space, the meaning and the end of our existence.[37]

Many of us are unfamiliar with the natural night. Its experiential value is derived from the view of the starlit sky and the edges of landscapes barely discernible in dark shades. Darkness heightens our senses.

Light pollution obscures the stars; artificial light captures our attention and keeps our gaze trapped in its haze. We become accustomed to excessive light and lose our connection to nature and the environment. The gradual loss of unspoilt night landscapes leaves scars on our culture, spirituality and identity.

It is essential to emphasise the value of the darkness as a good to be protected at the tense intersection between economic and environmental interests. The elimination or consistent optimisation of lighting systems can prevent disturbance of residents, visitors, landscapes, animals, plants and their interaction. Darkness is a natural resource that must be acknowledged, appreciated and protected as such.

The age of the LED

Around the turn of the millennium, it became clear that LED lights had entered a period of rapid development and increased use due to their high energy efficiency.[38] LED technology has many advantages, such as precise light control, dimming capacity, spectrum modelling (various colour temperatures) and low energy consumption. **But this energy efficiency encourages the wasteful and environmentally harmful use of artificial light.[39]** The deliberate decision not to use artificial light is often a sensible course of action, not only for health and environmental purposes but also in terms of energy and resource conservation.

Studies have found that LEDs have a better environmental footprint than other sources of artificial light. Ultimately, these results are due to their lower energy requirements when in operation. During the production process, however, LEDs have a poorer environmental footprint than e.g. high-pressure sodium vapour lamps or metal halide lamps due to greater amounts of energy and chemicals consumed.[40] In order to minimise the environmental impact and resource consumption of the production and disposal processes, the lighting system needs to remain in operation until the end of its useful life.

For general lighting, white light is generated by converting the radiation of blue LEDs using a conversion layer. The composition and thickness of this layer are essential for the spectral composition of the diode. Due to this structure, neutral white and cool white LEDs (>3000 kelvin) use up to 10 per cent less energy for the same value. This has led to the installation of many lighting systems with 4000 kelvin, which are often perceived as disruptive to residents, townscapes, health and the environment. **Economic factors and energy efficiency alone are not sufficient characteristics of a suitable lighting system or technology.[22]**

Regulating light pollution

Public law: artificial illumination of the environment and landscape is governed by the Tyrolean nature protection act (TNSchG) of 2005, the environmental impact analysis act (Umweltverträglichkeitsprüfungsgesetz) of 2000, the Tyrolean spatial development act (Tiroler Raumordnungsgesetz, TROG) of 2016 and the Tyrolean events act (Tiroler Veranstaltungsgesetz, TVG) of 2003. Protection from disruptive light emissions is relevant to the commercial code (Gewerbeordnung) of 1994, the Tyrolean building code (Bauordnung, TBO) of 2018 and the TVG 2003. Protecting the appearance of areas is mentioned in the Tyrolean act on townscape protection (Stadt- und Ortsbildschutzgesetz) of 2003, the TBO 2018, the TVG 2003 and the TROG 2016.

Besides the TNSchG 2005, the TROG 2016 is considered an important toolkit for limiting light pollution. Sustainable spatial development, soil-conserving construction and the protection of recreational spaces near towns are their stated objectives. Early consideration of guidance on e.g. the nature of tolerable lighting within the scope of the mandatory creation of local spatial development plans (*Örtliche Raumordnungskonzepte)* in the municipalities of Tyrol would encourage the mindful use of artificial light.

It would be beneficial if this guidance were further enshrined in law in order to curb light pollution. Adaptation of the individual relevant laws would be a suitable approach.[41]

Guidelines, directives and standards: in the public sector, in particular, planning and implementation processes can be controlled through the strategic provision of information and resources. The Austrian guidelines on outdoor lighting (Österreichischer Leitfaden Außenbeleuchtung)[42] are a national aid for planning environmentally friendly outdoor lighting systems.

The GPP (Green Public Procurement Criteria for Road Lighting and Traffic Signals) guidelines[43] are aimed at public authorities of all EU member states. They govern the environmentally friendly procurement of traffic lighting systems and beacons. Instructions on preventing light pollution have been taken into consideration.

To prevent interference from artificial light with traffic users, the guidelines and regulations for road traffic (Richtlinien und Vorschriften für das Straßenwesen, RVS) of 5 June 2011 and 5 June 2012[44] lay down limits and criteria among other rules.

