

## Occurrence of a large congregation of synchronous Fireflies and Firefly species diversity at Anamalai Tiger Reserve, India.

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The captivating bioluminescence of fireflies has long fascinated researchers and nature enthusiasts worldwide. Among these enchanting insects, synchronous fireflies, with their mesmerizing, coordinated flashing displays, have become a subject of intrigue. The Anamalai Tiger Reserve (ATR), geographically located between the longitudes 76°E and 77°E and latitudes 10°N and 10°N, falls in the southern part of the Western Ghats in India. Encompassing an extensive area of 958.59 square kilometers, this reserve is a vital biodiversity hotspot, teeming with a diverse range of endemic flora and faunal species, including the captivating fireflies. With an annual rainfall range of 500-4500 mm, ATR provides an ideal and thriving habitat for studying the behavior and ecological roles of these mesmerizing insects.

The research conducted at ATR was focused on unraveling the synchronization patterns of these

bioluminescent organisms and investigating their roles in the delicate ecological balance of the reserve. Comprehensive field surveys have been carried out to document the congregation of fireflies and identify the various species present, shedding light on their unique behaviors and interactions within the ecosystem. As an indicator species, fireflies play a crucial role in biodiversity conservation and ecosystem management. Their synchronized flashing behavior serves as a vital ecological marker, reflecting the health of their habitat and the surrounding environment. Understanding their behavior and the factors influencing their flashing patterns can provide valuable insights into the overall health and functioning of the ecosystem. This research manuscript presents a wealth of findings gathered from the field surveys, providing a comprehensive understanding of the firefly community at ATR. The observed congregation and diversity of species highlight the reserve's importance as a thriving

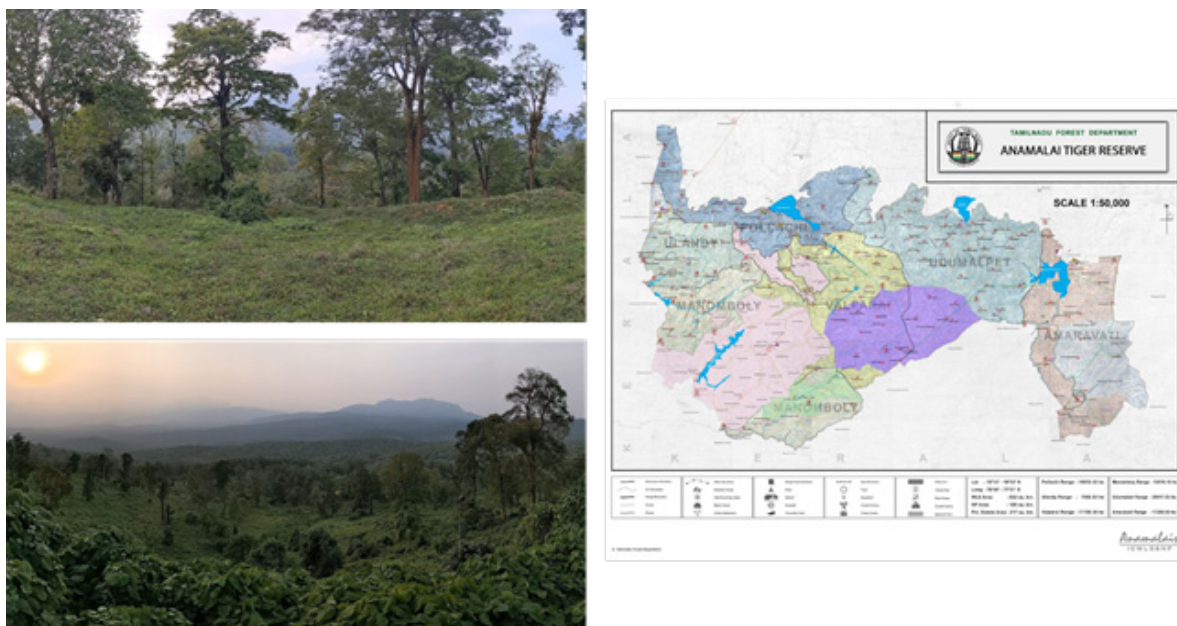


Fig. 1. Study location: Map of Anamalai Tiger Reserve: Depicting the diverse ranges within the protected area



Fig. 2. A. Adult fireflies roosting under the vegetation during the day hours; B. Firefly larva



Fig. 3. These are 15.83-minute exposure reveals firefly activity and star trails. Stacking 50 photos with 19-second exposures, the final image captures the brightest pixel and counts flashes per pixel once. The stationary fireflies during flashing are evident from the absence of flash trails in the trees.

habitat for these captivating insects. Moreover, by studying their behavior and interactions with other species in the food chain, this research underscores the significance of proactive conservation measures to preserve their habitat and safeguard the entire ecosystem.

