



POPULAR SCIENCE ARTICLE

Vanishing Darkness: How Artificial Light at Night is Badly Rewiring the Aquatic Ecosystems

Ehtesham Hussain, Irshad Ahmad and M. Junaid Sidiq*

Department of Aquaculture, Faculty of Fisheries, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, India

*Email: mrjunaidsideq88@gmail.com

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Abstract

Artificial light at night (ALAN) has emerged as a pervasive yet often overlooked environmental stressor in aquatic ecosystems. The rapid expansion of urbanization, coastal development, transportation networks, and waterfront infrastructure has substantially increased nocturnal illumination across freshwater and marine habitats, altering natural light-dark cycles to which fish have evolved over millions of years. This short review synthesizes current knowledge on the physiological, behavioural, and ecological consequences of ALAN exposure in fishes. Exposure to artificial lighting can interfere with endocrine signalling, impair orientation and navigation, migration, modify habitat use, and alter species interactions, with potential consequences extending from individual fitness to ecosystem functioning. Collectively, the available evidence highlights ALAN as an increasingly important anthropogenic pollutant that warrants greater consideration in fisheries management, aquatic conservation, and environmental planning. Future research should focus on species-specific responses, long-term ecological effects, and the development of evidence-based lighting guidelines for aquatic environments.

Keywords: ALAN; light pollution; melatonin; circadian rhythm; fish migration; reproductive ecology; fisheries conservation; aquatic ecosystems

Introduction

Artificial light at night (ALAN) is one of the fastest growing anthropogenic disturbances to animals across all ecosystems, that has come to be recognized as a major 21st century global issue (Davies & Smyth, 2018). The benefit of artificial lighting for humans has led to an increase in the duration, distribution and brightness of light at night, as well as the quality of light emitted as the colour spectrum (Smith, 2009). It is estimated that the extent of the Earth's artificially lit landscape has been increasing by 2.2% each year, with the level of brightening in already-lit areas increasing at this same rate (Kyba *et al.*, 2017). The effects of ALAN extend throughout the biological hierarchy ranging from the physiology of organisms to shifts in ecological communities (Sanders *et al.*, 2021). It is now broadly accepted that ALAN has been reshaping nature for more

than a century without getting noticed. In particular, its potential to impact the diverse range of organisms, processes, and habitats in marine environments, that rely on light cycles, had mostly gone unexamined until recently (Longcore & Rich, 2004; Davies *et al.*, 2014). ALAN has now been recognized as major sensory pollutant of concern due to its apparent and pervasive impact on pathways linked to natural circadian regulations in marine life.

While visible light is the portion of the electromagnetic spectrum that typically ranges from 380 nm (violet) to 700 nm (red), ALAN relatively comprises of a shorter wavelength range between 450 and 600 nm. Animals perceive light information through their eyes or through photoreceptors in the absence of eyes (Stanton *et al.*, 2022). Different wavelengths or colours have different effects on circadian clocks in organisms. For instance, wavelengths around

480 nm (blue light) triggers a photopigment called melanopsin which stops melatonin production. Natural daylight follows a predictable curve, heavily leaning toward blue wavelengths in the morning to promote alertness, while shifting to warmer (red/yellow) wavelengths in the evening. Thus, ALAN affects the circadian rhythm of organisms by altering the natural light pattern (or diurnal variation) to which the organisms are exposed.

Over the past century, humans have substantially altered their surroundings by constantly illuminating them, leading to “*the eradication of darkness*”. Nowadays aquatic environments are illuminated by an array of artificial light sources, ranging from streetlights that line coastal highways and river bridges. Also, the extensive illumination of offshore oil platforms and neon-lit urban harbours create a persistent twilight across these aquatic ecosystems. The phototactic nature of aquatic organisms, such as fish, results in their light-directed swimming and aggregation with varying preferences for different wavelengths (Marchesan *et al.*, 2005).

Nearly all organisms rely on natural fluctuations of light as cues for synchronizing physiological processes and behavioural actions associated with foraging, growth, sleep and rest, reproduction, and migration (Fig. 1) (Bassi *et al.*, 2021). In fish, continuous exposure constitutes not merely a nuisance but is also a significant environmental stressor that modifies behaviour, dysregulates endocrine or hormonal functions, impairs reproductive processes, and jeopardizes survival (Canosa and Bertucci, 2023).

