Chapter

Introductory Chapter: Ecological Effects of Light Pollution - A Review

Levente Hufnagel and Ferenc Mics

1. Introduction

Ecologists have long studied the regulatory role of natural light in species interactions, but the effect of overnight electrical lighting was only recently studied. In the 20th century, the size of the area illuminated by artificial light and the intensity of the light increased rapidly, as did its impact on wild species, however, light trapping has also become important in scientific research [1–4]. A distinction is made between astronomical light pollution, which obscures a clear night sky, and ecological light pollution, which modifies the natural light conditions of the environment. Adverse effects have been observed in a number of taxonomic groups, such as the extinction of migratory birds due to high, illuminated structures, or the orientation of hatching sea turtles is also disturbed by the light of surrounding settlements. The impact of artificial night light on animals is a new challenge for researchers and conservationists. Mankind has been looking for opportunities since prehistoric times to make the days longer and to be able to orientate themselves at night. In the pre-industrial era, they were able to be active in the dark by lighting wood or oil. The impact of this on wildlife was still very limited. After the discovery and spread of the electricity, it has changed natural day and night light conditions in an increasing part of the planet. The term light pollution has been used for years, but not in an ecological sense, but in the sense that celestial bodies are harder to observe because of the light from the lamps. The combined effect of many millions of terrestrial light sources causes the "skyglow" phenomenon, making the stars less visible to the human eye. We will continue to addres light pollution in ecological term, which affects the behavior of living things. Large areas are lit unnecessarily, which is a great waste. In the US alone, 3600 billion kilowatt-hours of electricity was produced in worth of 362 billion USD in 2018 [5]. About 30% of outdoor lighting is a waste because it is turned on even when it is not needed or is not directed to where it needs to be [6]. Verheijen [7] wrote about this phenomenon as "photopollution" first, suggesting that artificial light has a detrimental effect on wildlife. This embraces unusual light intensities and unexpected fluctuations. The source of light pollution is the phenomenon of "nightglow", illuminated buildings, towers, street lighting, vehicles, oil rigs. They are all, more or less, disrupting the normal functioning of ecosystems, almost all over the planet today [8]. This harmful effect of anthropogenic activity on the ecosystem occurs almost everywhere on the inhabited continents, the only exception is Antarctica [9]. The highest light pollution is observed in temperate forests and the Mediterranean climate zones. The effect is least intensive in the Arctic tundra and alpine areas [10]. In the tropics, wildlife is particularly severely affected, as the length of the illuminated period varies little during the year [11]. In tropical zone, the species have evolved over the course of evolution to vary the length of days only minimally seasonally. Species living in the temperate zone have adapted to seasonal changes in the length of the day, which is also disturbed by artificial lighting and, through this, the behavior of the animals. At full moon the illumination is between 0.1–0.03 cd/m^2 and at new moon it is between 0.01–0.003 cd/m^2, in case there is no light pollution [12]. Significant deviation from this values affects the physiology and behavior of both plants and animals, as well as the functioning of the entire ecosystem.