In the captivating realm of Anamalai Tiger Reserve, billions of synchronously flashing fireflies adorn the landscape with a mesmerizing carpet of yellowish-green brilliance during April. These bioluminescent wonders have long fascinated people of all ages, as they illuminate the darkness to communicate and find mates (Branham et al., 2003, Cladistics, 2019). Through the fascinating process of bioluminescence, fireflies produce their enchanting cool light. Unfortunately, once abundantly present firefly populations are facing drastic decline globally (Kevin

et al., 2016; Owens et al., 2022) due to anthropogenic mediated climate change, habitat fragmentation and light pollution. Remarkably, large congregations of synchronous fireflies are a rarity, found in only a few locations worldwide, including the USA (Carlson et al., 1985), Malaysia (Copeland et al., 1995; Razak et al., 2016; Abu Seri et al., 2022), Thailand (Razak et al., 2016), and Brazil (Jaikla et al., 2020; Hagen et al., 2015; Viviani et al., 2001). This study delves into an in-depth study of the synchronous firefly populations dwelling within the breathtaking Anamalai Tiger Reserve in Tamil Nadu, India.

Extensive field surveys were conducted during the firefly mating seasons from 2022 to 2023 in the Anamalai Tiger Reserve (ATR), India (Fig. 1.) to observe and document the behavior and synchronization patterns of fireflies (Fig. 3). The



