

## ANTHROPOGENIC PRESSURES ON FIREFLY DIVERSITY LOSS AND POPULATION DECLINE IN CHANGING LANDSCAPES

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**Abstract**

Discussion of the decline of insects in various nations necessitates some key questions that must be answered by conservation biologists regarding the causes and measures to address them. Among the groups of insects gaining prominence lately are fireflies belongs to Coleoptera: Lampyridae, because of the distinct characteristics that they possess, including bioluminescence. While in-depth population surveys are rare for most species, there is anecdotal evidence that some firefly populations have declined over the past few decades. The decline of natural habitats, the use of chemical pesticides, and increasing light pollution at night are some of the primary threats to fireflies in North America, but their overall impact has not been investigated across extensive geographic scales. To disentangle these factors, machine learning models were trained on more than 24,000 surveys submitted between 2008 and 2016 as part of the citizen science program Firefly Watch. Several ecological aspects were explored, such as exposure to pesticides, artificial light pollution, land-use types and patterns, soil parameters, short-term weather phenomena, and long-term climatic data. Future work is needed to confirm the influence of these multiple interactions among soil composition, climatic conditions, and landscape characteristics (e.g., agricultural land and urban surfaces) on firefly abundance. The significant effects of climate and weather also suggest that climate change might play an important role in influencing future firefly populations. For some locations, firefly populations may flourish as ideal habitat conditions become available, while other locations will continue to see declining populations. It is clear that monitoring, climate change control, and the creation of friendly insect habitats will be crucial for firefly survival into the future.

## INTRODUCTION

Fireflies (Coleoptera: Lampyridae) are among the most remarkable, interesting, and well-known insects that produce light through bioluminescence. Globally, more than 2,200 species (Table 01) of fireflies have been identified. Some species are diurnal and attract mates using pheromones rather than light (Table 01). They are found in wet environments, including mangroves, rice fields, marshes, and desert springs, as well as in grasslands, forests, agricultural lands, suburban gardens, and urban parks (Riley *et al.*, 2021).

Most firefly species spend the majority of their lives as larvae (Table 01) and have a single reproductive event in their lifetime. The larvae are predatory and can be found in aquatic habitats, wet soil, or terrestrial environments. The final adult stage is relatively short, usually lasting only a few weeks, with the major functions being reproduction and dispersal. Yet, relatively little information is available in the scientific literature about larval stages compared to adults, and many species remain poorly documented (Lewis *et al.*, 2024).

Fireflies and glowworms are among the most visible insects, challenging our perceptions of insects due to their striking bioluminescent courtship displays, cultural significance, and economic value in ecotourism. Flickering lights in the dark, produced by fireflies, are probably among the most beloved insects worldwide, and there is increasing evidence that such species are declining globally. It was established that habitat destruction, light pollution, and pesticides (Table 01) constitute the most significant threats (Lewis *et al.*, 2020).

The mechanism involves a protein called luciferase that catalyzes the reaction between the chemical luciferin and the oxygen and ATP molecules (Table 01). About 5% of the total energy generated is released as heat, while the rest of the energy is released as light. Hence, the light generated by fireflies is popularly known as cold light (Nada *et al.*, 2004). Firefly populations are shrinking across the world due to numerous reasons.

Bioluminescence is an amazing signaling system in animals, functioning both as a warning (aposematic) trait and as a means of sexual communication. The family Lampyridae is cosmopolitan, consisting of seven subfamilies, 67 genera, and approximately 2,000 described species (Table 01), with the highest diversity in tropical regions (Martin *et al.*, 2017). Fireflies (Lampyridae) belong to a cosmopolitan family of beetles with seven subfamilies, 67 genera, and around 2,000 species, showing the highest diversity in tropical regions.

Bioluminescence, an evolutionary trait serving both as a warning signal to predators and as a means of sexual signaling (Table 01). Beetles host the greatest diversity of luminescent species among terrestrial animals, with representatives from four families: Lampyridae (true fireflies), Rhagophthalmidae (glow worms), Phengodidae (railroad worms), and Elateridae (click beetles) (Riley *et al.*, 2021).