2. Light and ecology

Measuring the intensity and cycle of natural light is the first step in being able to determine the extent of pollution at a given location. The intensity, spectrum and period of the light may vary. Ecologists ideally measure the amount of photons per unit area per second. More often, however, light intensity is measured in lux, which expresses the intensity of light perceived by the human eye. In this case, the visible light to the human eye is measured primarily and less emphasis is placed on the invisible range. Since many animal can perceive light of a different wavelength than humans, it is worth measuring a wider range, because wavelengths out of range sensible to human eye can affect affect the behavior of animals [13]. The instruments are designated to be most sensitive in range that can be perceived by human eye, which makes the measurement more complicated [14]. For example, a light source may emit UV light that is not perceptible to the human eye, but some animals are attracted to UV source [15]. Orientation and disorientation are responses to changes in external lighting. Attraction and repulsion, on the other hand, are a response to the light source itself and its luminance [16, 17]. Increased illumination prolongs the activity of species active during the day, or at dusk, because they are still able to orientate. Many diurnal species continue to forage by artificial light [18]. Therefore, the so-called “night light niche” have developed in cities, which is very beneficial to certain species as they can seek food for longer periods of time. This is, of course, detrimental to their prey species [19]. In the case of birds, territorial behavior, i.e. singing, also takes longer due to artificial light [20]. Continuous artificial lighting, however, causes disorientation in nocturnal animals. The best-known example is the disrupted migration of sea turtle hatchlings to the water They normally move away from the low, dark silhouttes, which is generally the surrounding vegetation, to reach the water as quickly as possible. Due to the light of the surrounding settlements, the plants have no shade or the direction of the shade changes. This confuses the little turtles and they loose direction. Females, preparing to lay eggs, can also be disturbed by the light from the villages [21]. Nocturnal animals have adapted to low light intensity, and they can be blinded by sudden strong light, making them disoriented. In some cases, the adaptation of the eye can take up to hours, during which the animal loses its ability to orient itself [22]. In the case of birds, the light source sometimes traps the animals, they do not leave the surrounds of illuminated structures. Birds may collide with each other, the lit-up building, or fall prey to predators [23]. In the case of insects, many taxa are known to be attracted to night light. Such as moths, veils, beetles, bugs, quails, mosquitoes, flies, buzzards, wasps and crickets. Attraction depends on the spectrum of light emitted [24]. In the case of non-flying arthropods, the reaction can be varied. Nocturnal species are often repelled by night light, trying to move away from it. Others prefer to take advantage of artificial light [25]. Some insects always show positive phototaxis as adaptive behavior, while others always show negative [26, 27]. In some cases, phototaxis can be exploited to protect animals. For example,

DOI: http://dx.doi.org/10.5772/intechopen.99648

in the case of the American eel (*A. rostrata*), animals can be diverted to a detour route if a dam or power plant on the river prevents the migration [28].

