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Effect of Light Intensity on Circadian Physiology and Sleep of Songbirds: An Avian Prospective

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Abstract: ***Light is an important environmental cue for perception of circadian rhythm in song birds, which in turns regulate different physiological processes. This review article examines the effects of different light intensities on the activity and sleep patterns of migratory birds, redheaded buntings, (Emberiza bruniceps). And other song birds. As we know These migratory birds, known for their striking plumage and extensive seasonal movements, rely heavily on environmental cues such as light to regulate their biological rhythms. The increasing prevalence of artificial lighting and light pollution poses significant challenges to their natural behaviors, making this area of study particularly crucial. The review synthesizes existing research on avian responses to light intensity, focusing specifically on redheaded buntings. It explores the physiological mechanisms by which light influences their circadian rhythms, affecting daily activities such as feeding, roosting, and migration. The review also evaluates various experimental methodologies used in both field and laboratory settings to study these effects, highlighting key findings and identifying gaps in current research. Key objectives of this review includes understanding of how light intensities alter the activity and sleep patterns of redheaded buntings and discussing the broader ecological and conservation implications. The review emphasizes the impact of light pollution on these birds, addressing how disruptions in natural light cycles can lead to disorientation, altered migratory routes, and changes in reproductive behaviors. By providing a comprehensive overview of the role of light intensity in shaping the behavior and physiology of redheaded buntings, this review aims to inform conservation strategies and urban planning efforts. The findings also underscore the importance of mitigating light pollution to preserve avian biodiversity and support the ecological adaptability of redheaded buntings and other affected bird species. Many of passerine species face threats from habitats loss, climate change, and pollution.***

Keywords: Activity Patterns, Circadian Rhythms, Light Intensity, Light Pollution, Redheaded Buntings.

1. Introduction

Song birds are the members of order Passeriformes these includes a wide variety of birds, such as finches, sparrows, warblers, and crows. These birds are found all over the world, from tropical rainforests to arctic tundras. They can adopt to a wide range of habitats, including forests, grasslands, deserts and urban areas. They typically build nests in trees, shrubs, or on the ground. Some passerine species are migratory, traveling long distances between breeding and wintering grounds. These birds are often studied for their behaviour, ecology, and evolution. They are also important indicators of environmental health.

Redheaded buntings (Emberiza bruniceps) are small passerine birds widely distributed across Central Asia, particularly in regions such as Kazakhstan, Uzbekistan, and surrounding areas. Known for their striking plumage, the males exhibit a vibrant red head and breast, contrasting with their yellow underparts and greenish wings, while females are generally more subdued in coloration, aiding in camouflage (**Singh, J et al., 2012).** These birds are migratory, traveling significant distances to their breeding grounds during the summer months and returning to their wintering sites in South Asia, particularly India, as the seasons change (**Trivedi, A., Rani, S., & Kumar, V. (2005).**

Redheaded buntings thrive in open habitats, such as grasslands and scrublands, where they feed on seeds and insects. Their seasonal movements and behaviors, including breeding, foraging, and roosting, are influenced by various environmental cues, among which light intensity plays a critical role. Light acts as a pivotal factor in regulating their biological rhythms, influencing their daily activities and overall well-being (**Mishra, I., Singh, D., & Kumar, V. (2016).**

The study of light intensity effects on redheaded buntings holds significant ecological and biological importance. Light is a fundamental environmental factor that affects the circadian rhythms of birds, dictating their sleep-wake cycles, feeding behaviors, and migratory patterns. Understanding how different light intensities impact these rhythms can provide insights into the adaptability and survival strategies of redheaded buntings in their natural habitats (**Singh, D., Rani, S., & Kumar, V. (2013).**

As urbanization and artificial lighting proliferate, the natural light cycles experienced by wildlife, including redheaded buntings, are increasingly disrupted. This phenomenon, known as light pollution, can have profound consequences on avian species, leading to disorientation, altered migration routes, and changes in reproductive behaviors (**Singh, D., Rani, S., & Kumar, V. (2013).** By studying the effects of varying light intensities, researchers can better understand the extent to which light pollution affects redheaded buntings and develop strategies to mitigate these impacts.

