The dark side of artificial light

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ABSTRACT

In the recent past, Earth inhabitants had a completely dark night and sky full of stars at night, while in the last twenty years, only the inhabitants of less-developed countries could enjoy the starry sky, who had no possibility to install sources that would threaten the night sky by overuse of artificial lighting.
Specifically, today we are faced with light pollution, which is primarily the result of the scattered light of cities and other light emissions from artificial sources, mainly from urban areas and areas where economic operators (factories, warehouses, etc.) are concentrated. Much of the light flux from these sources, and therefore energy, is scattered and lost in the sky, which makes the night sky brighter and the celestial objects in its background become invisible. Light pollution is now considered a complex problem that has a detrimental effect on the environment with a very wide range of consequences.
The harmful effects on the environment are primarily reflected in disturbances in astronomical observations, inducing hormonal disorders in humans working at night, in plants disturbing vegetation cycles in plants, disorienting birds in space, sea turtle cubs and some other animal species, which all together directly affects at their survival, often causing changes in the habitat of endangered animal species. This has led to the development of scotobiology, which as a branch of biology deals with the benefits of darkness and helps to establish a safe level of brightness, duration and color of night illumination to avoid the harmful effects of light pollution on the living world.
Given that there is a need to protect the environment as a whole, and human health as well, from light pollution, it is necessary to take appropriate measures to educate the public about the potential adverse effects of light pollution while at the same time improving legislation in this area of environmental protection, because only through valid legal framework for the adoption of regulations on protection against light pollution, it is possible to reduce, if not completely eliminate, the harmful effects of light pollution in the environment.

1. INTRODUCTION

For decades, air, water and soil pollution have been the most important challenges in environmental policy, while light pollution has remained scientifically, culturally and institutionally in complete darkness. Due to the fact that the emission of artificial light has dramatically increased in the last few decades, there is an urgent need to investigate the physiological, ecological and socioeconomic impact of dark and night loss on the living environment, as well as finding solutions for technical and institutional lighting improvement in order to reduce harmful effects.

Artificial light began to be used by humans before Paleolithic times or 2.5 million years ago, when hollow stones or shells were filled with moss soaked in animal fat and lit to produce their first lamps. The tallow, which was first burned in these lamps, was later used with natural wax to make candles until the 19th century, when they were replaced by stearin produced from tallow and paraffin, which began to be widely produced from oil at the end of the century.

At the beginning of the 19th century, the light flame of burning carbon gas replaced candles and oil lamps, and began to be produced on an industrial scale, thus spreading artificial light first in large cities and later beyond. In the middle of the same century, the production of kerosene began, the use of which in lighting artificial light conquered even the most remote rural settlements.

Shortly afterwards, lighting, along with electric propulsion, was the main area of application for electrification after the construction of the first DC power plants for public use and the first AC power plant, and the electric light bulb is one of the most important symbols of technical progress since its early 19th century concept until today.

Although the invention and widespread use of artificial light are one of the most important technological achievements of man, the disappearance of night darkness is increasingly recognized as harmful. Namely, night lighting can have serious physiological consequences for humans, ecological and evolutionary consequences for animal and plant populations and can shape entire ecosystems. However, the possible harmful effects of light pollution have not yet been fully investigated. In response to climate change and energy shortages, many countries, regions and communities are developing new lighting programs and concepts with a strong emphasis on energy efficiency and greenhouse gas emissions. Given the dramatic increase in artificial light at night (0-20% per year, depending on the geographical region), there is a need to introduce measures to prevent and protect against light pollution that go beyond energy efficiency and include human well-being, structure and functioning of ecosystems and interconnected socio-economic consequences. Such a shift in policy requires a healthy transdisciplinary understanding of the importance of night darkness and its loss to the people and natural systems on which we depend. This requires knowledge of appropriate lighting technologies and concepts that are environmentally, socially and economically viable, as otherwise society may encounter global detrimental effects of artificial light with unpredictable outcomes.

2. ON LIGHT POLLUTION

Until recently, light, i.e. the visible part of the electromagnetic spectrum, although the most important type of radiation for humans, along with thermal radiation, has not been treated as something that can adversely affect the environment and pollute it.

Once upon a time the Earth inhabitants had a completely dark night and sky full of stars at night, while today, only the inhabitants of less-developed countries could enjoy the starry sky, who had no possibility to install sources that would threaten the night sky by overuse of artificial lighting. Much of the artificial light emitted from various sources (urban settlements, industry, roads, etc.) is scattered and lost in the sky, making the night sky brighter and celestial objects in its background becoming less visible or completely lost. Namely, astronomers were forced to relocate their observatories outside urban areas, whose lighting, illuminating the atmosphere, drastically reduced the contrast between the natural darkness of interstellar space and the dim light of distant astronomical objects, due to increased sky brightness. This side effect is due to excessive artificial lighting and scattering of visible and invisible light on various particles in the atmosphere (gases, water vapor, pollen, dust) and causes harmful consequences for humans and the environment as a whole.