Artificial light also affects reproduction. The calling sound of male frogs (*Physalaemus pustulosus*) changes around urban cities without increasing the risk of predation, as there are fewer predators due to light. For this reason, their reproduction is also more successful than in the case of individuals living far from the city [29]. The reproductive success of birds is also affected by artificial lighting, but here the effect is more negative. The brooding birds are disturbed in their sleep, resulting in a significant reduction in reproductive success [30]. Visual communication, both within and between species, is strongly influenced by the light of the lamps. Some animals use the chemical reaction of bioluminescence for communication. The best known example of this is the fireflies (Coleoptera: Lampyridae). Due to the unnatural light intensity, their signals are less noticeable, so they are less able to make contact with their peers, and their chances of reproduction also deteriorate [31]. The coyote (*Canis latrans*) holds the team together at night with vocals and also signals the boundary of the territory with its voice. Due to the light of the settlements, the pattern of vocalization changes, it is most pronounced in the new moon, when it is otherwise darkest at night [32]. Vision plays a very important role in orientation, no wonder the changed light conditions also affect the behavior of the animals. This should also be taken into account in nature conservation, as some species may decline as a result of light pollution. For other species, the effect is positive, but from the point of view of community ecology, this effect may not be positive. The connection between the *Physalaemus pustulosus* frog and Corethrella spp. parasite midges is also affected by the lights of the lamps. The parasite is very sensitive to light pollution, so significantly fewer parasites can be observed near the settlements. The relationship between the parasite and the host species is further complicated by the fact that noise pollution also affects the abundance of the parasite [33]. A frog called *Hyla squirrela* feeds in the range of 10–5 lux and ceases to feed above 10–3 lux [34]. *Bufo boreas* feeds between 10 and 1 and 10–5 lux, while *Ascaphus truei* only feeds below 10–5 lux [35]. These species are not sympatric, they live in same area, niche separation occurs along the gradient of illumination, hence interspecific competition increases under the influence of artificial light. It is a well-known fact that the light of street lights attracts flying insects and insects attract bats [36]. But not all bats are attracted to light. How attractive a particular species finds the abundance of food provided by a lamp depends primarily on how fast it can fly. Slower-flying species are less likely to come to illuminated places because they have to compete with faster species there, and despite the increased food density, they would not be able to take more prey. Therefore, they prefer to avoid light and hunt in the dark [37]. So in competing communities, changed light conditions also change interspecific relationships. Some species benefit from a longer clear period because they can search for food for a longer period of time, but this also has disadvantages because predation risk also increases during food search [38]. Strong lighting makes rats more cautious, spends little time in the illuminated area, and their movement is also slowed near lamps, and the time spent searching for food is shortened [39]. During a full moon, the predation of marine zooplankton by fish increases because plankton congregate near the surface due to illumination. Due to artificial lighting, this event has become commonplace, greatly increasing the predation pressure from which fish benefit [40]. Yurk and Trites [41] observed that the hunting success of seals (*Phoca vitulina*) is significantly enhanced by coastal lights. So at the next trophic level, the proximity of settlements also increases the efficiency of hunting. But there is an counter-example. Indian peafowl (*Pavo cristatus*) becomes more alert and sleeps less when exposed to artificial light. This just reduces predation risk [42]. Species belonging to the families Geometridae, Noctuidae, and Notodontidae families have sensory organs that detect ultrasound and try to evade bats. Conversly, by the light of mercury vapor lamp they does not exhibit evasive behavior. They do not seem to respond to ultrasound in the area lit by mercury vapor lamp. They do not also react to ultrasound flying in natural daylight. They detect ultrasound during the day, but then the source of the sound does not pose a threat to them, because in light they mostly perceive the sound emitted by Orthoptera species, which does not pose a threat to them. The light of mercury vapor lamp is interpreted by the animals 'nervous system as natural daylight and there is no danger of predation by bats. Therefore, they do not even try to avoid the source of ultrasound, significantly increasing the mortality rate and bat hunting success. It appears that in the light of led lamps that do not emit UV light, the evasive reaction is largely retained, and in the case of led lamp light, the power-dive maneuver is more often observed [43]. Altered animal behavior, as a spillover effect, endangers the functioning of the entire ecosystem in the long run. Good example is the diurnal drift of zooplankton. Zooplankton migrates vertically in the water body in a daily rhythm. They come close to the surface at night to feed and also follow the lunar cycle. Thus, they can avoid predation risk by fish [44]. Luarte et al. [45] during the study of zooplankton and invertebrate species found that artificial lighting reduced migration, and thus the time spent feeding. As a result, the size of the population has also decreased. Due to the decrease in predation pressure, the biomass of algae increased. Returning to the bats, the species that can fly slower do not gain anything from the food abundance caused by the light of the streetlamps due to the interspecific competition with faster species (*Lasiurus* spp., *Eptesicus* spp., *Nyctalus* spp. and *Pipistrellus* spp.) Therefore they prefer to continue hunting in the dark (*Rhinolophus* spp. *Plecotus* spp. and *Myotis* spp.) This leads to changes in community structure [46].

Sunlight is one of the most important abiotic factors that regulates plant development. During evolution, they developed a wide variety of receptors for the perception of light, which are used to obtain information about the amount, quality, seasonal changes, direction, length of illumination. Luarte et al. [45] during the study of zooplankton and invertebrate species found that artificial lighting reduced migration, and thus the time spent feeding. As a result, the size of the population has also decreased. Due to the decrease in predation pressure, the biomass of algae increased. Returning to the bats, the species that can fly slower do not gain anything from the food abundance caused by the light of the streetlamps due to the interspecific competition with faster species (*Lasiurus* spp., *Eptesicus* spp., *Nyctalus* spp. and *Pipistrellus* spp.) Therefore they prefer to continue hunting in the dark (*Rhinolophus* sp. *Plecotus* spp. and *Myotis* spp.) This leads to changes in community structure [46].