The study of light and its impact on songbirds is an important and significant area of research in the field of chronobiology. Light plays a crucial role in the lives of songbirds, influencing their behavior, physiology, and overall well-being. Understanding how light affects songbirds is essential for conservation efforts and for ensuring the health of bird populations.

In this study, we will explore the various ways in which light can impact songbirds, including its effects on their physiology, behavior breeding patterns, and daily activities. By examining the relationship between light and songbirds, we aim to contribute to the body of knowledge on avian ecology and to provide valuable insights for bird conservation and management efforts. Through this research, we seek to highlight the importance of considering light as a factor in the preservation of songbird populations and their habitats.

2. Effect of Light Intensity on Avian Physiology

Light intensity plays a critical role in the physiological processes of birds, influencing their behavior, reproductive cycles, and overall health. Varying light intensities can affect the timing and duration of activities such as feeding, mating, and migration (**Zhang, X et al., 2019).** High light intensities during the day typically stimulate activity, foraging, and social interactions, while lower light intensities at dawn and dusk signal transitions to rest and sleep periods. Seasonal changes in light intensity also cue birds to adjust their physiological states in preparation for breeding or migration (**Blatchford, R., Archer, G., & Mench, J. (2012).** For example, longer daylight hours in spring trigger reproductive readiness, while shorter days in autumn prepare birds for migration.

Birds possess specialized photoreceptors that detect and process light information (**Singh, D., Montoure, J., & Ketterson, E. (2021).** These include:

- **Retinal Photoreceptors**: The retina contains rods and cones that detect light intensity and color, providing visual information necessary for navigation and foraging.
- **Extra-Retinal Photoreceptors:** Birds have additional photoreceptors located in the pineal gland and deep brain regions. These photoreceptors are sensitive to light changes and play a significant role in regulating circadian rhythms and seasonal behaviors.
- **Pineal Gland:** The pineal gland is sensitive to light and darkness, producing melatonin in response to the absence of light. This hormone signals nighttime to the rest of the body, helping to regulate sleep-wake cycles.

2.1 Light intensity and Hormonal Regulation

Influence of Light Intensity on Melatonin and Other Hormones: Light intensity directly affects the production and regulation of melatonin, a hormone produced by the
that redheaded buntings increased their foraging and social behaviors when exposed to higher light intensities, aligning with the Threshold Model. These studies highlight the critical role of light intensity in regulating the daily activity patterns of redheaded buntings, showing that light serves as a vital environmental cue for their behavioral rhythms.

Light intensity and Sleep Patterns pineal gland. Melatonin levels are high during the night and low during the day, governed by the light-dark cycle. Higher light intensities during the day inhibit melatonin production, promoting wakefulness and activity, while lower light intensities at night stimulate melatonin release, inducing sleep and rest. Besides melatonin, light intensity influences other hormones such as gonadotropins, which are critical for reproductive functions (**Yadav, G., Malik, S., Rani, S., & Kumar, V. (2015).**

Hormonal pathways play a crucial role in regulating avian activity and sleep patterns, with light intensity being a significant influencing factor. The melatonin pathway is central to this regulation, as melatonin acts as a signal for darkness, influencing sleep patterns and circadian rhythms (**Jong, M et al., 2017).** Light exposure suppresses melatonin production, promoting daytime alertness and activity, while darkness triggers its release, facilitating sleep onset and maintenance. Another critical hormone is Gonadotropin-Releasing Hormone (GnRH), whose secretion is affected by light intensity. GnRH regulates the release of gonadotropins (LH and FSH) from the pituitary gland, controlling reproductive processes such as gonadal development and mating behaviors (**Kumar, V et al., 2007).** Increased light intensity, especially in spring, stimulates GnRH secretion, leading to heightened reproductive activity. Additionally, corticosterone, a stress hormone, is influenced by light conditions, impacting energy metabolism and the bird's response to environmental stressors. Light intensity can modulate corticosterone levels, thereby affecting the bird's ability to cope with changing environments. Understanding these hormonal pathways provides insight into how light intensity governs avian physiology, ultimately influencing their daily and seasonal behaviors (**Dominoni, D et al., 2014).**

