Analysis of Impacts of Artificial Light on Biodiversity –

Determination of indicators for impairments and recommendations for actions to avoid negative effects in the context of impacts

Federal Agency for Nature Conservation – Germany (2019)

Background

The results and recommendations outlined below are based on an analysis of existing literature on the impacts of artificial lighting and on a research and development project, both conducted by the Federal Agency for Nature Conservation (BfN). Research was conducted in an experimental plot in northeast Germany. The aim was to understand impacts caused by artificial lighting and quantify potential changes in affected ecosystems of aquatic and wetland habitats. This included changes caused by artificial lighting on the behavior of arthropods, flying insects, fish, birds, mammals, and amphibians.

Recommended Actions

Analysis of existing literature and research shows that additional regulatory measures on light pollution are urgently needed. Evidence presented in this study highlights the negative impacts of artificial light on terrestrial and aquatic ecosystems and their functions.

Evidence of population-threatening effects from artificial light exposure is difficult to obtain, and research on the relevance of the impacts on species' livelihoods and habitat is time-consuming and costly. Therefore, it is not the impact of light exposure on flora and fauna that should be used as the basis for assessment, but rather the quality and quantity of light emissions produced by the activity.

A critical concern is the potential for a *rebound effect* [1] as more efficient, though brighter, luminaires such as LED lightings are increasingly used. The *rebound effect* describes a process where increased efficiency in lighting products results in a higher overall demand for artificial lighting products, diminishing potential energy savings. In the case of artificial light impacts the increased uptake of energy efficient luminaries, which tend to be brighter than traditional luminaires, has lead to a further loss on natural nightscapes. Such effects can already be observed, as the illumination of surfaces is increasing globally despite the availability of modern, lower light-emitting LED technology.

Light emissions should especially be avoided in protected areas and special conservation areas and buffer zones, with strict lighting regulations, should be established around those areas. One study demonstrated that, even in a national park, 70% of mapped streets and roads caused unnecessary light emissions due to a lack of light-shielding. Not only streets and roads cause unnecessary light impacts on wildlife and ecosystems, but residential and industrial areas have the same effect: poorly installed or over-lit lighting systems increase the range of

[1] Rebound effect or "boomerang" effect: Despite an energy saving reached (e.g. by a new technology) the demand for energy increases (e.g. due to cheaper prizes of the new technology).

light emissions resulting in human made sky glow. Sky glow describes a bright night sky due to light pollution. Moreover, professional and environmentally friendly planning of lightning systems can both save resources and have a positive effect on climate.

There are four specific measures and technical solutions for less environmentally impactful lighting:

1. *Regulate the illumination level according to demand*

In general, the illumination level should be reduced to a necessary level for energy-saving reasons. A requirement profile for lighting installations should be drawn up, justifying the need and the lighting intensity required by the situation. Before increasing the illumination level, alternative designs - such as reflectors or colour differences in the infrastructure - should be considered first. Establishing a communal or regional lighting concept to reduce the large-scale illumination level is recommended.

Maximum luminance for illuminated or self-luminous surfaces of 1 to 2 cd/m² are recommended nighttime thresholds for areas that require special protection. In urban areas, maximum luminance should be between 50 and 100 cd/m².

The demand for street lighting must be justified and based on actual traffic volumes over time. The monitoring of the actual traffic volume must be carried out in time-limited periods during the night and must not use daytime data, which have no importance for nocturnal light pollution. This means that the lighting intensity according to demand must correspond with the nighttime infrastructure use over time, being set for example from sunset to 10 pm and from 10 pm until midnight and from midnight until 5 am. Measures to reduce traffic intensity (e.g., lowering the speed limit), should precede increases in street lighting, especially near ecologically sensitive areas (such as near water bodies or nature reserves).

2. *Adjust light colours to the environment*

Proper lighting in traffic is necessary for the safe perception of traffic signals and the colour coding of traffic signs. LED color temperatures below 1,800 Kelvin only allow limited colour recognition by the human eye. The accuracy of colour recognition increases with increasing colour temperature and above 3,000 Kelvin is nearly at 100%. Therefore, a colour temperature of 3,000 Kelvin is recommended for street lighting.

If there is no need for colour recognition (e.g., to detect colour differences on traffic signs) lower colour temperatures should be used. For lighting installations in protected areas and conservation areas, blue light components should be kept at a minimum, and light sources with a colour temperature below 2,000 Kelvin are recommended (e.g., low-pressure sodium vapour luminaires or PC Amber LED). A relatively high blue light component might be compensated by a low illumination level and by a narrow light beam angle.

Ultraviolet and infrared lighting is not visible for human perception, but can be perceived by insects, birds, reptiles and certain mammal species and can even strongly attract them. Ultraviolet and infrared lighting should be avoided completely since the potential danger for wildlife is greater than the potential benefits from using this type of light.

3. Optimise radiation geometry

Radiation geometry refers to the spatial distribution of light from a light source, which is defined and calculated using luminous intensity distribution curves.

For traffic areas, it is recommended to use fully shielded luminaires, which when installed only emit light below the horizontal (upwards light output ratio = 0 %). They cause as little glare as possible and are the most sustainable form of street lighting.