Sunlight is one of the most important abiotic factors that regulate plant development. During the evolution, many receptors have developed in them for the perception of light, with the help of which they obtain information about the amount, quality, seasonal changes, direction and length of illumination. This allows plants to adjust their biological clock and adapt life processes to optimal conditions. The mechanism that regulates the circadian rhythm is conserved and found almost throughout the kingdoms [47]. Plants utilize the energy of light during photosynthesis to produce organic matter. A wide variety of physiological processes, both light and dark, are required to coordinate regulatory processes. Light directs various plant physiological processes from seed germination to seed maturation [48, 49]. Changes in daily, monthly, and annual cycles may result in a shift in phenological phases caused by artificial light. A good example of this is the study of Škvareninová et al. [50] who observed sycamore (*Acer pseudoplatanus*) and stag's horn sumach (*Rhus typhina*) individuals in a park of Zvolen (Slovakia) between 2013 and 2016. On average, the autumn phenophase began 13–22 days later and lasted 6–9 days longer due to the light from the street lamps. As a result, however, they are more exposed to frost damage in late fall. French-Constant et al. [51] examined the phenology of urban trees' spring bud bursting in the UK. The trees around the lamps (*Acer psuedoplatanus*, *Fagus sylvatica*, *Quercus robur*, *Fraxinus excelsior*) sprout up a week earlier than specimens away from the light source. But urban heat island also contributes to this, namely, phenomenon that the average temperature in cities is a little higher. Lamp light also affects leaf movement, stomatal conductance, abaxial and adaxial cell elongation, cytoskeletal rearrangement, carbon dioxide uptake, hormone production and transport [52].

Another effect on plants is the reduction in the population size of pollinating insects, which is drastically decreased as a result of artificial light. Moths are important nocturnal pollinators, and due to the strong decline in their population, pollination fails often, so this indirect effect also threatens the healthy functioning of the ecosystem [53].

During the dark period, regeneration processes begin in plant cells to repair damages occur during the day. In this case, the normal physiological state is restored (Light-Independent Repair) [54]. Urban lighting makes it harder for plants to repair damage caused by oxidative stress. Ozone concentration in the air is also often high in cities due to pollution. Of course, ozone in high concentration also damages plant tissues, but the light pollution makes regeneration much more difficult for them [55]. Survival in a polluted urban environment is also made difficult for plants by abnormal lighting conditions (e.g. [56]).

Author details

Levente Hufnagel[1]* and Ferenc Mics[2]

1 Research Institute of Multidisciplinary Ecotheology, John Wesley Theological College, Budapest, Hungary

2 Department of Environmental Security, John Wesley Theological College, Budapest, Hungary

*Address all correspondence to: leventehufnagel@gmail.com

References

[1] Gimesi, L, Hufnagel, L. (2010): THE POSSIBILITIES OF BIODIVERSITY MONITORING BASED ON HUNGARIAN LIGHT TRAP NETWORKS - Applied Ecology and Environmental Research 8(3): 223-239.

[2] Nowinszky, L. (2004): NOCTURNAL ILLUMINATION AND NIGHT FLYING INSECTS- Applied Ecology and Environmental Research 2(1): 17-52

[3] Nowinszky, L, Puskás, J., Kúti, Zs. (2010): Light trapping as a dependent of Moonlight and clouds - Applied Ecology and Environmental Research 8(4): 301-312.

[4] Nowinszky, L, Puskás, J., Tar, K, Hufnagel, L, Ladányi, M. (2013): The dependence of normal and black light type trapping results upon the wingspan of moth species- Applied Ecology and Environmental Research 11(4): 593-610.

[5] EIA. (2018): Electric Sales, Revenue, and Average Price - Energy Information Administration. viewed on 28 january 2021. https://www.eia.gov/electricity/sales_revenue_p rice/.

[6] Tatro, K. (2020): Light Energy: Our Wasted Resource. – Consilience 22: 65-72.