However, biologists were the first to approach the systematic study of this phenomenon, so F. J. Verheijen [1] in the late fifties of the last century was the first to mention the so-called light traps, and twenty years later he used the English term photopollution, which today is mostly replaced by the term light pollution.

Although astronomers were the first to recognize changes caused by artificial light in the form of increased sky brightness, it was not until the beginning of this century [2-4] that multiple negative effects of artificial lighting on the environment, human health and social well-being were identified. It was quickly established that the consequences of light pollution can be biological, energy, economic, social, and ultimately aesthetic.

Scientists have paid more attention to the research of light pollution and its consequences for the last 30 years, which has resulted in the adoption of laws and other regulations prescribing measures to reduce and prevent the negative consequences of artificial lighting as a new form of environmental pollution. In this way, a modern definition of light pollution was reached, according to which light pollution is considered to be any change in the level of natural light at night caused by the introduction of light produced by human activity. In a broader sense, these are changes in the level of natural light at night caused by the emission of light from artificial light sources that adversely affects human health and endangers traffic safety due to glare, direct or indirect light radiation, interferes with life and/or migration of birds, bats, insects and other animals and disturbs the growth of plants, threatens the natural balance, interferes with professional and/or amateur astronomical observation of the sky and unnecessarily consumes energy and distorts the image of the night landscape [5].

Organized confrontation with light pollution on a global scale was started by the *International Dark Sky Association (IDA)* founded in the USA in 1988 as a non-profit organization, which today brings together numerous civil society members from more than 70

countries. IDA was the first who define light pollution *as any harmful effect of artificial light, including increased sky brightness, blinding, illumination outside the area to be illuminated, overexposure, reduced visibility at night, and scattering of light energy [6,7]*.

Satellites began to be used in the 1990s to investigate the problem of increasing the night sky brightness caused by the introduction of artificial light. Satellite images of the night side of the globe made it possible, with the help of light scattering theory, to calculate the increase in the brightness of the night sky caused by light sources recorded in these satellite images. As a result of these studies, a new Atlas with light pollution maps based on observations and collected data was released in 2016, which indicated a significant increase in light pollution compared to previous studies [8]. This atlas showed for the first time how light pollution affects the world population on the basis of statistically calculated values of pollution levels that are also visually shown, Figure 1.

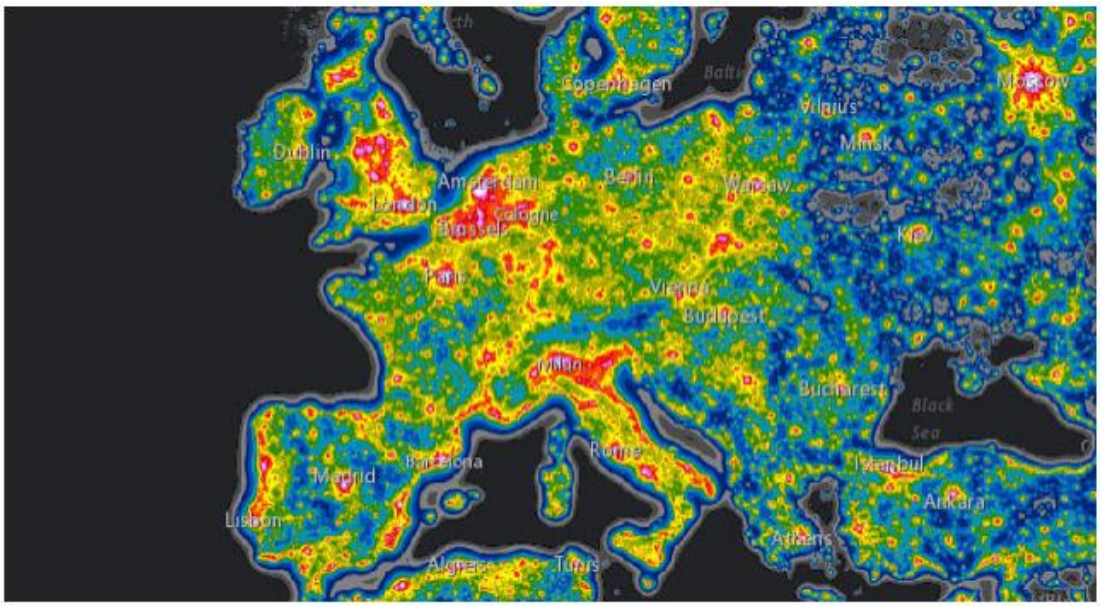

Figure 1: Map of Europe's artificial sky brightness [8]

The results of these studies showed that about 83% of the world's population lives under light-polluted night skies where the night sky brightness at the zenith is more than 14 microcandelas per square meter (μcd m^{-2}) or individually, more than 99% of American and European populations live under light-polluted skies. Also, due to light pollution, the Milky Way (Figure 2) is not visible to a population representing more than one-third of humanity, including 60% of Europeans and nearly 80% of North America [8].