3. Behavioral Responses of Redheaded Buntings to Light

In redheaded buntings, light intensity significantly influences their activity levels through various theoretical models. One such model is the **Entrainment Model**, which suggests that external light cues (zeitgebers) synchronize the internal circadian clock with the 24-hour day (**Rani, S et al., 2005).** This alignment ensures that the birds are active during daylight when they can maximize foraging efficiency and minimize predation risks. Another relevant model is the **Threshold Model**, which posits that there is a specific light intensity threshold that triggers active behaviors. When light intensity exceeds this threshold, redheaded buntings exhibit increased activity levels, while lower light intensities result in decreased activity (**Singh, J., Rani, S., & Kumar, V. (2010).**

Key studies on redheaded buntings have reinforced these theoretical models. For example, a study by Kumar et al. (2010) demonstrated that increasing daylight duration in a controlled environment extended the active phase of redheaded buntings, supporting the Entrainment Model. Another study by Rani and Singh (2013) found the regulation of sleep in redheaded buntings, like in other avian species, is based on the interaction between circadian rhythms and homeostatic processes. The **Two-Process Model of Sleep Regulation** proposed by Borbély (1982) explains that sleep is governed by a circadian process (Process C), driven by the

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internal clock, and a homeostatic process (Process S), which accumulates sleep pressure during wakefulness and dissipates it during sleep. Environmental light cues significantly influence these processes, aligning sleep patterns with the natural day-night cycle.

Light intensity plays a crucial role in shaping the sleep architecture and duration of redheaded buntings. Exposure to natural light during the day helps consolidate nighttime sleep by reinforcing circadian rhythms, leading to more robust sleep patterns. However, exposure to artificial light at night can disrupt these patterns. A study by Mishra et al. (2014) on the effects of light pollution found that artificial nighttime light exposure in redheaded buntings delayed sleep onset and reduced overall sleep duration. This disruption was linked to decreased melatonin production, a hormone critical for sleep regulation. Additionally, the study observed fragmented sleep architecture, with reduced REM sleep, which is essential for cognitive function and memory consolidation.