[7] Verheijen, F.J. (1985): Photopollution: artificial light optic spatial control systems fail to cope with. Incidents, causations, remedies. – The Journal of Experimental Biology 44(1): 1-18.

[8] Li, X., Zhou, Y., Zhao, M. (2020): A harmonized global nighttime light dataset 1992-2018. – Scientific Data 7: 168.

[9] Bará, S., Lima, R.C., Zamorano, J. (2019): Monitoring Long-Term Trends in the Anthropogenic Night Sky Brightness. – Sustainability 11(11): 3070.

[10] Bennie, J., Duffy, J.P., Davies, T.W., Correa-Cano, M.E., Gaston, K.J. (2015): Global Trends in Exposure to Light Pollution in Natural Terrestrial Ecosystems. – Remote Sensing 7: 2715-2730.

[11] Brighenti, L.S., Staehr, P.A., Gagliardi, L.M., Brandão, L.P.M., Elias, E.C., de Mello, N.A.S.T., Barbosa, F.A.R., Bezerra-Neto, J.F. (2015): Seasonal Changes in Metabolic Rates of Two Tropical Lakes in the Atlantic Forest of Brazil. – Ecosystems 18: 589-604.

[12] Sachsenweger, M., Sachsenweger, U. (2012): Stereoscopic acuity in ocular pursuit of moving objects: Dynamic stereoscopy and movement parallax: relevance to road safety and occupational medicine. – Springer Science & Business Media, Dordrecht.

[13] Donner, K., Zak, P., Viljanen, M., Lindström, M., Feldman, T., Ostrovsky, M. (2016): Eye spectral sensitivity in fresh- and brackish-water populations of three glacial-relict *Mysis* species (Crustacea): physiology and genetics of differential tuning. – Journal of Comparative physiology A, Neuroethology, Sensory, Neural, and Behavioral Physiology 202(4): 297-312.

[14] Schweikert, L.E., Fitak, R.R., Caves, E.M., Sutton, T.T., Johnsen, S. (2018): Spectral sensitivity in ray-finned fishes: diversity, ecology and shared descent. – Journal of Experimental Biology 221: jeb189761.

[15] Owens, A.C.S., Lewis, S.M. (2018): The impact of artificial light at night on nocturnal insects: A review and synthesis. – Ecology and Evolution 8: 11337-11358.

[16] Gaston, K.J., Visser, M.E., Hölker, F. (2015): The biological impacts of artificial light at night: the research challenge. – Philosophical Transactions of the Royal Society B 370(1667): 20140133.

[17] Schroer, S., Hölker, F. (2016): Impact of Lighting on Flora and Fauna. – In: Karlicek, R., Sun, C.-C., Zissis, G., Ma, R. Handbook of Advanced Lighting Technology. Springer International Publishing, Switzerland.

[18] Leveau, L.M. (2020): Artificial Light at Night (ALAN) Is the Main Driver of Nocturnal Feral Pigeon (*Columba livia* f. *domestica*) Foraging in Urban Areas. – Animals (Basel). 10(4): 554.

[19] Zozaya, S.M., Alford, R.A., Schwarzkopf, L. (2015): Invasive house geckos are more willing to use artificial lights than are native geckos. – Austral Ecology 40(8): 982-987.

[20] Da Silva, A., Kempenaers, B. (2017): Singing from North to South: Latitudinal variation in timing of dawn singing under natural and artificial light conditions. – Journal of Animal Ecology 86(6): 1286-1297.

[21] Dimitriadis, C., Fournari-Konstantinidou, I., Sourbes, L., Koutsoubas, D., Mazaris, A.D. (2017): Reduction of sea turtle population recruitment caused by nightlight: Evidence from the Mediterranean region. – Ocean & Coastal Management 153: 108-115.

[22] Contín, M.A., Benedetto, M.M., Quinteros-Quintana, M.L., Guido, M.E. (2016): Light pollution: the possible consequences of excessive illumination on retina. – Eye 30(2): 255-263.