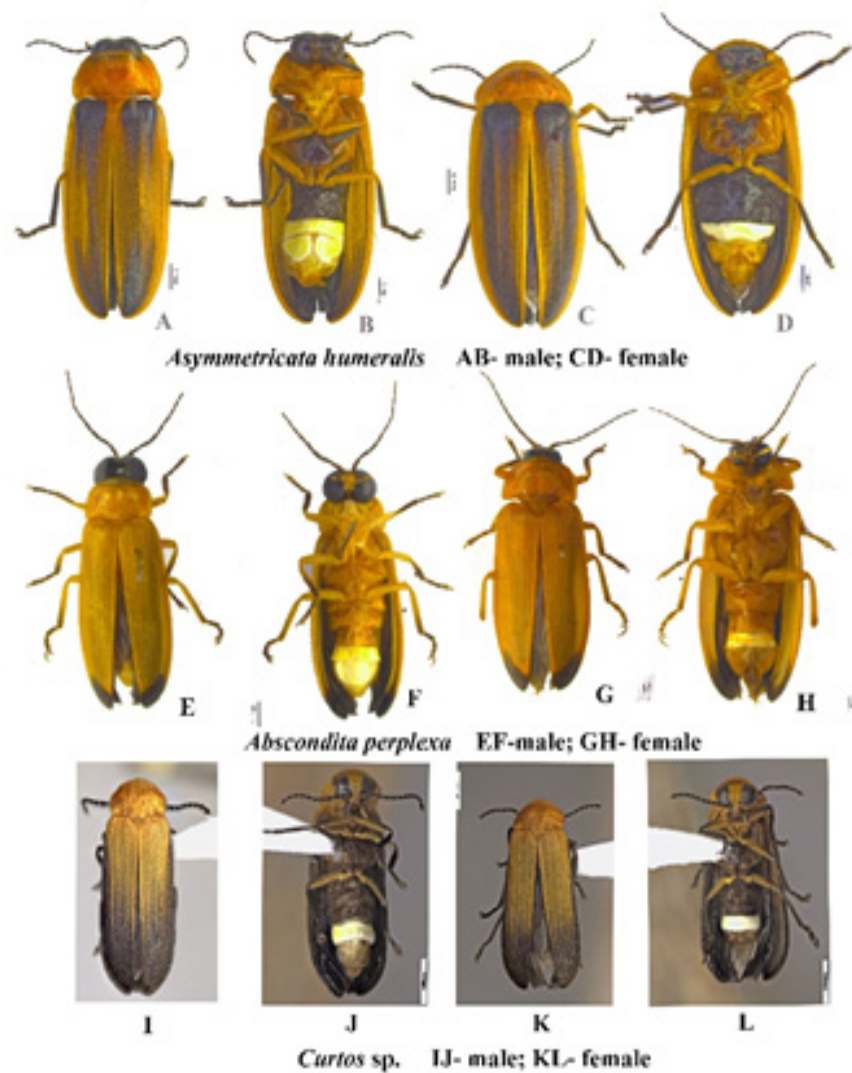


Fig. 4. Firefly species diversity in Anamalai Tiger Reserve

study aimed to understand the ecological significance of synchronous fireflies and identify the diverse firefly species present in this pristine habitat. Observations were made at various locations within the reserve to capture a representative sample of firefly activity. Researchers recorded the flashing patterns of fireflies in individual trees and documented whether the flashes were ascending or descending. The timing of flashing events was noted relative to sunset, allowing for an analysis of the synchronization phenomenon. Mating behaviors, such as rapid pulsations and the duration of flashing sequences, were carefully observed.

Firefly specimens were collected from different locations within the reserve for species identification. Each specimen's physical characteristics were examined, and distinguishing features were noted for species classification. To investigate the potential influence of environmental factors on firefly behavior, data on sunlight intensity, lunar face, wind direction, and weather conditions were recorded

during the observation period. Additional surveys were conducted in specific areas with unique habitat characteristics, such as the Anaikundhi valley, which experienced a forest fire in 2017, to understand how such events may impact firefly activity.

The research conducted at the Varagaliyar range of Anamalai Tiger Reserve (ATR), India, unveiled intriguing patterns of firefly synchronization within the observed trees. Each tree exhibited local synchronization, with flashes either ascending or descending. However, not all trees displayed synchronized flashing simultaneously, indicating a degree of individual variability in their behavior. A pivotal moment occurred precisely at 19:30, witnessing a remarkable peak of activity. Flashes initiated in a single tree and propagated like a "Mexican wave" across several adjacent trees. Interestingly, global synchronization was observed in most trees, with one exception. Surprisingly, the top section of one tree displayed its own local synchronization while the rest

remained in unison (Fig. 3). This unique behavior hints at a potential influence of moon light on the magnitude of synchronization, possibly indicating a correlation between light intensity and firefly activity. During the day, fireflies concealed themselves under leaves to avoid sunlight. The larvae, around 2 inches long with a glowing rear end, were observed burrowing underground and are predominantly nocturnal like the adults' fireflies (Fig. 2).

Analyzing the timing of flashing events offered further insights into the synchronization phenomenon. On average, flashes commenced 24 minutes after sunset, followed by local synchronization after about 33 minutes, and finally, the wave-like global synchronization after approximately 54 minutes post-sunset. The global synchronization persisted for several hours into the night, providing a captivating spectacle of light. Throughout the night, the wave-like synchronization displayed a consistent pattern, starting from one tree and propagating unidirectionally. However, occasional reversals in the direction of the wave were observed, suggesting a potential relationship with the prevailing wind direction. The findings indicate a complex interplay of environmental factors influencing firefly behavior and synchronization. Further investigation is warranted to understand the precise role of sunlight and wind in shaping these patterns (Fig. 3).

Moreover, the unique observations in the Anaikundhi valley, which experienced a forest fire in 2017, marked it as a hotspot for firefly activity. Each tree in the valley exhibited distinct flashing patterns, with rapid pulsations of 3 to 4 flashes per second, lasting about 4 seconds. Billions of fireflies contributed to the enthralling spectacle in this area. While the tall trees surrounding the Anaikundhi valley displayed typical global wave patterns, the slopes showcased a variety of exceptional flashing patterns, including upward, downward, and outward displays. Such diversity in flashing behavior was not observed elsewhere in the forest. The interspersed arrangement of trees in the valley is hypothesized to facilitate the transmission of firefly flashes across a large area. Additionally, one section of the forest housing rosewood trees demonstrated the highest concentration of global 360-degree synchronization. In contrast, firefly activity near Topslip was scarce, with no evidence of synchronization (Fig. 3).

On a separate observation day, during steady lightning and a slight drizzle, firefly activity was very low.

Conversely, more open areas with widely spaced trees showed little activity. The Anaikundhi valley, being an open area, exhibited no activity on this day. Some fireflies continued to flash despite the lightning, while others did not participate, possibly indicating variations in mating behavior and desperation among individuals. Firefly activity was very scarce in the denser forest areas during all the observation periods.