However, current criteria for glare protection are not yet sufficient for the protection of flying insects, since prescribed restrictions do not cover light emissions at the flight height of insects, which is between 1.7 m and 5.4 m. Therefore, for sustainable species protection, luminaires should be used that have reduced radiation within this flight height. In the case of façade illumination for example of historic buildings, the protection of endangered species must take priority and roosts (e.g. of bats) in walls and ruins must be protected from artificial lighting.

4. Improve research

Research on nightscape changes from anthropogenic light and its impacts on wildlife and biodiversity is very important and should have the same relevance as research on changes in temperature conditions due to climate change. It is strongly recommended that more attention should be dedicated to research on the effects of artificial light at night on flora and fauna. This elevated urgency is due to rapidly increasing levels[2] of illumination of night landscapes globally, contributed to in large part by urban and industrial areas.

There is a lack of legal frameworks in Germany for street lighting and the scientific data necessary for developing useful frameworks is missing. However, a German norm exists (DIN EN13201) exists and compliance with it is recommended. Nevertheless, there is a lack of scientific-empirical data to justify the recommended illuminance levels and the uniformity for the minimum requirements of the European standard. Therefore, more research is needed.

It would be relevant to investigate when differences in brightness are perceived by the human eye. Additionally, it would also be of interest at what illumination level the human eye can best perceive hazards points at different speed levels and in different surroundings. There is an urgent need for a clearer understanding of human vision under artificial light. Particularly since the quantity of artificial light emission is rapidly increasing and is changing in quality due to modern lighting technologies and growing infrastructure networks.

Interdisciplinary considerations are essential for both assessing the minimum requirements of outdoor lighting installations and limiting light emissions in sensitive areas. Biological and ecological aspects should be considered alongside lighting design and lighting technology.

[2] Global light pollution has increased by at least 49% over 25 years, new research shows. This figure only includes light visible via satellites, and scientists estimate the true increase may be significantly higher -- up to 270% globally, and 400% in some regions. (https://www.sciencedaily.com/releases/2021/09/210914111302.htm

Summary

Light is an essential energy and information carrier for most organisms. Plants, for example, use light for photosynthesis and light decisively determines the day-and-night cycle of many organisms. The result is that almost all life processes on Earth are coordinated with each other through temporal clocking. Therefore, natural rhythms and night landscapes must be protected as much as possible from the impacts of artificial lighting.

Until now, research and protection of nature and landscape have primarily focused on the daytime. However, there is growing evidence that artificial lighting has detrimental long-term effects on nocturnal landscapes. Artificial lighting, scattered light and light reflections can directly affect breeding sites, resting sites and other light-sensitive habitats.

During the experiment (described at the beginning of this document), several artificial lighting impacts on flora and fauna were recorded:

- It was noted that the composition of initial plant growth in water bodies can be affected by artificial lighting. These changes were probably caused by the high number of blue light components of LED lighting.
- Using specific flight traps, a high attraction of flying insects to illumination was reported. Insects active during dawn and nighttime were attracted to the luminairesover a radius of more than 20 meters. At the same time, other species like common toads (Bufo bufo) or hedgehogs (Erinaceus europaeus)in general avoided the illuminated habitats. The fact that some organisms avoid illumination and others are attracted to it could affect predator-prey relationships.
- Far more aquatic insects, such as caddisflies, dayflies, and midges, were counted in the flight traps of illuminated fields than in the traps of unilluminated fields. However, predators, such as spiders, preferred terrestrial insects as a food source more than aquatic insects. These changes in ecosystem dynamics suggest a lighting-induced oversupply of food. Slugs also seemed to prefer illuminated areas.
- Looking at bird species, starlings favoured artificially lit habitats as nesting sites, but there appeared to be no evident reproductive benefits from lighting.
- Steroid suppression was detected in fish. This means, that in these fish species (roaches and perches) the hormone balance - and thus the ability of successful reproduction - could be suppressed by street lighting.

Other studies conducted have shown the impacts on animals, including migratory species:

- Street lighting can prolong the season of the horse-chestnut leaf miner (*Cameraria ohridella*). However, in this case, this is likely due to altered physiological conditions in the leaves of chestnut trees, due to artificial lighting, rather than changes within the parasite.
- It has also been reported that migratory toad species avoid illuminated areas during their migration. When passing through illuminated areas, they seem to tolerate

monochromatic red radiation, but white, blue, and green radiation may cause serious barriers for these species.

- Research conducted on hedgehogs showed they tolerate artificial lighting but generally prefer unilluminated habitats.

The results of the literature review and the project show the urgent need for action to regulate lighting in outdoor spaces in order to protect flora, fauna and habitats from artificial light emissions and to assess more specifically the effects of these emissions on a variety of species.

Impacts on flora, fauna and habitat are highly complex and can also affect the habitat and living conditions of diurnal organisms.

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SCHROER,S. et al. (2019): Analyse der Auswirkungen künstlichen Lichts auf die Biodiversität – Bestimmung von Indikatoren für die Beeinträchtigung und Ableitung von Handlungsempfehlungen zur Vermeidung negativer Effekte im Rahmen von Eingriffen; Schriftenreihe „Naturschutz und Biologische Vielfalt", Band 168, des Bundesamts für Naturschutz, Bonn (ISBN 978-3-7843-4068-5)