[23] Ronconi, R.A., Allard, K.A., Taylor, P.D. (2015): Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. – Journal of Environmental Management 147: 34-45.

[24] Barroso, A., Haifig, I., Janei, V., da Silva, I., Dietrich, C., Costa-Leonardo, A.M. (2015): Effects of flickering light on the attraction of nocturnal insects. – Lighting Research & Technology 49(1): 1-11.

[25] Gomes, D.G.E. (2020): Orb-weaving spiders are fewer but larger and catch more prey in lit bridge panels from a natural artificial light experiment. – PeerJ 8:e8808.

[26] Okland, B. (2002): Canopy cover favours sporocarp-visiting beetles in spruce forest. – Norwegian Journal of Entomology 49: 29-39.

[27] Shimoda, M., Honda, K. (2013): Insect reactions to light and its applications to pest management. – Applied Entomology and Zoology 48(4).

[28] Elvidge, C.K., Ford, M.I., Pratt, T.C., Smokorowski, K.E., Sills, Patrick, P.H., Cooke, S.J. (2018): Behavioural guidance of yellow-stage American eel *Anguilla rostrata* with a light-emitting diode device. – Endangered Species Research 35: 159-168.

[29] Halfwerk, W., Blaas, M., Kramer, L., Hijner, N., Trillo, P.A., Bernal, X.E., Page, R.A., Goutte, S., Ryan, M.J., Ellers, J. (2019): Adaptive changes in sexual signalling in response to urbanization. – Nature Ecology & Evolution 3: 374-380.

[30] Raap, T. (2018): Effects of artificial light at night on the behaviour and physiology of free-living songbirds. – PhD thesis, University of Antwerpen, Belgium.

[31] Lewis, S.M., Wong, C.H., Owens, A.C.S., Fallon, C., Jepsen, S., Thancharoen, A., Wu, C., De Cock, R.,

Novák, M., López-Palafox, T., Khoo, V., Reed, J.M. (2020): A Global Perspective on Firefly Extinction Threats. – BioScience 70(2): 157-167.

[32] Birnie-Gauvin, K., Peiman, K.S., Gallagher, A.J., de Bruijn, R., Cooke, S.J. (2016): Sublethal consequences of urban life for wild vertebrates. – Environmental Reviews 24(4): 416-425.

[33] McMahon, T.A., Rohr, J.R., Bernal, X.E. (2017): Light and noise pollution interact to disrupt interspecific interactions. – Ecology 98(5): 1290-1299.

[34] Buchanan, B.W. (1998): Low-illumination prey detection by squirrel treefrogs. – Journal of Herpetology 32: 270-274.

[35] Hailman, J.P. (1984): Bimodal nocturnal activity of the western toad (*Bufo boreas*) in relation to ambient illumination. – Copeia 1984: 283-290.

[36] Plummer, K., Hale, J., O'Callaghan, M., Sadler, J., Siriwardeni, G. (2016): Investigating the impact of street lighting changes on garden moth communities. – Journal of Urban Ecology 2(1): juw004.

[37] Stone, E.L., Harris, S., Jones, G. (2015): Impacts of artificial lighting on bats: a review of challenges and solutions. – Mammalian Biology 80: 213-219.

[38] Bennie, J., Davies, T.W., Cruse, D., Inger, R., Gaston, K.J. (2015): Cascading effects of artificial light at night: resource-mediated control of herbivores in a grassland ecosystem. – Philosophical Transactions of the Royal Society B: Biological Sciences 370: 20140131.

[39] Farnworth, B., Meitern, R., Innes, J., Waas, J.R. (2019): Increasing predation risk with light reduces speed, exploration and visit duration of invasive ship rats (*Rattus rattus*). – Scientific Reports 9: 3739.