Figure 2: Milky Way over Rocky Mountains, Colorado, USA [9**]**

Furthermore, the possibility of seeing the Milky Way from their own homes on clear nights is excluded for all residents of Singapore, San Marino, Kuwait, Qatar and Malta, and for 99%, 98% and 97% of the population of the United Arab Emirates, Israel and Egypt. Bearing in mind the average number of inhabitants per unit area, the same study calculated that the countries with the largest part of their territory from which the Milky Way is not visible due to light pollution are Singapore and San Marino (100%), Malta (89%), Qatar (55%), Belgium and Kuwait (51%), Trinidad and Tobago and the Netherlands (43%) and Israel (42%) [8].

2.1 Impact of light pollution on the living world

For millions of years, the change of day and night has been a fundamental determinant of the ecosystem, and the life cycles of the entire plant and animal world, including man, have been adapted to their natural daily changes. So even at night, which is not completely dark because there are several sources of natural light, even in the most remote parts of the Earth, there is life that is adapted to just such conditions.

A constellation of eminent scientists from various scientific disciplines (mathematics, astronomy, philosophy, archaeology, etc.) from Socrates, Plato, Aristotle, Ibn Al-Haytham, J. C. Maxwell, Huygens, Newton, Young, Einstein [10], all the way to our contemporaries, studied the characteristics of light as electromagnetic radiation in the visible and invisible part of the spectrum [5] and its noble effect on the living world on Earth.

Unfortunately, today there is a lot of scientific evidence [11-15] of the negative and harmful effects of light pollution and the resulting disruption of the natural cycle day / night on flora and fauna because artificial light at night has become one of the most significant changes in the human environment. Today, many harmful effects of light pollution are still

not fully explained or are poorly understood, because the identified impact on the growth and survival of the organism is very complex due to the fact that these effects result from the way artificial light at night changes interactions with other species in the form of indirect effects and the way in which it changes the physiology of the individual in the form of direct or immediate effects.

These adverse effects can take various forms, such as reduced nesting of birds in overly lit areas, orientation weakening of migratory birds, declining populations of many insect and bat species, reproductive disorders of certain fish species, plant vegetation disorders, declining numbers of individuals and plant species in certain areas. due to the decline in the number of nocturnal pollinators or the complete extinction of certain animal and plant species. Artificial disturbance of the natural cycle day / night, in addition to the flora and fauna, can of course cause serious harmful psycho-physiological and even health effects on humans.

2.1.1 Impact of light pollution on plants

Plants, like animals, are sensitive to light, its color, intensity and duration of exposure. Light is a vital requirement for plants due to the fact that it is needed for photosynthesis as well as information for plants related to germination, budding, leaf and flower formation, affects flower color and induces flowering induction, etc., all based on absorption lights of appropriate wavelengths that comply with their development requirements. This mainly refers to the part of the light spectrum of wavelengths between 400 and 700 nm (Figure 3), which is also known as photosynthetically active light and corresponds to a more or less visible part of the spectrum, i.e. the part to which the human eye is sensitive [16,17].

Plants have different behavioral responses to different wavelengths of light, where flowering, germination, and photosynthesis associated with exposure to different parts of the visible light spectrum. Namely, photoreceptors in plants use light to obtain and feel information about the season and even the time of day, which directly affects or controls seed germination, stem growth or elongation, leaf spread, flower development, avoiding shade, etc. Although light is dominant factor in the life of plants because it affects their physiology, excessive and uncontrolled exposure to artificial light can cause harmful consequences.

In most cases, the intensity of light pollution is not enough to affect the process of photosynthesis, but changing the perception of the day/night cycle due to artificial increase in day length, directly disrupts their biological daily rhythm or so-called circadian cycle [18].