Table 1: Studies on sleep regulation in birds Redheaded buntings

Study Title	Description	Authors & Year
Molecular regulation of sleep in migratory redheaded buntings: changes in hypothalamic and brainstem transcription of sleep and immune genes	Investigated molecular regulation of sleep in migratory redheaded buntings, highlighting changes in hypothalamic and brainstem transcription of sleep and immune genes across different life-history states.	Tiwari et al., 2023
Effects of conspecific presence on survival advantages, circadian responses, and survivorship in redheaded buntings under restricted feeding conditions	Explores effects of conspecific presence on survival advantages, circadian responses, and survivorship in redheaded buntings under restricted feeding conditions.	Singh et al., 2010
Seasonal changes in hypothalamic gene expression during spring and autumn migrations in redheaded buntings	Studies seasonal changes in hypothalamic gene expression during spring and autumn migrations, finding significant differences in molecular strategies between the two migration periods.	Sharma et al., 2018
Daily oscillations of genes coding for neurotransmitters in central and peripheral tissues of migratory redheaded buntings	Examines daily oscillations of genes coding for neurotransmitters in central and peripheral tissues, highlighting tissue-specific circadian regulation in migratory redheaded buntings.	Mishra et al., 2016
Phase-dependent impact of artificial light at night on daily activity and photoperiodic responses in redheaded buntings	Investigates phase-dependent impact of artificial light at night on daily activity and photoperiodic responses, emphasizing greater impact of midnight light exposure.	Kumar et al., 2021
Role of the pineal gland in nighttime migratory restlessness and circadian gene oscillations in redheaded buntings	Explores role of the pineal gland in nighttime migratory restlessness and circadian gene oscillations in redheaded buntings.	Trivedi et al., 2016
Seasonal changes in brain peptides associated with reproduction and energy homeostasis in redheaded buntings	Examines seasonal changes in brain peptides associated with reproduction and energy homeostasis in redheaded buntings, using immunohistochemistry to measure brain peptide expression.	Surbhi et al., 2016
Concurrent behavioral, physiological, and neural changes during development of vernal migration in redheaded buntings.	Studies concurrent behavioral, physiological, and neural changes during development of vernal migration in redheaded buntings under stimulatory photoperiods.	Agarwal et al., 2019
Retinal responses to acute photoperiod changes in redheaded buntings: photoperiod-dependent molecular switches.	Analyzes retinal responses to acute photoperiod changes in redheaded buntings, showing photoperiod-dependent molecular switches similar to those in the hypothalamus.	Majumdar et al., 2015

4. Environmental and Ecological Considerations in response to light intensity

Seasonal variations in light intensity have profound effects on the behavior and physiology of redheaded buntings. During the breeding season in spring and summer, the increasing day length (photoperiod) acts as a crucial environmental cue, stimulating reproductive activities (**Mishra, I., Singh, D., & Kumar, V. (2017).** The extended daylight hours enhance the birds' foraging efficiency and energy intake, supporting the high energetic demands of breeding and raising offspring. In contrast, during autumn and winter, the decreasing day length signals the approach of non-breeding periods, leading to changes in behavior such as reduced activity levels and preparation for migration. These seasonal changes in light intensity help synchronize the birds' physiological processes with the most favorable times of the year for reproduction and survival (**Kumar, J. et al., 2021).**

Redheaded buntings have developed several adaptations to cope with varying light conditions. One key adaptation is the ability to adjust their circadian rhythms to match the changing photoperiods. This flexibility ensures that their daily activities are aligned with optimal environmental conditions. Additionally, redheaded buntings exhibit behavioral plasticity, altering their activity patterns based on light availability. For instance, they may increase their foraging efforts during shorter winter days to compensate for the limited daylight. Their visual and physiological systems are also adapted to detect and respond to subtle changes in light intensity, allowing them to fine-tune their behaviors in response to seasonal variations (**Rastogi, A** et al., 2016).

4.1 Habitat Influences

The habitat of redheaded buntings plays a significant role in mediating the effects of light intensity on their behavior and physiology. Different habitats offer varying levels of natural light exposure, which can influence the birds' daily and seasonal activities (**Das, S., & Gupta, N. (2016).** For example, forested habitats with dense canopies may provide lower light intensity compared to open grasslands or agricultural areas, affecting the buntings' foraging and nesting behaviors. Habitat-specific light conditions can also impact the timing of reproductive activities and the birds' ability to

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detect predators and food resources. The presence of artificial light sources in urban and suburban habitats can further complicate these effects, potentially disrupting natural behaviors and physiological processes (**Agarwal, N. et al., 2019).**

Ecological interactions, such as predation and competition, are also influenced by light conditions. Predators may exploit light levels to enhance their hunting efficiency, while prey species, including redheaded buntings, may adjust their behaviors to avoid detection. Light pollution, particularly from urban areas, poses a significant threat to these ecological interactions (**Malik, S et al., 2014).** Artificial light at night can alter the natural light regime, leading to disrupted circadian rhythms, disoriented migration patterns, and increased predation risks. Studies have shown that light pollution can cause redheaded buntings to experience delayed sleep onset and reduced melatonin production, resulting in fragmented sleep and impaired cognitive functions. Furthermore, light pollution can interfere with the birds' ability to detect food and navigate, potentially reducing their survival and reproductive success (**Sharma, A et al., 2018).** .