The cosmopolitan family Lampyridae consists of nine subfamilies i.e. Lampyrinae, Luciolinae, Amydetinae, Photurinae, Psilocladinae, Cyphonocerinae, Pterotinae, Otoretinae, and Otoretadrilinae, containing around 100 genera and approximately 2,000 species. Rhagophthalmidae is a small family restricted to Asia, whereas Phengodidae occurs in the New World, from southern Canada to northern Chile and Argentina (Chen *et al.*, 2019). Phylogenetically, luminous beetle lineages are closely related to each other and even to some non-luminescent families within Elateroidea.

After careful observation, it has been noted that fireflies possess several remarkably unique characteristics. Firstly, fireflies are not, in fact, flies, as the name suggests, but are small, soft-bodied beetles belonging to the family Lampyridae. In addition, male fireflies are the winged, mobile organs of reproduction that search for potential mates, protecting their flight organs with their elytra, which are the hard, leathery wings used for covering the actual wings themselves (Lewis *et al.*, 2016).

Then you look at their larvae, and they are the opposite of the grown ones. While the grown ones

are out flying around being beautiful, the larvae are little armored tanks that live in the mud. These larvae have flat bodies with hard plates on their backs. The larvae are also hardcore predators, unlike the grown ones that just peacefully live on flowers. The larvae live in the mud, and their mouthparts are adapted to hunt and consume soft

tissue. The larvae mostly prey on other creatures that live in the mud, like slugs and snails (Sivinski *et al.*, 2018). The difference in the characteristics of the delicate winged adult form and the terrestrial predatory larva is interesting.

**Table 01: Comprehensive Overview of Fireflies (Lampyridae)**

Category	Details	Key Points	References
General Description	Fireflies are bioluminescent beetles known for their light-producing ability.	Produce “cold light”; used for communication and mating displays.	Nada <i>et al.</i> , 2004
Species Diversity	Over 2,200 species worldwide.	Wide variation in behavior and life cycles; includes diurnal and glow-worm forms.	Riley <i>et al.</i> , 2021
Behavioral Patterns	Courtship involves species-specific flashing signals.	Some species use pheromones instead of light; glow-worm females emit constant glow.	Riley <i>et al.</i> , 2021
Habitat Distribution	Found in diverse environments.	Includes wetlands (mangroves, marshes), forests, grasslands, agricultural lands, and urban parks.	Riley <i>et al.</i> , 2021
Life Cycle	Majority of life spent in larval stage.	Larvae are predatory; adult stage is short and focused on reproduction	Lewis <i>et al.</i> , 2024
Larval Ecology	Larvae inhabit aquatic, moist soil, or terrestrial environments.	Feed on snails, earthworms, and soft-bodied invertebrates.	Lewis <i>et al.</i> , 2024
Adult Ecology	Adults live for a few weeks.	Limited feeding; energy stored during larval stage; some (Photurinae) are predatory.	Lewis <i>et al.</i> , 2024
Bioluminescence Mechanism	Light produced via luciferin-luciferase reaction.	Requires oxygen and ATP; highly efficient with minimal heat loss (~5%).	Nada <i>et al.</i> , 2004
Ecological Role of Light	Used for mating and defense (aposematism).	Larvae glow brighter when threatened; signaling function is evolutionary.	Martin <i>et al.</i> , 2017
Taxonomy	Family Lampyridae includes ~2,000 species.	Organized into multiple subfamilies, genera; highest diversity in tropics.	Martin <i>et al.</i> , 2017
Related Bioluminescent Families	Other beetle families include Elateridae, Phengodidae, and Rhagophthalmidae.	Share similar biochemical pathways of light production.	Chen <i>et al.</i> , 2019
Evolutionary Significance	Bioluminescence evolved as warning and mating signal.	Important model for studying evolution of novel traits.	Chen <i>et al.</i> , 2019
Conservation Status	Many species are declining globally.	Limited conservation assessments despite ecological importance.	Lewis <i>et al.</i> , 2020

Major Threats	Habitat loss, light pollution, pesticide use.	Threat intensity varies regionally; affects survival and reproduction.	Lewis <i>et al.</i> , 2020
Research Gaps	Limited data on larval stages.	Many species poorly documented; need for long-term monitoring.	Lewis <i>et al.</i> , 2024
Ecotourism & Cultural Value	Fireflies are iconic and culturally significant insects.	Used in ecotourism; raise awareness for invertebrate conservation.	Lewis <i>et al.</i> , 2020