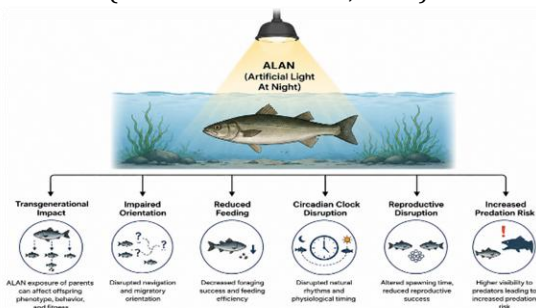


Fig. 1. Effects of ALAN in fishes

In particular, unnatural intense light can alter or delay migration-patterns of aquatic organisms. It can lead to collective behavioural changes, driving entire groups of migrating communities off their migration paths or into light-polluted urban areas, consequently reduces migratory success (Vega *et al.*, 2024; Vowles and Kemp, 2021). Acute ALAN events such as sudden light bursts from vehicles or industrial activities are associated with immediate physiological

stress responses, including rapid escape behaviours, transient spikes in blood cortisol, and disruptions in fish schooling dynamics (Borba *et al.*, 2022).

1. Disruption of the circadian clock

In order to understand the effects of artificial light on fish behaviour and physiological processes, internal mechanisms of fish-ALAN interaction must be taken into consideration. Similar to humans, fish have their own molecular oscillators, called “*circadian clocks*”, that are regulated by the presence of internal and external environmental stimuli referred to as ‘zeitgebers’. Many specific fish behaviors and physiological processes are evolutionarily adapted to the rhythms of natural photoperiods (Tidau *et al.*, 2021).

The primary controller of the circadian clock is the melatonin hormone, often called as “*hormone of darkness*”. Its production is tightly controlled by the suprachiasmatic nucleus (SCN) located in hypothalamus, which relays signals from the retina to the pineal gland in response to light exposure (Wani, 2026). In natural photoperiod conditions, fish pineal gland produces high levels of melatonin at night-time in order to trigger the processes of rest, restoration and metabolism. ALAN, on the contrary, suppresses or disturbs the melatonin synthesis at night and has been found linked to a reduction in fitness of organisms including fish (Fig. 2) (Jones *et al.*, 2015; Grubisic *et al.*, 2019).

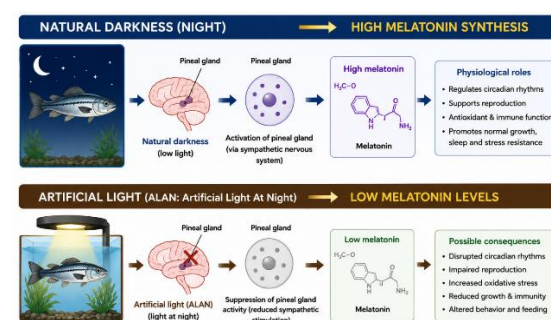


Fig. 2. In fish, melatonin is synthesized in the pineal gland during darkness. ALAN exposure at night suppresses pineal activity and reduces melatonin synthesis. (references: Brüning *et al.*, 2018)

Presence of ALAN makes the fish think that there is natural light all the time. As a result of research conducted with freshwater species like the European perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*), it was discovered that low-intensity ALAN is enough to suppress the production of melatonin in the fishes (Brüning *et al.*, 2018). Without the proper stimulus, the body systems of the fish are continuously disoriented. Their metabolic activity remains

higher than needed during the times that are supposed to be for rest, which in turn results in quick consumption of energy resources.

2. Modified foraging behaviour and predation risk: The illusion of the midnight feast

Chronic exposure to ALAN has been shown to disrupt circadian rhythms and nocturnal behaviours in many fish species, leading to diminished foraging efficiency and increased susceptibility to predation (Grubisic *et al.*, 2019; Nelson *et al.*, 2022). In natural systems, many fish species are efficient visual feeders, which use light for hunting or gathering purposes. In the normal night-time environment, darkness serves as a refuge for smaller and more vulnerable fish, allowing them to rest and move safely in the absence of danger. However, artificial light pollution fundamentally disrupts this evolutionary predator-prey balance since light becomes an artificial source of illumination (Czarnecka *et al.*, 2019).