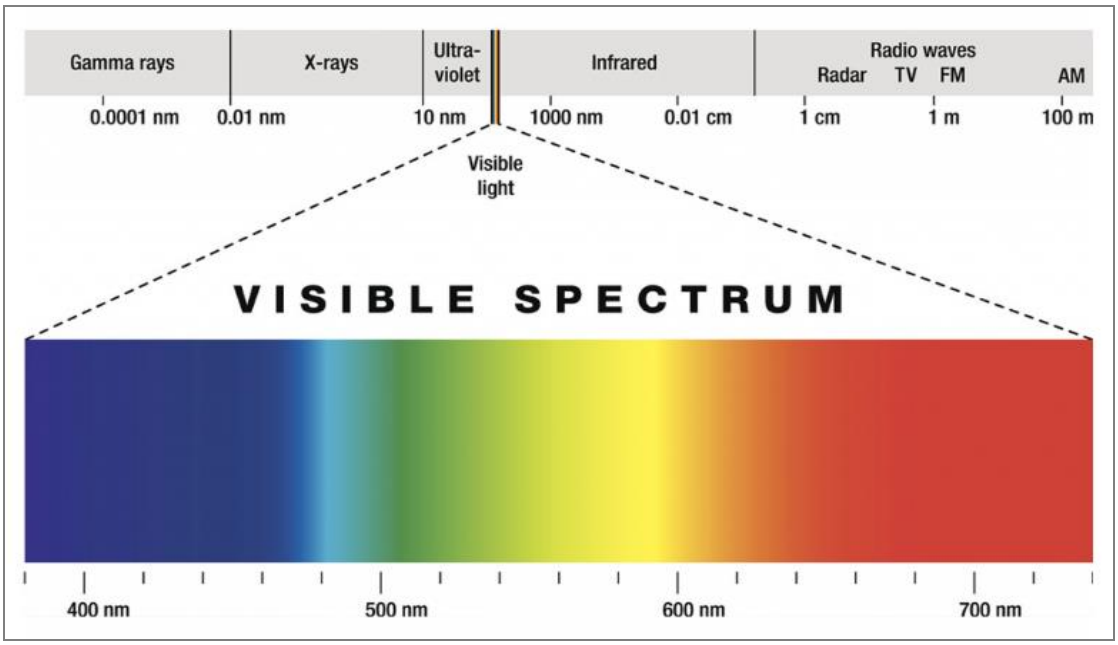

Figure 3: Electromagnetic spectrum [17]

Due to such a conditioned disorder of plant physiology, phenomena such as promoting the spread of leaves, and thus increased exposure of plants to air pollutants, or greater susceptibility to water stress are possible. For the same reason, in urban areas, delays in leaf drop from deciduous trees near street lights can be observed (Figure 4), as well as the early onset of spring bud burst, thus increasing the risk of exposure to frost and pathogens.

Figure 4: A tree that keeps the leaves longer on the illuminated side.
This light can shorten the tree's life [19]

Another form of indirect harmful effects of light pollution on plants is related to plant pollination [20, 21]. It is known that pollination of plants takes place day and night, but there are plants whose pollination takes place mainly at night thanks to nocturnal pollinators, and which attract with their seductive scents and abundant amounts of nectar. Unfortunately, with the appearance of light pollution or street lamps near these plants, pollinators (e. g. moths and others) are attracted to light and do not pollinate plants, because they are attracted to a light source that is usually their mortal enemy, Figure 5.

Another form of indirect harmful effects of light pollution on plants is related to plant pollination. It is known that pollination of plants takes place both day and night, but there are plants whose pollination takes place mainly at night thanks to nocturnal pollinators. Plants attract nocturnal pollinators with their seductive scents and abundant amounts of nectar. Unfortunately, with the appearance of light pollution or street lamps near these plants, pollinators (e. g. moths and others) are attracted to light and do not pollinate plants, because they are attracted to a light source that is usually their mortal enemy, Figure 5.

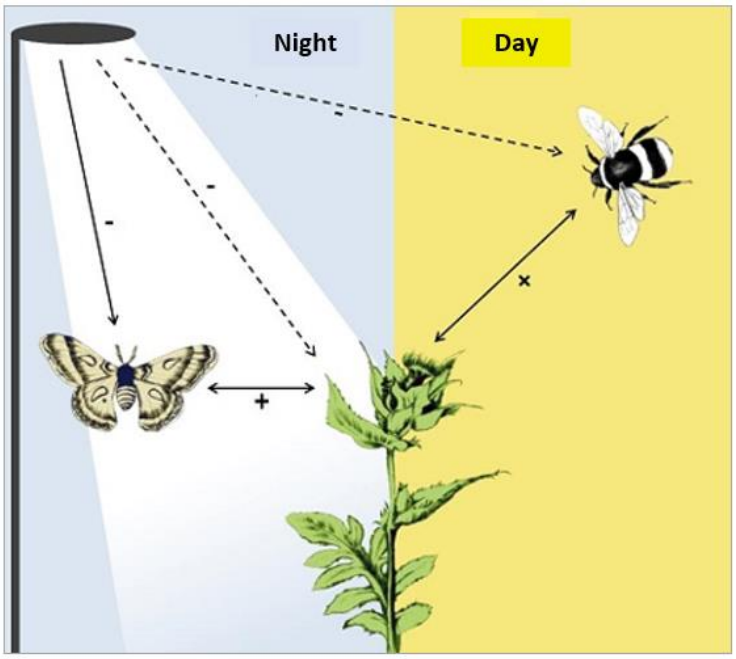

Figure 5: Indirect impacts of artificial light at night on plant communities and pollinators [22]

Figure 5 shows the cascading action of artificial light at night on plant communities and pollinators, where solid lines indicate direct or immediate effects, while dashed lines indicate indirect effects. The direct negative impact of light pollution on nocturnal pollinator communities is transmitted to plants, reducing their reproductive success, which has consequences for day pollinators, as it reduces the amount of available food resources.