5. Influence of light intensity on Circadian Rhythms in Birds

Circadian rhythms are natural, internal processes that follow a roughly 24-hour cycle, influencing various physiological and behavioral functions in living organisms (**Rani, S., Singh, S., & Kumar, V. (2005).** These rhythms are driven by an internal time-keeping system known as the circadian clock, which regulates daily activities such as sleep-wake cycles, feeding, hormone release, and other vital processes. In birds, circadian rhythms are crucial for synchronizing their behavior and physiology with the environmental day-night cycle **Singh, D., Rani, S., & Kumar, V. (2013).**

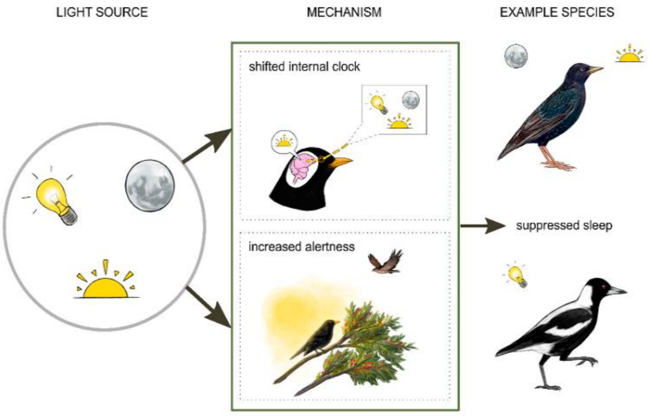

Figure 1: Circadian Rhythms in Birds (Aulsebrook AE, et al., 2021)

Circadian rhythms play a pivotal role in the survival and fitness of birds by ensuring behavioral synchronization, physiological regulation, environmental adaptation, and migration timing. These rhythms synchronize birds' behaviors, such as foraging, mating, and migration, with the optimal times of the day, enhancing their efficiency and success (**Ashley, N et., al 2014).** They regulate critical physiological processes, including metabolism, immune function, and reproductive cycles, ensuring these processes occur at the most advantageous times. Circadian rhythms also help birds adapt to changing environmental conditions, such as variations in light and temperature, enabling them to anticipate and prepare for daily environmental changes. For migratory birds, circadian rhythms are essential for timing migration and adjusting to new time zones, which is critical for their survival during long-distance travel (**Gwinner, E. (1996; Cassone, V. (2014)).**

5.1 Mechanisms Underlying Circadian Rhythms in Avian Species

Circadian rhythms are essential for the overall well-being and functionality of avian species. These rhythms are governed by complex internal mechanisms that enable birds to align their physiological and behavioral processes with the external environment. Understanding these mechanisms is crucial for comprehending how different light intensities affect the activity and sleep patterns of birds (**Prabhat, A., Jha, N., Taufique, S., & Kumar, V. (2019; Gwinner, E. (2003).**