Standards are recommendations which may be made legally binding for developers of lighting systems. ÖNORM O 1052[21] lists ways of producing appropriate light. It specifies limits that reduce the disruptive effects of artificial light on the human habitat and the environment.

The relevant standards for the various purposes of artificial light (traffic, sports facilities[45] etc.) also specify minimum standards, such as maintenance factors. They are based on empirical data. These values should not be exceeded for economical and ecological reasons.[46]

Funding: compliance with safety-related minimum standards and energy efficiency are often the sole requirement for the provision of funding for various lighting systems. Measures for limiting light pollution have only played a marginal role to date. This needs to change.

Funding providers can consult the aforementioned reference works (guidelines, directives and standards) and the present series of positions papers in order to develop corresponding funding criteria, such as demand-oriented lighting systems based on traffic density and the reduction of light pollution in residential areas and the environment.[22]

For more information, see **www.hellenot.org**.

[1] Kyba CCM, Kuester T, de Miguel AS, Baugh K, Jechow A et al. (2017) Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances 3(11) e1701528.

[2] Burkert FH (1995) Licht als Last. Licht und Raum 5:28-30.

[3] Vgl. Böttcher M (2001) Auswirkungen von Fremdlicht auf die Fauna im Rahmen von Eingriffen in Natur und Landschaft. Analyse, Inhalte, Defizite und Lösungsmöglichkeiten. BfN 67. Bundesamt für Naturschutz Bonn (ed.).

[4] As per Section 1 Subsection 1 of the Tyrolean nature conservation act (Tiroler Naturschutzgesetz) of 2005.

[5] As per Section 24 Subsection 2 of the Tyrolean nature conservation act of 2005, it is prohibited knowingly to disturb any of the bat species occurring in Tyrol, especially during mating season, rearing periods, hibernation and migration.

As per Section 26 of the Tyrolean nature conservation act of 2005, non-huntable, wild animal species (many birds, insects etc.) in any form of development must not be disturbed, pursued or destroyed deliberately and needlessly.

As per Section 5 of the Tyrolean nature conservation ordinance of 2006, non-huntable, wild animal species as listed in Annex 6 (hedgehogs, dormice, squirrels, frogs, toads etc.) in any form of development must not be disturbed, pursued or destroyed deliberately and needlessly, and their habitat must not be treated in a manner that will make their continued survival impossible.

As per Section 42 Subsection 2 of the Tyrolean hunting act (Tiroler Jagdgesetz) of 2004, huntable game (martens, European polecats, badgers, foxes, roe deer, red deer etc.) must not be disturbed deliberately. Horned owls, tawny owls, boreal owls and little owls are considered huntable animals, but they are protected all year round and must not be disturbed.

[6] See Section 29 Subsection 5 of the Tyrolean nature conservation act of 2005.

[7] Hänsch R, Könecke B, Pottharst M, Wukovitsch F (2013) Kosten und externe Effekte des künstlichen Lichts sowie Ansätze der ökonomischen Bewertung. Universitätsverlag der TU Berlin, BMBF-Verbundforschungsprojekt Verlust der Nacht (eds).

[8] Heilig P (2018) Im Rampenlicht. Concept Ophthalmologie 2:29-30.

[9] https://research.arup.io/story/cities-for-girls und https://theconversation.com/more-lighting-alone-does-not-create-safer-cities-look-at-what-research-with-young-women-tells-us-113359, accessed on 31 January 2021.

[10] The following example illustrates that artificial light does not always improve well-being: imagine a secluded, illuminated path at the outskirts of a town. It is easy to use, but those who travel along it are visually trapped in a beam of light. While they are easily visible to others, those who may be observing them remain invisible in the darkness.

[11] Min J, Min K (2018) Outdoor Artificial Nighttime Light and Use of Hypnotic Medications in Older Adults: A Population-Based Cohort Study. J Clin Sleep Med 14(11):1903-1910.

To ensure adequate, regenerative sleep from 10:00 pm, it is recommended that you are no longer exposed to artificial light after 8:00 pm. Artificial light of the brightness normally used in domestic settings continues to have an impact on the human body for approximately 90 minutes after the last exposure.