2.1.2 Impact of light pollution on wild animals

The fundamental importance of light on animals is primarily reflected in its role in encouraging daily and seasonal activities such as feeding, food storage, reproduction, nesting and migration. In the case of excessive light in the environment, animals have a biological rhythm disorder that regulates wakefulness, sleep and metabolic activity through hormones, as well as circadian rhythm disorders that control physiological processes and patterns of behavior through which animals adjust their biological daily rhythm to daily variations, i.e. 24-hour variations in the environment.

Numerous results of research conducted so far on the harmful effects of light pollution on the living world have shown that these effects have a very wide range, both in their form and in the number of taxa including plants [23], insects [24], amphibians [25], birds [26] and mammals [27,28]. Although light pollution affects both nocturnal and daily animals, it has been found to pose a greater threat to animals that are active at night. According to the International Dark Sky Association, the animals most affected by light pollution are sea turtles, bats, Atlantic salmon, zooplankton, certain species of butterflies, owls, mice, etc. [29].

Given the fact that all bats are nocturnal animals, as well as about 90% amphibians, about 60% mammals and invertebrates and about 30% primates [30], it is evident that these animals have serious problems during light nights and ultimately their survival depends on taking the necessary measures to prevent light pollution in the environment. Some of the examples that will be mentioned here can serve as different effects of light pollution on different animals.

2.1.2.1 Insects

According to a 2017 study by German scientists [31], Europe has lost almost 80% of 'its' insects in less than 30 years, causing a domino effect and the disappearance of more than 400 million birds. It is important to note that in addition to birds, hedgehogs, lizards, fish, amphibians also depend on insects as a food source, and the possible domino effect should be investigated in relation to these species. It is important to point out here that this decrease in the populations of certain insects, among which the most endangered species are butterflies (lat. Lepidoptera), bees, wasps, ants, hornets (lat. Hymenoptera) and beetles (ladybirds, fireflies), is caused not only by excessive deforestation, using pesticides, mineral fertilizers and urbanization that brings lighting and participates in light pollution. In addition to the most well-known causes of harmful effects on insect life, light pollution is not given due attention, especially if we take into account that about 60% of all insect species are classified as nocturnal (nocturnal) and a third of them die from harmful effects of artificial light [32]. Possible harmful effects of light pollution on insects are numerous and can be classified according to the changes they cause in terms of physiological processes and patterns of behavior to those that cause: a) eating disorders, b) communication and reproduction disorders, c) temporal and spatial disorientation, d) increased attractiveness to light sources leading to danger, etc. [33,22-24].

2.1.2.2 Aquatic organisms

Natural light and its intensity are associated with the life of many aquatic species and the entire structure of aquatic environments. Thus, at night, the only natural light that spreads underwater comes from natural sources, and these are the stars, the Moon, and the light of aquatic organisms that glow in the dark (bioluminescence). Therefore, any, even the slightest light pollution, changes the intensity, color´s and frequencies to which aquatic organisms may be exposed, and this can influence the behavior of aquatic organisms by changing their natural circadian cycle [34]. Light pollution of water systems is due to the fact that today more than half of the world's population lives within 100 km from the sea shores, lakes or rivers, and half in their immediate vicinity. This indicates that this proximity is the cause of exposure of water systems to artificial light emitted from urban areas, hotel settlements, recreation centers, industrial plants, roads and the like.

An example of the harmful effects of light pollution on aquatic organisms is the change in zooplankton behavior. Namely, like many other aquatic invertebrates, zooplankton move vertically in the water column, and with this vertical migration at night, in order to avoid their fish predators, it feeds on surface by phytoplankton. However, in the conditions of present light pollution, the illumination of its migration path lasts both night and day, and therefore the number of migrating zooplankton and the amplitude of vertical migration decreases. This not only causes a decrease in the zooplankton population, but also leads to an increase in the phytoplankton population on the water surface. In the long run, these changes could have consequences for the balance of aquatic ecosystems and, due to changes in the prey / predator ratio, affect the food chain and water quality [34,35].

The way in which artificial light or light pollution can adversely affect fish can serve as a series of examples of research about harmful effects of Atlantic salmon (lat. *Salmo salar* L.), which is a conserved and economically important species and its ecology and behavior have been studied for a long time. Thus, recent research has shown that salmon exhibit behavioral changes in response to artificial light, although the physiological processes behind the observed behavioral changes have not yet been fully established [36].

It is known that in natural light salmon migration correlates with sunset, but in the presence of artificial light, e. g. from street lighting, their migration becomes accidental which can jeopardize its chance of survival. In addition, it has been found that in rivers where salmon spawn, artificial light at night can be detrimental to younger salmon as it becomes more exposed to predators.

Of course, there is evidence that some species other than salmon have experienced the harmful effects of light pollution, such as trout fish and sea trout fish, barbell fish, grayling fish, eel, etc. [37].

2.1.2.3 Amphibians and reptiles

Because of the detrimental effects of artificial light, many amphibians have shown both physical and behavioral disorders, including a disruption of their ability to know when to return home and reproduce that calls into question their reproduction.