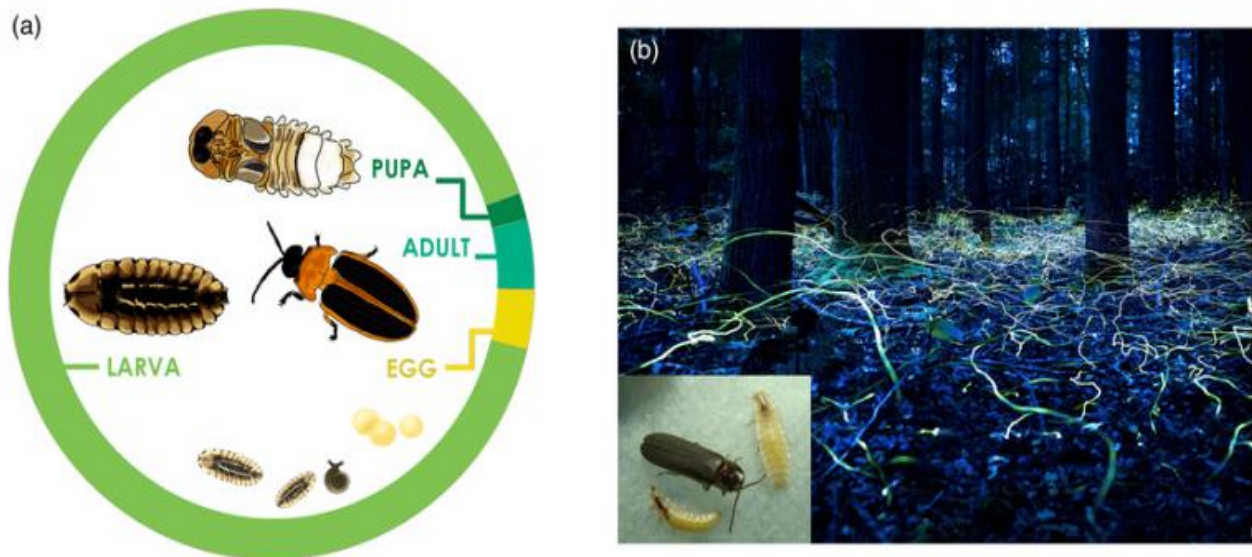


Fig. 01. (a) Firefly's life cycle (b) A glimpse of an adult firefly glowing in the forest

The life cycle of these fireflies has four stages, namely, the egg, larva, pupa, and adult. It all starts when the female firefly lays her eggs in damp mud after mating. Weeks go by, and then the larvae are born. This stage, by far, is the longest in the lifespan of these fireflies, as they stay in the ground for a year or two, feeding on insects and becoming plump in the process. When the time is right, they make a small mud chamber, after which they undergo metamorphosis into the pupa stage (Lloyd *et al.*, 2015).

The final stage in the life cycle of these fireflies is the adult stage, which we get to see as we watch them fly on a warm, humid summer night, especially after it has rained. It is surprising that the sole purpose of this stage is for them to mate and reproduce before they die (Copeland *et al.*, 2019). It is interesting and, in a sense, lamentable that these organisms go through an extended period of development in the substrate yet only have a short adult life in which they are unable to

feed and are only present to reproduce before death.

### Bioluminescence Mechanism and Communication

But the way it happens is the coolest chemical trick in the world. It happens inside the bug, in what we might call the lantern of the bug, the bioluminescent process. It involves the chemical luciferin, reacting with oxygen and an enzyme, luciferase. Add some ATP, or energy, and voila! Light appears. But the cool part is, no heat is involved, and it remains cool to the touch, hence the name cold light (Cock *et al.*, 2017).

They use the glow to talk to each other in the dark and even to find a mate. Each species has its own flash code, or secret language, as it were. Some flash fast, some glow steadily for a long time, and some even flash in combinations of these two methods. The male in flight transmits the signal, and the female perched below deciphers the code to determine if it is the male she wants to mate

with. If she is interested, she pauses for a moment, and if she is not, she does not flash in return (Faust *et al.*, 2020). The ability to produce cold light for signaling in flirtatious communication is a remarkable attribute, but the use of the light as a warning signal can be a dangerous practice if a wrong or predator observer notices it.