Source: Gooley JJ, Chamberlain K, Smith KA, Khalsa SBS, Rajaratnam SMW et al. (2011) Exposure to Room Light before Bedtime Suppresses Melatonin Onset and Shortens Melatonin Duration in Humans. J Clin Endocrinol Metab 96:E463-E472.

[12] McFadden E, Jones ME, Schoemaker MJ, Ashworth A, Swerdlow AJ (2014) The Relationship Between Obesity and Exposure to Light at Night: Cross-Sectional Analyses of Over 100,000 Women in the Breakthrough Generations Study. Am J Epidemiol 180(3):245-250.

[13] Obayashi K, Saeki K, Iwamoto J, Ikada Y, Kurumatani N (2014) Association between light exposure at night and nighttime blood pressure in the elderly independent of nocturnal urinary melatonin excretion. Chronobiol Int 31(6):779-786.

[14] Spiegel K, Knutson K, Leproult R, Tasali E, van Cauter E (2005) Sleep loss: A novel risk factor for insulin resistance and Type 2 diabetes. J Appl Physiol 99(5):2008-19.

[15] Obayashi K, Saeki K, Kurumatani N (2017) Bedroom Light Exposure at Night and the Incidence of Depressive Symptoms: A Longitudinal Study of the HEIJO-KYO Cohort. Am J Epidemiol 187(3):427-434.

[16] Kloog I, Stevens RG, Haim A, Portnoy BA (2010) Nighttime light level co-distributes with breast cancer incidence worldwide. Cancer Causes Control 21:2059-2068.

Rybnikova NA, Haim A, Portnov BA (2017) Is prostate cancer incidence worldwide linked to artificial light at night exposures? Review of earlier findings and analysis of current trends. Arch Environ Occup Heal 72(2):111-122.

Johns LE, Jones ME, Schoemaker MJ, McFadden E, Ashworth A et al. (2018) Domestic light at night and breast cancer risk: a prospective analysis of 105 000 UK women in the Generations Study. Br J Cancer 118(4):600-606.

[17] Wu J, Seregard S, Algvere PV (2006) Photochemical damage of the retina. Surv Ophthalmol 51(5):461-481.

[18] Ratnayake K, Payton JL, Lakmal OH, Karunarathne A (2018) Blue light excited retinal intercepts cellular signaling. Sci Rep 8(1):1-16.

[19] Grubisic M, Haim A, Bhusal P, Dominoni DM, Gabriel KMA et al. (2019) Light Pollution, Circadian Photoreception, and Melatonin in Vertebrates. Sustainability 11, 6400.

[20] Dominoni DM, Quetting M, Partecke J (2013) Long-term effects of chronic light pollution on seasonal functions of European blackbird (Turdus merula). PLoS One 8(12):1-9.

[21] ÖNORM O 1052 Light pollution – measurement and assessment (1 June 2016).

[22] Cf. Schroer S, Huggins B, Böttcher M, Hölker F (2019) Leitfaden zur Neugestaltung und Umrüstung von Außenbeleuchtungsanlagen – Anforderungen an eine nachhaltige Außenbeleuchtung. BfN-Skripten 543. Bundesamt für Naturschutz Bonn (ed.).

[23] Huemer P, Kühtreiber H, Tarmann G (2011) Anlockwirkung moderner Leuchtmittel auf nachtaktive Insekten: Ergebnisse einer Feldstudie in Tirol (Österreich). In: Wiss Jb, TLM Innsbruck. 110–135. A study conducted on behalf of the Tyrolean Environmental Ombudsoffice.

Huemer P, Kühtreiber H, Tarmann G (2011) Anlockwirkung moderner Leuchtmittel auf nachtaktive Insekten: Feldstudie 2011. Tiroler Landesmuseen Innsbruck. A study conducted on behalf of the Tyrolean Environmental Ombudsoffice.

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

[25] Artificial light lures nocturnal insects away from their natural habitats. Emissions in the ultraviolet, short-wave, visible range have the strongest attracting effect. Once the animals reach the beam of light, they either become inactive or they continue to buzz around the source of light until they either die of exhaustion or lose a significant amount of energy. They are also at risk of becoming easy prey.

When the days grow shorter in winter, some insects enter diapause, a period of suspended development. Even low levels of artificial light at night prevent their transition into diapause, and their odds of surviving the winter decrease. Nocturnal moths have been observed to avoid illuminated areas and limit their mating frequency considerably.