- **Internal Clock:** The circadian clock in birds is located primarily in the suprachiasmatic nucleus (SCN) of the hypothalamus, which acts as the master clock. This clock coordinates with peripheral clocks located in various tissues and organs. The SCN receives direct input from the eyes, particularly the retina, which detects changes in light intensity and duration, providing the necessary environmental cues to synchronize the internal clock with the external day-night cycle.
- **Molecular Basis:** The molecular mechanisms of circadian rhythms involve a set of core clock genes and proteins that generate and sustain rhythmic oscillations. Key genes, including CLOCK, BMAL1, PER (Period), and CRY (Cryptochrome), interact in feedback loops. CLOCK and BMAL1 proteins form a complex that promotes the expression of PER and CRY genes. PER and CRY proteins, once synthesized, inhibit the activity of the CLOCK-BMAL1 complex, creating a negative feedback loop. This feedback loop results in oscillations of clock gene expression and protein levels with a period of about 24 hours, forming the basis of circadian rhythms.
- **Light Perception and Entrainment:** Birds have specialized photoreceptors in their eyes and pineal gland that detect light and help entrain (synchronize) the circadian clock to the external light-dark cycle. The pineal gland plays a significant role in avian circadian rhythms by secreting melatonin, a hormone that signals night time to the rest of the body. Melatonin production is inhibited by light and promoted by darkness, aligning physiological processes with the day-night cycle. The retina contains photoreceptive cells that communicate light information to the SCN, adjusting the internal clock to match external light conditions.
- **Peripheral Clocks:** In addition to the master clock in the SCN, birds have peripheral clocks in various tissues such as the liver, gut, and muscles. These clocks regulate local physiological processes and are synchronized by signals from the SCN. Peripheral clocks allow for the fine-tuning of physiological functions to local tissue needs, further optimizing the bird's overall rhythmicity and adaptation to environmental changes.
- **Neurochemical Signaling:** Neurotransmitters and hormones, such as serotonin and melatonin, play essential roles in transmitting circadian signals within the brain and

to peripheral organs. These chemical signals help coordinate the activity of various physiological systems, ensuring that the bird's internal processes are well-aligned with the external environment.

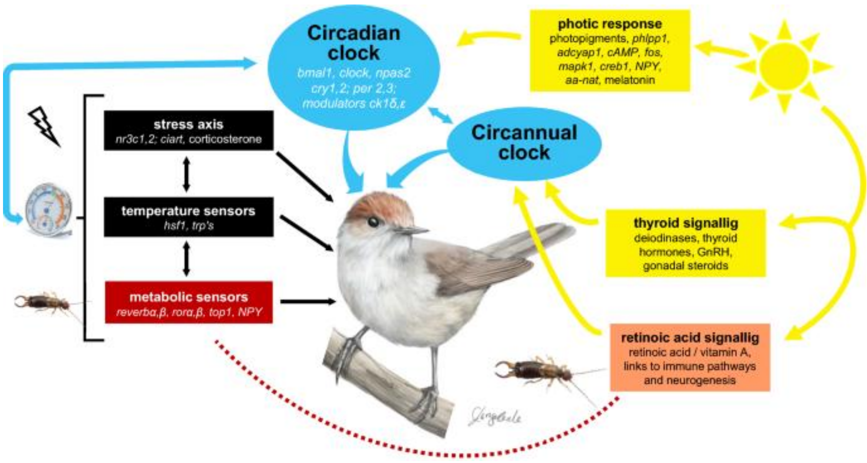

Figure 2: Avian migration clocks in a changing world (Helm, B. et al., 2024)