Our research revealed a diverse firefly community within the reserve, with three identified species: *Asymmetrica humeralis* (Walker, 1858), *Abcondita* genus (species unknown), and *Curtos* sp (Fig. 4). All the three species showed variation in size morphology. They shared similar habitat types with overlapping zones. Among the three species *Asymmetrica humeralis* being the most abundant population in all the study areas during this observation period. *Curtos* sp was the smallest among the three species with single segment of light organ in both male and female while males of *Abcondita* sp and *Asymmetrica* had 2 and 3 segments.

***Abcondita perplexa*:** Asian genus, usually pale yellow or brownish yellow, with black elytral apices; males have an entire Light organ in abdomen segment 7 ventrally occupying almost entire segment. Most species of this genus exhibit the very widespread dorsal colour pattern of yellowish-brown dorsum with or without black tipped elytral apices, which is very common in Luciolinae fireflies of South East Asia. Species with pale dorsum and black elytral apices, which both have very dark terminal abdominal tergites, distinguished by the pale terminal abdominal tergites in the male.

***Asymmetricata humeralis*:** Dorsal colouration having paler brown elytra with darker brown markings restricted to base and apex, pronotum entirely yellow. Light organ is bipartite on the abdominal segment 7.

***Curtos* sp.:** The genus is very easy to see distinguish by the yellow colour with black areas on their elytra than other genus.

The documentation of these species contributes to a deeper understanding of their composition and distribution patterns in this specific habitat. Notably, synchronous fireflies are found in various other locations worldwide, including the entire stretch of Western Ghats specifically in Maharashtra, India, mangrove forests in Malaysia, and several places in Southeast Asia, particularly the Smoky Mountains

National Park in the USA. This underscores the global significance of these mesmerizing bioluminescent insects and their captivating natural displays.

In conclusion, the congregation of synchronous fireflies at the Anamalai Tiger Reserve represents a captivating natural spectacle with significant ecological importance. These mesmerizing insects potentially serve as crucial pollinators and bioindicators of the reserve's environmental health. Understanding their ecological functions is vital for effective biodiversity conservation and ecosystem management.

However, the study also highlights the potential threats posed by light pollution to firefly populations. Fireflies rely on bioluminescence for communication and mating, and artificial lights in the buffer zone of the reserve may disrupt their delicate synchronization and mating behaviors. Thus, it is crucial to establish a sustainable tourism model in the buffer area that minimizes light pollution to preserve the firefly population and their unique displays.

### Conservation strategies

Conservation efforts play a pivotal role in preserving the habitat of the diverse firefly community within the Anamalai Tiger Reserve. The well-preserved core zone of the reserve, which is a result of decades of conservation efforts, serves as a critical sanctuary for firefly activity, especially during the crucial breeding season in April and May. It is vital to maintain this area undisturbed to safeguard the firefly eggs and larvae from any potential harm caused by soil unrest or the introduction of foreign elements (Abu Seri, 2022; Hagen, 2015).

To ensure a thriving population of fireflies, measures should be taken to minimize the impact of artificial light on their communication and mating behaviors. Introducing lighting within the reserve should be carefully considered, and if necessary, shielded and of lower color temperature than white LEDs to minimize its effect on fireflies (Owens, 2022). During patrolling, field staff should use low luminosity torch lights whenever possible and reserve high-intensity lights for emergencies. Limiting vehicular movement at night, especially during the breeding season, is essential to mitigate disturbances (Abu Seri, 2022; Hagen, 2015).

Additionally, religious festivities coinciding with the peak firefly mating season at the Kozhikamuthi settlement should be regulated to prevent increased

foot traffic and light pollution near the firefly hotspot areas. Providing suitable alternative lighting options can help reduce the impact on firefly habitats. Designating a firefly watcher to monitor the population and prevent illegal activities such as vehicle entry, forest fires, or felling can further safeguard the firefly population for the future.

By implementing preventive measures and raising awareness about light pollution's detrimental effects, we can effectively protect the captivating firefly community within the Anamalai Tiger Reserve. Proactively conserving this unique habitat and educating visitors about the ecological significance of fireflies will foster appreciation and ensure the preservation of this natural wonder for generations to come. The delicate balance of nature, exemplified by the reserve's rich biodiversity and the enchanting beauty of synchronous fireflies, serves as a powerful reminder of our responsibility to protect, and cherish these fascinating creatures and their habitat.

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