Source: Briscoe AD, Chittka L (2001) The evolution of color vision in insects. Ann Rev of Entomol 46(1):471–510.

Eisenbeis G (2006) Artificial Night Lighting and Insects: Attraction of Insects to Streetlamps in a Rural Setting in Germany. In: Rich C, Longcore T (Hrsg) Ecological consequences of artificial night lighting. Island Press 281-304.

van Geffen KG, van Grunsven RHA, van Ruijven J, van Berendse F, Veenendaal EM (2014) Artificial light at night causes diapause inhibition and sex-specific life history changes in a moth. Ecol Evol 4(11):2082–2089.

van Geffen KG, van Eck E, de Boer RA, van Grunsven RHA, Salis L et al. (2015) Artificial light at night inhibits mating in a geometrid moth. Insect Conserv and Div 8(3):282–287.

[26] Robins, blackbirds, great tits and blue tits living in illuminated habitats begin their dawn chorus earlier in the year. As a result, they also start breeding, foraging and developing earlier, which can have adverse effects on their fitness and life expectancy.

Artificial light influences bird migration, too, as its attracting and disorienting effects can cause the animals to lose energy and have fatal collisions.

Source: Da Silva A, Valcu M, Kempenaers B (2015) Light pollution alters the phenology of dawn and dusk singing in common European songbirds. Phil Trans R Soc B Biol Sci 370(1667):1-9.

Haupt H, Schillemeit U (2011) Lichtanlagen bringen Zugvögel vom Kurs ab. Natur und Landschaft 43(6):165-170.

[27]Lesser horseshoe bats avoid artificially lit flight paths which they used to frequent before they were illuminated. Researchers fear that this may cause them to expend additional energy on longer flights to their hunting grounds.

One vole species releases increased amounts of stress hormones when exposed to artificial light. It neither procreates nor adapts its metabolic rate to the winter and ultimately freezes to death.

Urban hedgehogs avoid illuminated areas. They tolerate street lighting when linear road structures are in place to provide direction.

Source: Stone EL, Jones G, Harris S (2009) Street Lighting Disturbs Commuting Bats. Curr Biol 19, 1123-1127.

Zubidat AE, Ben-Shlomo R, Haim A (2007) Thermoregulatory and endocrine responses to light pulses in short-day acclimated social voles (Microtus socialis). Chronobiol Int 24(2):269-288.

Schroer S, Weiß NS, Grubisic M, Manfrin A, von Grunsven RHA et al. (2019) Analyse der Auswirkungen künstlichen Lichts auf die Biodiversität. Naturschutz und Biologische Vielfalt 168. Bundesamt für Naturschutz Bonn (eds).

[28] Common toads prefer dark passages when migrating to spawning grounds; artificial light has a barrier effect.

Source: van Grunsven RHA, Creemers R, Joosten K, Donners M, Veenendaal EM (2017) Behaviour of migrating toads under artificial lights differs from other phases of their life cycle. Amph-Rept 38(1):49-55.

[29] Young salmon are attracted to red light with a luminous intensity of less than 1 lx. This makes them easy prey to diurnal grey herons and predatory fish.

Source: https://www.knkx.org/post/light-pollution-identified-potential-issue-threatened-puget-sound-chinook-salmon, accessed on 1 February 2021.

[30] Under cover of darkness, microbial fauna swim to the surface of the water to feed on algae. In the daytime, zooplankton can be found in lower layers of water. Even the levels of brightness caused by urban light pollution suppress its nightly ascent. This can disrupt the aquatic food chain and lead to more frequent algal bloom.

Source: Moore M, Pierce SM, Walsh HM, Kvalvik SK, Lim JD (2000) Urban light pollution alters the diel vertical migration of Daphnia. Verh Internat Verein Limnol 27(1-4):779-782.

[31] Artificial light at night suppresses flower formation and photosynthetic capacity, probably because the cells do not have enough time to regenerate.

In illuminated areas, tree buds open more than one week earlier than they do in areas with natural brightness levels. The study accounted for the effect of urban heat islands. This early budding can expose the plants to damage from frost and weakens them overall.

Source: Bennie J, Davies TW, Cruse D, Inger R, Gaston KJ (2015) Cascading effects of artificial light at night: resource-mediated control of herbivores in a grassland ecosystem. Phil Trans R Soc B 370:20140131.