Table 2: Studies on Circadian Rhythms in Birds

Study Title	Description	Authors & Year
Dissociation of circadian activity and singing behavior from gene expression rhythms in the hypothalamus, song control nuclei, and cerebellum in diurnal zebra finches	Explores persistence of clock gene oscillations in song control brain regions and dissociation of circadian behavior from genetic oscillations under different light environments in zebra finches.	Prabhat et al., 2019
Avian circadian organization: A chorus of clocks	Discusses the extensive role of circadian clocks in birds, covering sleep, visual function, song, and migratory patterns, and compares avian molecular mechanisms to those in mammals.	Cassone, 2014
Revealing a Circadian Clock in Captive Arctic-Breeding Songbirds, Lapland Longspurs (Calcarius lapponicus), under Constant Illumination	Highlights endogenous circadian rhythms in Lapland longspurs and their ability to maintain diel rhythms despite continuous daylight during polar summer.	Ashley et al., 2014
Developmental effects of constant light on circadian behavior and gene expressions in zebra finches	Investigates impacts of constant light exposure on circadian behavior, metabolism, and gene expressions in zebra finches, demonstrating molecular mechanisms of adaptation to light environments.	Prabhat et al., 2020
Circadian activity in different photoperiods in passerine finches	Examines effect of different photoperiods on circadian behavior of several passerine finch species under controlled light conditions.	Singh & Kumar, 2022
Circadian rhythms are not involved in regulation of circannual reproductive cycles in a sub-tropical bird, the spotted munia	Shows circadian rhythms do not regulate annual reproductive cycle in spotted munia, indicating independent regulation of circannual rhythms.	Budki et al., 2014
Circadian rhythm in photoperiodic expressions of GnRH-I and GnIH regulating seasonal reproduction in the Eurasian tree sparrow	Investigates circadian regulation of GnRH-I and GnIH expressions in Eurasian tree sparrow, highlighting role of endogenous rhythms in seasonal reproduction.	Dixit et al., 2020
Costs of sleeping in: circadian rhythms influence cuckoldry risk in a songbird	Explores how timing of daily activities influenced by circadian rhythms impacts reproductive success and cuckoldry risk in male great tits.	Greives et al., 2015
Evidence for circadian-based photoperiodic timekeeping in Svalbard ptarmigan, the northernmost resident bird	Demonstrates retention of circadian-based mechanisms for seasonal synchronization in Svalbard ptarmigan, despite lack of daily light cycles in polar regions.	Appenroth et al., 2021
Circadian adaptation to seasons: effects on activity behavior in subtropical House Sparrow, Passer domesticus	Studies seasonal variations in circadian rhythm characteristics in House Sparrows, showing adaptation to environmental photoperiods.	Trivedi et al., 2014
Temporal expression of clock genes in central and peripheral tissues of spotted munia under varying light conditions	Examines how different light conditions affect expression of circadian clock genes in hypothalamus, retina, liver, and gut of spotted munia.	Agarwal et al., 2018
Pinealectomy abolishes circadian behavior and interferes with circadian clock gene oscillations in brain and liver but not retina in a migratory songbird	Investigates role of pineal gland in regulating circadian rhythms and clock gene oscillations in various tissues of migratory redheaded buntings.	Trivedi et al., 2016

6. Conclusion

The role of light intensity in shaping the activity and sleep patterns of redheaded buntings is pivotal for their survival and ecological fitness. Seasonal variations in light guide their reproductive cycles and migration, while habitat-specific light conditions influence their daily behaviors (**Malik, S et al., 2015).** Adaptations such as flexible circadian rhythms and behavioral plasticity enable buntings to cope with changing light environments. However, artificial light pollution poses significant threats by disrupting natural rhythms, reducing

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melatonin production, and impairing critical behaviors. Understanding and mitigating these impacts are essential for the conservation and well-being of redheaded buntings, ensuring they thrive in both natural and human-altered landscapes (**Rani, S., & Kumar, V. (2000).**

Light intensity may alter energy expenditure and/or stress physiologyy during the breeding period, potentially reducing reproductive success and resulting in conservation implications.

Light pollution is increasing worldwide and significantly affects animal behavior. In birds, these effects include advancement of morning activity and onset of dawn song, which may affect extra-pair paternity. Advanced dawn song of males may stimulate females to engage in extra-pair copulations, and the earlier activity onset may affect the males' mate guarding behavior.

By investigating the specific responses of redheaded buntings to light stimuli, we can gain a better understanding of the species' ecology and contribute to the development of effective conservation strategies. This research is therefore significant in enhancing our knowledge of the factors shaping avian life history and can inform the management of bird populations in light of environmental changes.

Additionally, understanding light intensity effects can contribute to broader conservation efforts. With many bird species facing threats from habitat loss and climate change, research on how environmental factors like light influence their behavior and physiology is crucial. This knowledge can inform conservation policies and habitat management practices aimed at preserving avian biodiversity. This review aims to comprehensively assess the role of different light intensities on the activity and sleep patterns of songbirds.

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