Since most amphibian species are nocturnal and water-dependent, it has been found that light pollution causes orientation disorders and they may have difficulty migrating during the mating and breeding stages, which may result in reproductive difficulties. It has been noted that it is for this reason that populations of many amphibian species face declining numbers, although the harmful effects of light pollution occur in other areas of their lives and artificial light is a major problem [37].

Most salamanders, for example, which are also nocturnal animals and have about three hundred species that live exclusively in humid environments on all continents except Antarctica and Australia, are not phototactic animals and run away from light. Artificial night lighting near their habitat can affect their physiology and behavior, although the results of research to date have not been sufficient to explain whether and what the possible impact of artificial light is on their population.

Among reptiles, and in the animal world in general, sea turtles are one of the most dramatic examples of how artificial light on beaches can disrupt their behavior. Namely, females of many species of sea turtles return to the same beaches for decades and lay their eggs in the sand, where they were born. Since these beaches are brightly lit at night today, it happens that the light bothers the females and they stop nesting on them and look for a new habitat. If females lay eggs on these beaches, it happens that young turtles that lay during the night due to the reduced danger of predators, instinctively move towards the sea following the reflection of the moon on its surface, and very often, disoriented by artificial light sources, instead of the sea, move towards the coast where they perish on roads etc. [33,37,38].

2.1.2.4 Birds

Birds, like insects, play a very important role in their ecosystems and are vital for agricultural production as well as for the movement of nutrients in natural systems. Unfortunately, birds are not spared the harmful effects of light pollution, especially those that migrate and hunt at night with the help of moonlight and starlight, because artificial lights can disorient them and divert them towards dangerous urban brightly lit "traps". Namely, when the bird is attracted by the artificial light of urban areas and once in the city, there is a big problem of navigating the space, and the glass facades of skyscrapers and bright lighting of buildings are often fatal traps. Such stray birds are usually not able to leave the city during the day, nor can they recognize the dangerous glass surface on which they see attractive reflections of trees or indoor ornamental plants behind the glass. Their rapid flight towards these reflections, or plants on the other side of the glass, usually leads to severe injury or death. Experts estimate that about 100 million birds die each year in the

United States alone due to collisions with glass facades of buildings, and some studies indicate that glass surfaces are more dangerous to birds than any other human activity [39].

One of the most vulnerable groups facing the threat of global extinction are birds because about 40% of their 11,000 species are declining, and some of the reasons for this decline are related to light pollution affecting bird disease transmission, ability to move during migration, numerous fatal collisions with buildings in urban centers, lighthouses at sea, wind turbines, etc. [30,39,40].

2.1.2.5 Mammals

In the world of wildlife, where many species are exposed to light pollution and experience its harmful effects on a daily basis, mammals are not immune, so bats, raccoons, coyotes, deer, elks, etc., have long since begun to show changes in behavior when it comes to their nutrition, due to the harmful effects of excessive lighting. Visual impairment of certain species due to the harmful effects of artificial light leads to an increased risk of their exposure to natural predators and increased mortality within the population.

The harmful effects of light pollution on the behavior of mammals in the wild are also reflected in the increased risk of predators, which directly affects the reduction of certain populations. Behavioral changes in animals can also affect changes in their nutrition and have effects not only on individual species but also on entire ecological communities. For example, if a predator has a long time to hunt due to the presence of artificial light, then it is given the opportunity to expand the number of species of its prey. At the same time, for a species that has become a “new” prey to a particular predator for these reasons, the risk of its survival increases and the population in that habitat decreases.

Bats make up almost a quarter of the world's mammals, with more than 1,300 species, and are a very important group of mammals that are adversely affected by light pollution. This is supported by the fact that they are a very important link in the natural regeneration of tropical forests, pollination of a number of plants that bloom at night and control the number of active insects at night. In addition to all this, it is important to note that bats are one of the slowest-breeding mammals because they have only one young per year, and the infant mortality rate is more than 50%, so the populations of some species are very difficult to recover. Although bats live extremely long (up to 30 years), they are one of the most endangered species due to the influence of various environmental factors, including light pollution [41].

The results of a recent study [42] challenged the popular myth that bats are attracted to light, and it has been found that bat activity decreases in areas that are illuminated at night.

This is in contrast to previous assumptions that bats are helped by public lighting because it allows them to feed more easily on insects that accumulate around lighting fixtures. Light pollution interferes with their orientation in space, and bothers them when hunting insects, so often in urban areas, you can see bats flying around lighting fixtures with swarms of insects, but they, unfortunately, then do not have a feast, but in fact fight, to catch anything.

This can, of course, cause malnutrition in bats, which in turn often leads to negative effects on the speed of reproduction of this species [43].

Migratory bats, which cover great distances between their summer and winter habitats, attract many and varied light installations during migration, which causes them to deviate from the usual routes, and at the same time causes the body to weaken due to loss of excess energy.

Unfortunately, there are a number of examples that could illustrate the different forms of harmful effects of light pollution on other species from the group of mammals (wolves, lions, bears, coyotes, possums, raccoons…), but the most common harmful effects for all of them are declining reproduction, difficulties in finding food due to too much light, increased exposure to predators, all together leading to population decline and even biodiversity.