Kwak MJ, Je SM, Cheng HC, Seo SM, Park JH et al. (2018) Night Light-Adaptation Strategies for Photosynthetic Apparatus in Yellow-Poplar (Liriodendron tulipifera) Exposed to Artificial Night Lighting. Forests 9(2):74.

ffrench-Constant RH, Somers-Yeates R, Bennie J, Economou T, Hodgson D et al. (2016) Light pollution is associated with earlier tree budburst across the United Kingdom. Proc R Soc B 283:20160813.

[32] In habitats illuminated by street lights, invertebrate predators and scavengers have been observed to occur in larger numbers than they do in comparative locations without artificial light.

Source: Davies TW, Bennie J, Gaston KJ (2012) Street lighting changes the composition of invertebrate communities. Biol Lett 8(5):764-7.

[33] Artificial lighting reduces the number of nocturnal pollinators, and plants produce fewer fruit as a result.

Source: Knop E, Zoller L, Ryser R, Gerpe C, Hörler M et al. (2017) Artificial light at night as a new threat to pollination. Nature 548:206-209.

[34] Krop-Benesch A. (2019): Licht aus!? Lichtverschmutzung. Die unterschätzte Gefahr. Rowohlt Verlag, Hamburg.

[35] Hölker F, Moss T, Griefahn B et al. (2010) The Dark Side of Light: A Transdisciplinary Research Agenda for Light. Ecol Soc 15(4):13.

[36] Huemer P (2009) Potentielle Auswirkungen der Beleuchtung des Nachtschibetriebes in Söll-Hochsöll auf nachtaktive Insekten. A study by the Tyrolean Environmental Ombudsoffice and Berg- und Skilift Hochsöll.

[37] Wöbse HH (2001) Licht – ein Thema des Landschaftsbildes. In: Böttcher M (2001) Auswirkungen von Fremdlicht auf die Fauna im Rahmen von Eingriffen in Natur und Landschaft. Analyse, Inhalte, Defizite und Lösungsmöglichkeiten. BfN 67. Bundesamt für Naturschutz Bonn-Bad Godesberg (ed.).

[38] Spillmann T (2002) LED – die neue Lichtquelle: Nahezu wartungsfreie Beleuchtung: Lichterzeugung im Rekombinationsprozess. Technik am Bau 4:83-86.

[39] Posch T (2010) Licht im Wandel der Zeiten. In: Posch T, Freyhoff A, Uhlmann T (Hrsg) Das Ende der Nacht. Die globale Lichtverschmutzung und ihre Folgen. Wiley-Vch Verlag.

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Abdul Hadi S., Al Kaabi MR, Al Ali MO, Arafat HA (2013) Comparative Life Cycle Assessment (LCA) of streetlight technologies for minor roads in United Arab Emirates. Energy for Sustainable Development 17(5):438-450.

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[42] Bierbaum H, Donat M, Doppler W, Juhasz P, Heilig P et al. (2018) Österreichischer Leitfaden Außenbeleuchtung – Licht, das mehr nützt als stört. Ämter der Österreichischen Bundesländer und Magistrat der Stadt Wien (ed.).

[43] Donatello S, Quintero RR, Caldas MG, Wolf O, van Tichelen P et al. (2019) Revision of the EU Green Public Procurement Criteria for Road Lighting and traffic signals. Publications Office of the European Union Luxembourg, EUR 29631 EN.

[44] RVS 5 June 2011 Visuelle Störwirkungen – Kriterien zu Standorten von Informationsträgern (December 2011).

RVS 5 June 2012 Visuelle Informationsträger für verkehrsfremde Zwecke (December 2019).

[45] ÖNORM EN 13201 Pt 2–5 (Part 2: quality features , part 3: calculating the quality features, part 4: methods for measuring the quality features of traffic lighting systems, part 5: energy efficiency indicators).

ÖNORM EN 12193 Light and lighting – sports facility lighting (15 June 2019).

[46]Operating equipment for LED lamps with CLO (Constant Lumen Output) are designed to counteract the wear-related drop of luminous flux in the system and ensure compliance with the maintenance factors specified in the

standard. Formula: maintained illuminance = value on installation ensured through CLO over entire service life. Because the luminous flux required by the lamp can be kept constant for the duration of its service life, devices with CLO considerably contribute to a reduction in light pollution as well as energy consumption. For these reasons, CLO-controlled operating equipment is an important component of the lighting system.