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Effects of Artificial Light on Ecological Processes of Wildlife

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Abstract. Artificial light at night (ALAN) has become a widespread anthropogenic disturbance that changes the natural alternation of light and darkness across human-dominated landscapes. This article mainly shows how artificial nighttime-light influences wildlife from individual organisms to communities and whole ecosystem. The discussion first distinguishes light pollution as an "additive disturbance" that effects sensory and temporal environments rather than removing habitat directly. Then considers behavioral and physiological pathways, which include: altered activity schedules, disrupted circadian rhythms, reduced dark periods, sleep disturbance, and changes in melatonin-related recovery. The analysis considers how these individual responses have connection with predator-prey relationships, insect-mediated pollination, temporal niche partitioning, interspecific competition, and food-web structure. As for responses, it shown to differ among taxonomic groups because species vary in sensory systems, activity patterns, and tolerance to light intensity and spectral composition. This article also identifies some major research needs, include particularly long-term field monitoring and empirical evaluation of mitigation strategies. Overall, artificial nighttime illumination can reorganize ecological processes across multiple biological levels, and reducing unnecessary illumination, controlling intensity and spectrum, and protecting dark spaces are important directions for limiting ecological disruption.

Keywords: Artificial light at night, Wildlife, Circadian rhythms, Species interactions, Ecosystem functioning

1. Introduction

Throughout the whole history, human beings have demonstrated a tendency drive for territorial expansion. Land development and other anthropogenic activities have intensified pressures on natural ecosystems, resulting in diverse ecological disturbances, including water pollution, deforestation, habitat loss, and fragmentation associated with infrastructure development. These activities directly destroy, occupy, and fragment the original habitats of wildlife and reduce available living space, which can be defined as "subtractive disturbance". Such interventions fundamentally damage and deplete the original ecological environment of wild animals.

In contrast to subtractive habitat degradation, artificial light pollution at night represents a typical human-induced "additive disturbance". Rather than directly destroying or reducing existing habitats like last one, this way of pollution imposes additional artificial illumination, which is "plus" on

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natural environments. By altering diel rhythmicity and sensory conditions, artificial light fundamentally resets the living environments of wildlife, especially to nocturnal animals.

This essential distinction enables artificial light pollution to serve as a more precise indicator of exclusive human ecological impacts. Habitat loss, vegetation disturbance, and landscape disruption may arise from both anthropogenic activities and natural events. Earthquakes, flash floods, and wildfires, that environmental disaster making it difficult to attribute such changes solely to human activity. By contrast, ecologically relevant artificial illumination at night is directly associated with human infrastructure and activit. As a purely human-derived ecological stressor, artificial light provides a direct and accurate reflection of human-specific influence to wildlife ecosystems.

While rapid urbanization, artificial light at night(ALAN) has increased continuously in not only spatial scope, but also light intensity over recent decades, creating widespread nocturnal light pollution across continents [1]. Unlike many other pollutants, ALAN primarily acts as a sensory disorder rather than a toxic pollutant. It covers natural light-dark cycles by the Earth rotation, disrupting the reliable environmental stimuli that majority of wildlife rely on to coordinate circadian and seasonal biological rhythms. Although intuitive nocturnal species are thought to be most affected, a growing body of evidence suggests that diurnal animals can also be affected by night-time illumination, with changes in behavior, physiology and reproductive timing recorded in vertebrate and invertebrate taxa [2].

Animals' basic characteristics, including activity, foraging, mating and migration, are controlled by natural light–dark cycles. ALAN cause the shortens of natural darkness and destroys biological rhythms from the environmental timing cues with which they co-evolved. For example, streetlights attract nocturnal insects, impacting their movement and reproduction, birds begin dawn songs and reproduction earlier, and small mammals reduce their nocturnal activity when conditions are lit [3]. These contrasting responses show that not all taxa respond to ALAN in the same way; rather, its ecological consequences depend on species-specific sensory systems, temporal niches, and behavioural strategies. The effects of artificial night lighting extend beyond individual physiology and behavior to interactions among species. When light changes visual detectability or the timing of activity, it can reshape predator–prey interactions, pollination mutualisms, and competition among co-occurring species. These species interaction changes then cascade through food webs and ultimately affect ecosystem functions such as nutrient cycling and primary [4].

Light pollution was once mainly an issue for astronomers. Over the past two decades, it has come to be recognized as a global threat to biodiversity. Researchers have documented how ALAN alters animal activity rhythms, reshapes species interactions, and disrupts ecosystem functions. However, many reviews still concentrate on individual taxonomic groups or isolated behavioral responses. We still lack a clear mechanistic account of how individual behavioural and physiological responses translate into community- and ecosystem-level consequences. A synthesis that connects organism-level responses to population, community, and ecosystem-level outcomes would help address this gap. This article integrates the main effects of artificial nighttime illumination on wild organisms and the ecological mechanisms involved. It traces the key pathways and contrasts responses among taxonomic groups. It also identifies gaps in current research and discusses what these patterns mean for reducing light pollution in human-altered landscapes.