These few examples of the harmful effects of excessive and unnecessary use of artificial light at night are enough to point out the seriousness of artificial light as an environmental burden with harmful effects on the biorhythm of living organisms, especially those with increased nocturnal activity. In order to prevent the harmful effects of artificial light on living organisms, scientists have expanded the field of scotobiological research, so now scotobiology is no longer a biological branch focused on the benefits of darkness for the living world, but also deals with harmful effects of artificial light at night on plant and animal physiology, biochemistry and behavior, including humans [44].

2.1.3 The impact of light pollution on man

Humans, like plants and animals, are susceptible to the harmful effects of light pollution given that in modern society a very large number of people are exposed to artificial light sources during the night, and night activities and night shifts have become a way of life for modern society. Thus, and due to the growing consumer demands of society for the availability of goods and services during 24 hours, the number of hours that the average person spends under artificial light is increasing every day. Due to man's excessive exposure to artificial light, his natural biological cycles are disrupted, which were established during evolution in the conditions of the natural change of day and night. This is also the reason why the natural rhythm of biological cycles in the human body is very slow and very difficult to adapt to changes in the usual distribution of light and changes in day and night. Namely, biological rhythms are time cycles within which many normal functions of the human body take place, including periods of sleep and activity, then behavior and most physiological and endocrine processes, Figure 6. These daily or 24hour rhythms within the body, similar to those described in plants and animals, controls the main so-called a circadian clock located in the area of the hypothalamus in the brain and adjusts its work according to the natural change of day and night, i.e. light and darkness [45].

Circadian rhythm in the human body includes all physiological and psychological changes, and changes in individual behavior, related to the change of day and night, i.e. during one whole day and lasts about 24 hours. This rhythm is regulated by the internal biological clock, which determines the basic physiological activities - feeding and sleeping

pattern, body temperature, blood pressure, heart rate, brain wave activity, hormone and urine production, hormone secretion, blood sugar levels, regeneration of our cells, etc.

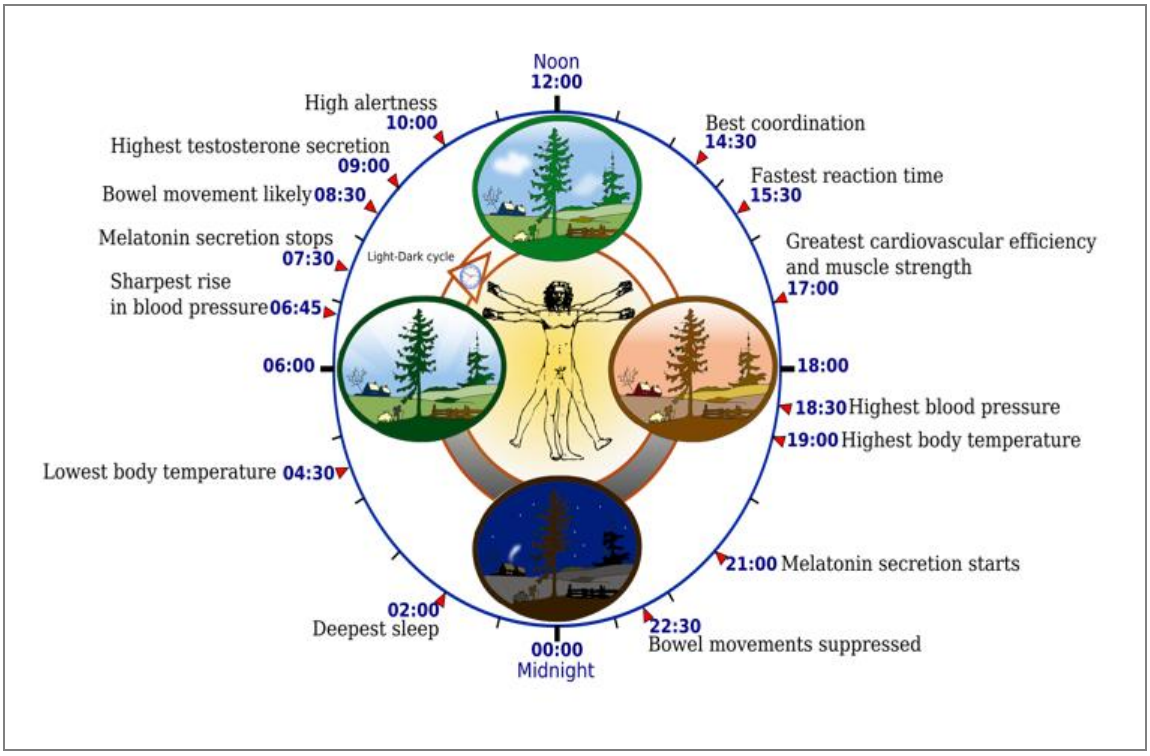

Figure 6: Circadian cycle scheme in man [46]