The "illusion of the midnight feast" describes as ecological phenomenon when ALAN creates an immediate, concentrated amount of food for predatory fish, hiding long-term ecosystem damage (Bassi *et al.*, 2021). Coastal infrastructure, such as illuminated bridges, oil rigs, and piers, creates localized light-hotspots where light pierce the water column. Many small fish and planktonic organisms exhibit positive phototaxis (a movement towards light) and they swim towards the light sources, turning these illuminated zones into dense aggregate prey sites for predators (Hassan *et al.*, 2024; Ślusarczyk *et al.*, 2024). While this constant availability of prey can lead to a highly productive ecosystem but it strips away the dark-refuge that smaller species rely on for survival. Consequently, larger aquatic predators use this effect to increase the number of hours they spend foraging during night-time hours. Over time, the hyper-efficient hunting conditions can cause unsustainable predation pressure on local prey communities. Such overexploitation would eventually lead to local food web imbalances, driving down species richness and ultimately collapsing the prey base on which predators depend on (Tałanda *et al.*, 2022). While predators might initially profit from this approach, it is likely to lead to a depletion of their prey population, leaving them either starved or forced to other prey options, eventually.

The "harbour seal effect" is an example of ecological light pollution where predators exploit anthropogenic lighting to find and catch migrating fish (Longcore & Rich, 2004). This

unusual behavior was first documented in British Columbia's Puntledge River, where city bridges illuminated the water column at night (Yurk & Trites, 2000). Typically, juvenile salmonids (smolts) use the darkness to migrate downstream safely towards the ocean, minimizing their exposure to visual predators. However, artificial bridge lights create a highly distinct light-shadow boundary across the river's surface. Harbor seals (*Phoca vitulina*) quickly learned to take advantage of the illumination by positioning themselves side by side beneath the bridge and waiting downstream for fish. This positioning creates an efficient acoustic and visual barrier that allows seals to easily detect, intercept and capture surface-drifting smolts. Thus, by turning a safe nocturnal route into a well-lit hunting trap, ALAN increases predation rates, severely threatening the survival and recovery of vulnerable salmon populations (Wells, 2025).

3. Disrupted endocrine signalling: Effects on reproductive success and offspring viability

3.1. Interruption of the hormonal cascade

ALAN, that disrupts the day-night cycle, interrupts the brain-pituitary-gonad (BPG) hormone cascade or axis in fishes, leading to reproductive dysfunctions. Under natural conditions, the brain-pituitary-gonad (BPG) axis relies on precise environmental photoperiods to determine the timing of gamete development and spawning (Bassi *et al.*, 2021). ALAN disrupts this axis at its origin by reducing the nighttime synthesis of melatonin, the hormone that signals darkness to endocrine system (Kupprat *et al.*, 2020). Without this clear signal of darkness, the hypothalamus fails to release gonadotropin-releasing hormone (GnRH), which in turn lowers the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the pituitary gland (Bassi *et al.*, 2021). This disruption in hormone production reduces the levels of sex steroids like estradiol and testosterone, which are vital for vitellogenesis and healthy sperm maturation. Consequently, fish that are continuously exposed to artificial light at night may show delayed or failed gonadal development, leading to lower egg quality and reduced spawning success, posing an invisible, yet significant, threat to wild populations for their natural recruitment (Brüning *et al.*, 2018).