2. Behavioral and physiological disruption

Natural light and dark alternate in one of the most stable environmental rhythms on Earth. Over evolutionary time, this cycle has shaped how animals behave and how their bodies function. It tells many wildlife species when to be active, when to rest, and how to organize the basic rhythms on

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which survival depends. Because light–dark cycles create stable diel boundaries, organisms can time foraging, predator avoidance, mating, and other essential activities, which in turn helps maintain individual metabolism and population stability. Urban artificial lighting has steadily reduced natural darkness, however. Artificial light at night (ALAN) disrupts the balance of diel illumination and uncouples animal circadian rhythms from natural environmental periodicity. The effects on behavior and physiology are lasting, visible in altered activity schedules, resting patterns, and diel activity boundaries [3, 5].

One of the clearest ecological effects of ALAN is on activity schedules. Nocturnal species tend to forage, migrate, and reproduce during dark periods, whereas diurnal animals are active in daylight, which produces relatively stable daily routines. Artificial illumination interferes with this division by distorting the photoperiod cues animals use to tell day from night. Nocturnal insects provide a well-studied example: streetlights and landscape lamps attract many moths and other flying insects, pulling them away from their usual midnight activity and changing both the distance and duration of their movement, with knock-on effects on locomotion and reproduction [3]. Mammals respond differently. Instead of being attracted, small mammals often reduce or shift their nocturnal activity under bright conditions, narrowing the temporal window they evolved to use. This contrast between attraction in insects and avoidance in mammals is one reason why ALAN cannot be treated as a single selective pressure.

Sleep and physiological recovery are affected in a less visible way. Circadian rhythms govern metabolism, hormone secretion, and physical repair, and many animals need complete darkness to rest effectively. Night lighting interferes with this need. It prevents organisms from registering darkness and suppresses melatonin secretion, so sleep becomes fragmented, rest periods shorten, and behavioral rhythms lose regularity. If this occurs night after night, animals may fail to complete normal physiological recovery. The likely knock-on effects include weakened immunity, impaired growth and development, and reduced survival and reproductive potential. How pronounced these effects are probably depends on the species, its life stage, and the intensity and spectral composition of the light source. This variation is important because it means that fitness and population-level impacts cannot be inferred directly from behavioral disruption alone [6].

Finally, artificial night lighting also redraws the temporal boundaries of animal activity and weakens the stable spatiotemporal patterns that long-term natural adaptation has produced. Natural light and dark separate species into distinct temporal niches and create a stable chronological structure in which diurnal and nocturnal activities are coordinated. ALAN removes the sharp contrast between day and night light intensity and blurs species-specific diel activity boundaries. These changes go beyond individual rhythmic disorders: they disrupt the spatiotemporal matching of interspecific interactions. Such rhythmic alterations extend to trophic relationships, interspecific competition, and other ecological processes, reshape food web structures, and ultimately modify nutrient cycling, primary productivity, and other core ecosystem functions, leading to systematic changes in how ecosystems operate [4].

3. Species interactions and community processes

Artificial light at nite (ALAN) not only disrupts the circadian rhythms of individual animals but also acts as a critically important additive ecological disturbance that re-organizes interspecific relationships and re-shapes community structures. Natural light-dark periodicity creates stable temporal niches for a variety of species, balancing predator-prey dynamics, species competition and mutualistic interactions, maintaining intact food webs and ecosystem stability. ALAN disrupts the coevolutionary coordination of co-occurring species by disrupting natural visual and temporal cues

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in the environment. The impacts on interspecific interactions are primarily addressed in three core aspects: the rewritten predator–prey relationships, the cascading food web disturbances triggered by insect phototaxis, and the restructured temporal niche partitioning among sympatric species, with multi-level ecological consequences propagating across biological communities [4, 7].

ALAN fundamentally modifies predator–prey interactions by changing visual detectability and activity patterns of species for nocturnal animals. In the natural darkness, nocturnal ecosystems are a balance of predator foraging and prey avoidance. Darkness provides a fundamental refuge for small mammals, insects and other prey species to escape predation, and predators rely on low-light sensory cues to hunt. However, the ubiquitous artificial nite illumination removes the natural night-time light restriction and thus considerably enhances the foraging efficacy of visual-dependent predators. Prey species, in contrast, lose their dark shelter and become more exposed and vulnerable to predation pressure.Such an asymmetric, light-dependent advantage upsets the long-term evolutionary balance of trophic interactions. Most prey species respond to luminous environments by constricting their nocturnal activity windows or switching to shaded microhabitats, which decreases their foraging opportunities and energy intake. The ongoing imbalance in predator–prey relationships alter the population abundance of different trophic groups, destabilizing original community structures and causing cascading ecological fluctuations [4].

Insect phototaxis driven by ALAN is a major driver of food web degradation with wide-ranging ecological consequences. Most insects that are active at nite have an innate positive phototaxis and are therefore extremely sensitive to urban artificial light sources such as streetlights and landscape lamps. Bright nite lights attract large numbers of flying insects, heavily disrupting their normal foraging, mating and migration behaviors and significantly increasing non-predatory mortality [3]. The drastic decline and behavioral disorder of nocturnal insects leads to bottom-up trophic cascades. Severe food shortages for insectivorous birds, bats and small mammals due to reduced insect biomass Changes in insect activity and abundance also interfere with mutualisms between insects and plants involving pollination, hindering plant reproduction and growth. This sequence of changes reduces the connectivity of terrestrial food webs, diminishes the biodiversity, and erodes the basic material cycle basis of ecosystems [8].