Thus, for example, a person who wakes up around 7 am has the best wakefulness around 10 am, his reaction time is the shortest around 3 pm, the highest cardiovascular efficiency and physical fitness is at its peak around 5 pm, and the highest blood pressure and body temperature are around 7 pm. After that, the preparation of the organism for sleep begins at around 9 pm, because then the secretion of the hormone melatonin begins, and at around 2 am after midnight the organism is in the deepest sleep. As early as around 4.30 am, the body has the lowest body temperature, and around 7 am it starts waking up and after that the secretion of melatonin stops. All these times are approximate and vary from individual to individual and are valid in the case when the organism is not exposed to light pollution, or when the circadian rhythm is not disturbed by the action of artificial light. Although the circadian rhythm varies from individual to individual, in humans it cannot be shorter than 23.5 or longer than 24.6 hours without detrimental effect on health.

The results of numerous studies [11-15] indicated a large number of potentially harmful effects of short-term and/or long-term exposure to artificial light during the night, ranging from traditional industrial, municipal and domestic sources to exposure via TV screens, personal computers, mobile phones and the like devices, without which modern man cannot imagine everyday life. All of these sources, some less, some more, cause circadian rhythm disorders, which are associated with sleep disorders such as insomnia and late sleep

syndrome, as well as depression, hypertension, attention deficit disorder, obesity, diabetes and cardiovascular disease.

Another important biological function that is disrupted by the presence of artificial light at night is the production of melatonin since melatonin is a powerful antioxidant and anticarcinogen and is responsible for regulating metabolism and the immune response. This is evidenced by the results of research [47] on the impact of exposure to artificial light at night as a possible etiological factor in the development of human cancer, since darkness during the night stimulates the secretion of this hormone, while daylight as artificial, slows its secretion. As melatonin is involved in many processes (sleep control, circadian rhythm, retinal physiology, cancer development and growth, immune system, removal of free radicals, etc.), its secretion disorder can result in a weakened immune system associated with increased incidence of cancer (breast, prostate, colon…) and other diseases and other physical and mental disorders [44,47].

The *International Agency for Research on Cancer (IARC)* at the *World Health Organization (WHO)* in its last published monograph in 2019, as well as earlier in 2007, published results [43] according to which it classified night work as a carcinogen in group 2A - *probably a carcinogen for humans* based on limited evidence of cancer in humans, sufficient evidence of cancer in experimental animals.

This is particularly important for people working in night-time activities, such as the health, industrial, transport, trade and services sectors, where approximately one of 5 workers worldwide is engaged in the night shift [48]. In these activities, it is necessary to implement measures that would reduce night work to the minimum, as well as to conduct regular medical examinations of all employees in shift work, i.e. those who work at night. It is known, according to the *World Health Organization,* that 30-50% of all cancer cases can be prevented [49], so prevention offers the most cost-effective long-term cancer control strategy. The most important thing is to provide conditions for the implementation of national policies and programs to raise awareness, reduce exposure to cancer risk factors, including artificial light at night, and provide people with available information and support they need to adopt healthy lifestyles.

3. CONCLUSION

Although artificial light was recognized as an environmental factor in the late 1950s, it was not until the beginning of this century, when multiple negative effects of artificial lighting on the environment, wildlife, human health and social well-being were identified, that the effects of light pollution were systematically studied. In the past period, many harmful effects of light pollution have been identified, which can be biological, energy, economic, social and even aesthetic in nature.

This paper attempts to briefly present the possible harmful effects of light pollution on the living world of the environment, with special emphasis on the harmful effects on human health. In addition to the basic concepts of light pollution, examples of scientific evidence of the negative and harmful effects of light pollution and the resulting disturbance of the natural

cycle day/night on flora and fauna are presented. Although artificial light at night has become one of the most significant changes in the human environment, many harmful effects of this environmental factor on the growth and survival of organisms in conditions changed by artificial light at night, and thus resulting in the changes in the interaction of organisms with other species, either directly or indirectly, as well as changes in the physiology of individual plant and animal species, were not fully explained.

Since light pollution alters the natural metabolism of the circadian clock day and night in plants, insects and animals, humans are not spared its harmful effects on health. This is of course confirmed by scientific research and there is evidence of deteriorating human health at both epidemiological and physiological levels, which is associated with exposure to artificial light at night, which includes insomnia, sleep disorders, mood swings, early diabetes, obesity and even increased risk of some cancers.

Based on the above, it is possible to conclude that it is necessary to take measures as soon as possible and provide conditions for the implementation of these measures through national policies and programs, to raise awareness of the importance and dangers of artificial light and light pollution and to ensure the information and support for people who need to adopt healthy lifestyles without consequences for the environment and their own health.

Measures to protect against light pollution should include protection against unnecessary and harmful light emissions into space, in order to protect components and the living world of the environment and improve the life quality of present and future generations. It is necessary to take into account that no measure should be in conflict with the regulations in the field of occupational safety and health, especially for people working in activities where night work is common.

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