3.2. Transgenerational impact

The impact of light pollution is not restricted to only the parental fish. Field experiments conducted in a coral reef environment with an anemonefish (*Amphiprion chrysopterus*) have

indicated a transgenerational impact of light emitting diode (LED) white light (given for 1 month) on the fish. Although, adult anemonefish exposed to LED (18.4 ± 3.5 lux) experienced increased growth rate because of continuous foraging but their eggs exhibit massive developmental deficiencies (Schligler *et al.*, 2021). Similarly, different studies have also demonstrated a transgenerational effect of ALAN on their developing offspring as following:

Offspring metric	Impact of nocturnal LED exposure
Embryo heart rate	Significantly reduced, resulting in decelerated developmental progression (Schligler <i>et al.</i> , 2021).
Yolk sac size	Drastically diminished, thereby limiting early energetic reserves available to larvae (Spitschan <i>et al.</i> , 2024).
Larval escape response	Critically impaired, increasing susceptibility to predation (Schligler <i>et al.</i> , 2021).
Swimming performance	Severely weakened capacity to locate food sources or appropriate habitats

As a result, the surviving larvae have very little chance of survival in the harsh pelagic zone after hatching. This can also lead to the collapse of reef fish populations due to recruitment failures.

4. Roadblocks in aquatic environments: Disruption of fish migrations

Many fishes are known to travel great distances in order to find food or reproduce, covering thousands of kilometres within rivers and seas. Many migratory aquatic species have adopted to travel exclusively under the night to evade visual predators and maximize their survival rates and ALAN is one of those factors that become barrier during their journey (Vowles & Kemp, 2021).

For instance, the European eel (*Anguilla anguilla*) is a fish that makes an amazing journey from freshwaters of continents to the Sargasso Sea where they spawn. The fish demonstrates a high phototaxis sensitivity, preferring night time for migration. When these fish encounter artificial lights from bridges, coastal roads, or urban harbours, the sudden change in the light environment disrupt their spatial orientation and route navigation (Manfrin and Hölker, 2018). Upon reaching an illuminated river boundary, these eels often stop moving forward, turn back, or use extra metabolic energy in search of dark alternative (Vowles & Kemp, 2021). The same is true for juvenile salmon while making their way downstream to reach marine habitats for foraging. The presence of ALAN causes disorientation, causing the smolts to remain in pools under urban bridges where there is light instead of making use of the night currents to make their way to the sea (Vega *et*

al., 2024). Such disruptions not only delay important stages of the fish life cycle, but also concentrates the fish in highly visible zones, exposing them to predation from opportunistic visual predators (Yurk & Trites, 2000).

Conclusion

The growing spread of ALAN is no longer a superficial urban issue. It is a widespread pollutant that has the potential to alter ecological processes and community dynamics. The disruption of the boundary line between day and night by ALAN means disturbed processes such as fish hunting/feeding, migration, and mating and resting patterns. Human induced lighting disrupts the natural boundary between light and darkness. As a result, it causes physiological stress and confusion in fish, altering ancient behaviors like diel vertical migrations and reproductive timing that are essential for the stability of marine and freshwater food webs. These biological changes, ranging from reduced melatonin synthesis to poor offspring fitness and disrupted migratory pathways, translate into large-scale disruptions that degrade overall ecosystem resilience and biodiversity.

Restoring natural darkness to our oceans, rivers, and lakes is of urgent ecological importance. Protecting these photic boundaries ensures the long-term survival, reproductive success, and behavioral freedom of wild fish populations worldwide. Unlike many other environmental problems caused by climate change and human activities that may take decades to recover, light pollution is an environmental stressor that can be reduced quickly through practical and effective measures. By using conservation measures we can drastically reduce light pollution. Although it is not desirable to plunge the whole coast of the city into complete darkness, there are ways to avoid harmful impacts as following:

1. Shielding & directionality: Upgrading external lighting fixtures with the appropriate shielding system allows the light to be directed straight down onto the roadway and sidewalks, and thus eliminates incidence of light laterally to rivers, lakes, and coastlines.
2. Spectral manipulation: Replacing blue short-wavelength LED light sources, which transmit through water and interfere with melatonin production, with the long red or amber wavelength light will greatly reduce biological harm from artificial lighting.
3. Intelligent lighting design: The integration of sensors and timers on coastal boardwalks, bridges, and industrial

buildings will allow the lights to be automatically turned off or dimmed in the absence of human or traffic presence, and thereby restore dark conditions essential for healthy fish populations.

By taking into account the underwater ecosystem into design and architecture, it is possible to recreate the natural balance of light and darkness, ensuring that our waterways, and the species within, stay healthy for years to come.

CONFLICT OF INTEREST STATEMENT

The author declares that there is no conflict of interest.

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