Moreover, ALAN modifies temporal niche patterns of coexisting species, enhancing interspecific competition and disrupting coordination of communities. Different species have different light tolerance and circadian plasticity. The behavioral responses to the same light pollution are different. Species tolerant of light extend their activity into the nite, whereas light-sensitive species are restricted to very narrow ranges during the day. Such differential responses broke the temporal niche partitioning established under natural diel cycles, which originally segregates the activity time of diurnal and nocturnal species to balance the uncontrollable competition of resources. The artificial overlap of species activity time increased the interspecific competition for food, space and other limited resources. Besides, dislocation of species activity time disrupted the synchronicity of ecological processes (e.g. pollination and resource distributions). Persistent niche variations reshaped the species coexistence pattern, decreased community stability and resilience, and led to systematic loss of ecological functions in the end [4, 9].

4. Research gaps and mitigation priorities

Artificial light at night (ALAN) is now widely treated as a pervasive ecological stressor driven by human activity, one that changes wildlife behaviour and ecosystem processes. Its mode of action differs from that of habitat loss or deforestation. Those are subtractive disturbances: they remove resources or space. Light pollution, by contrast, is additive. It does not remove the night; it resets the

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diel environment and separates animal circadian rhythms from the environmental timing cues they evolved with [3]. The consequences begin at the level of the individual. Activity schedules shift, sleep physiology is disrupted, and the natural boundaries between day and night activity become less distinct. But the effects do not stop there. Artificial night light also reorganises interactions among species, including predator–prey dynamics, insect-mediated pollination mutualisms, and the temporal niche partitioning that allows coexisting species to share a habitat. These biotic changes then move through trophic networks and ultimately reshape ecosystem functions, from nutrient cycling to primary productivity [4].

Responses to ALAN are far from uniform. They depend on taxon, light intensity, and spectral composition, and this context-dependence makes generalisation difficult. Nocturnal insects provide the clearest case: many show strong phototactic responses, and the resulting disruption to movement and reproduction is severe. Small mammals respond in almost the opposite way. Rather than being attracted, they tend to avoid illuminated areas and compress their nocturnal activity windows. Diurnal species add a further complication. They were once assumed to be largely unaffected by night-time light, but a growing body of evidence indicates that they too suffer physiological and reproductive perturbations [2, 10]. Taken together, these divergent responses mean that the same light pollution can produce very different ecological outcomes in different communities. That heterogeneity is one reason why community-level impacts remain hard to predict.

Two priorities follow from these gaps. The first is to move beyond short-term laboratory observations and invest in long-term field monitoring. Only such monitoring can capture the cumulative and delayed effects of chronic light pollution, which are likely to matter more than the immediate behavioural responses that most studies record. The second is to test mitigation strategies empirically rather than assume they work. Reducing light intensity, optimising spectral composition, and protecting regional dark spaces are all plausible measures, but their ecological benefits have rarely been evaluated in practice. Where such measures are implemented, they may help restore natural diel rhythmicity, stabilise disrupted species interactions, and improve the resilience of urban and suburban ecosystems under continued urbanisation [11, 12].

5. Conclusion

Artificial light at night is a peculiar kind of anthropogenic disturbance. It does not remove habitat outright; instead, it changes the sensory and temporal conditions in which organisms live. The ecological effects discussed here span several levels of biological organisation. For individual animals, artificial illumination can shift activity schedules, shorten the period of natural darkness, interfere with sleep and physiological recovery, and uncouple circadian rhythms from environmental timing cues. Species do not respond in the same way. Nocturnal insects are often drawn strongly to artificial lights, whereas small mammals may avoid lit areas or confine their activity to shorter periods. Even diurnal species can show behavioural and physiological changes when nighttime darkness is disrupted.

At the community level, these species-specific responses can alter ecological relationships. Shifts in visual conditions and activity timing may reshape predator–prey interactions, insect-mediated pollination, competition, and temporal niche partitioning. When the timing or abundance of one group changes, the effects can travel through trophic networks and influence broader ecosystem functions. It follows that short-term behavioural measurements on isolated species cannot capture the full ecological outcome. What happens depends on taxonomic identity, light intensity, spectral composition, exposure duration, habitat context, and the structure of local species interactions.

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Future work should give more weight to long-term field monitoring, community-level observation, and direct tests of mitigation measures under realistic conditions. Management should avoid unnecessary nighttime illumination, reduce intensity where lighting is required, limit spectral components that are ecologically disruptive, direct light only to intended areas, and maintain dark refuges within developed landscapes. Such measures can reduce disruption while still allowing for human lighting needs. A gradual shift toward ecologically informed lighting design and stronger protection of natural darkness would offer a practical way to reduce light pollution effects on wildlife and to maintain ecosystem stability and resilience as urbanisation continues.

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