[40] Berge, J., Geoffroy, M., Daase, M., Cottier, F., Priou, P., Cohen, J.H., Johnsen, G., McKee, D., Kostakis, I., Renaud, P.E., Vogedes, D., Anderson, Last, K.S., Gauthier, S. (2020): Artificial light during the polar night disrupts Arctic fish and zooplankton behaviour down to 200 m depth. – Communications Biology 3: 102.

[41] Yurk, H., Trites, A.W. (2000): Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. – Transactions of the American Fisheries Society 129: 1360-1366.

[42] Yorzinski, J.L., Chisholm, S., Byerley, S.D., Coy, J.R., Aziz, A., Wolf, J.A., Gnerlich, A.C. (2015): Artificial light pollution increases nocturnal vigilance in peahens. – PeerJ 3:e1174.

[43] Wakefield, A., Stone, E.L., Jones, G., Harris, S. (2015): Light-emitting diode street lights reduce last-ditch evasive manoeuvres by moths to bat echolocation calls. – Royal Society Open Science 2: 150291.

[44] Last, K.S., Hobbs, Berge, J., Brierley, A.S., Cottier, F. (2016): Moonlight Drives Ocean-Scale Mass Vertical Migration of Zooplankton during the Arctic Winter. – Current Biology 26: 1-8.

[45] Luarte, T., Bonta, C.C., Silva-Rodriguez, E.A., Quijon, P.A. Miranda, C., Farias, A.A., Duarte, C. (2016): Light pollution reduces activity, food consumption and growth rates in a sandy beach invertebrate. – Environmental Pollution 218: 1147-1153.

[46] Mathews, F., Roche, N., Aughney, T., Jones, N., Day, J., Baker, J., Langton, S. (2015): Barriers and benefits: implications of artificial night-lighting for the distribution of common bats in Britain and Ireland. – Philosophical

Transactions of the Royal Society B: Biological Sciences 370: 20140124.

[47] Andreani, T.S., Itoh, T.Q., Yildirim, E., Hwangbo, D.S., Allada, R. (2015): Genetics of circadian rhythms. – Sleep Medicine Clinics 10(4): 413-421.

[48] Sreenivasulu, N. (2017): Systems biology of seeds: deciphering the molecular mechanisms of seed storage, dormancy and onset of germination. – Plant Cell Reports 36(5): 633-635.

[49] van Gelderen, K., Kang, C., Pierik, R. (2017): Light Signaling, Root Development, and Plasticity. – Plant Physiology 176: 1049-1060.

[50] Škvareninová, J., Tuhárska, M., Škvarenina, J., Babálová, D., Slobodníková, L., Slobodník, B., Středová, H., Minďaš, J. (2017): Effects of light pollution on tree phenology in the urban environment. – Moravian Geographical Reports 25(4): 282-290.

[51] French-Constant, R.H., Somers-Yeates, R., Bennie, J., Economou, T., Hodgson, D., Spalding, A., McGregor, P.K. (2016): Light pollution is associated with earlier tree budburst across the United Kingdom. – Proceedings of the Royal Society B: Biological Sciences 283(1833): 20160813.

[52] Roni, Z.K., Islam, S., Shimasaki , K. (2017): Response of *Eustoma* Leaf Phenotype and Photosynthetic Performance to LED Light Quality. – Horticulturae 3(4): 50.

[53] MacGregor, C.J., Pocock, M.J.O., Fox, R., Evans, D.M. (2015): Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review. – Ecological Entomology 40(3): 187-198.

[54] Gill, S.S., Anjum, N.A., Gill, R., Jha, M., Tuteja, N. (2015): DNA Damage and Repair in Plants under Ultraviolet and Ionizing Radiations. – The Scientific World Journal Article ID 250158.

[55] Meravi, N., Prajapati, S.K. (2018): Effect street light pollution on the photosynthetic efficiency of different plants. – Biological Rhythm Research 51(1): 67-75.

[56] Yang, J, Duan, R. (2019): The effect of artificial illumination on postponing plant phenology – Applied Ecology and Environmental Research 17(6):13289-13296