### Geographical Distribution and Diversity

Fireflies are little beetles that glow in the dark, and they belong to family Lampyridae. They can be found throughout much of the world, from hot tropical forests to colder areas with seasonal change. Scientists have discovered more than 2,200 distinct species of them, each with a shape, habits, and way of living unique to this type. Species diversity is greatest in tropical areas where warm temperatures and moist air help baby fireflies (larvae) develop and survive (Lewis *et al.*, 2024).

So many firefly species are endemic to small geographic areas and tend to occur in biodiversity hotspots, regions with many plants and animals living together. Some Lampyrid groups, for instance, are found in Neotropical areas where thick forests and humidity provide suitable conditions for their survival and evolution. Previous research focused on their external characteristics, such as color patterns, but many species were not fully recognized. (Vaz *et al.*, 2020). The Lampyridae family of fireflies can be found throughout the globe utilizing relevant scientific information.

Fireflies can be found in a variety of habitats, including wetlands, meadows, forest edges, farms, and riverbanks. Their offspring, which are known as larvae, develop in different environments; this has led to grouping of fireflies into three groups: aquatic, semi-aquatic or semi-terrestrial and terrestrial. Water-dwelling fireflies have specialized body parts, such as gills, to aid in their survival, while those on land develop in moist soil or beneath leaves. (Yang *et al.*, 2024).

Fireflies live most of their lives as their baby stages, known as larvae, so picking the right little homes to settle in is important for growing and surviving. In block, for example, one large survey examined

376 research papers on firefly larvae but only gave detailed research-based focus to 139 species. That means we still do not know much about most fireflies during this important stage of life. (Riley *et al.*, 2021). Insects can live in different environments and rely on moisture, food, and other similar conditions, but it does not really explain larger problems such as pollution or climate change very clearly.

Firefly numbers in different places really depend a lot on the habitats they have, how good those habitats are, and what people are doing around there. Over time, studies show that in many spots, the populations have dropped quite a bit. Things like pollution messing up the natural areas, or climate shifts, they all hit the fireflies hard by lowering how many eggs make it, or slowing down the larvae as they grow, and even making it tougher for the adults to reproduce (Chatragadda *et al.*, 2020).

For one species, like *Aquatica lateralis*, the larvae start out in wet spots such as rice fields or wetlands. Adults show up more in warm weather, usually active from April through November. The biggest groups come out in early summer and mid-summer, when it is hot and humid enough. These changes in seasons affect how fast the larvae develop, if they survive winter okay, and when the adults come out to mate. (Takatsu *et al.*, 2023). But it does not go deep into why these issues happen exactly, or what to do about protecting them better. That part feels a bit open.

### Threat and Decline

Fireflies, also called lightning bugs, are unique creatures that can be identified by the bright light they emit at night. The natural light produced by bioluminescence is primarily employed in communicating and mating with another partner. These creatures belong to the Lampyridae family and prefer habitats such as forests, wetlands and grassy areas. They were abundant in many parts of the world some time back, but there has been a significant decline in the number of fireflies in recent times (Lewis *et al.*, 2016). All the same, fireflies are not just ornamental insects; they are

very important for maintaining the equilibrium in nature.

However, habitat loss has proven to be one of the significant factors causing a reduction in the population of fireflies. For instance, most of these insects and the environments that support them such as wetlands, urbanization, and agricultural practices are gradually destroying the forest cover, riverbeds, and breeding areas. Nonetheless, an urban nature ecosystem is created rapidly (Owens *et al.*, 2020).

Moreover, wetlands play an important role in the life cycle of fireflies because the larvae of these insects mostly develop in damp soil near a body of water. As soon as these wetlands are drained or converted into agricultural land, residential buildings, and other construction sites, fireflies will lose their crucial breeding and habitat grounds. Moreover, when vast natural habitats are broken down into smaller areas or fragmented, we refer to this process as habitat fragmentation (Hellmann *et al.*, 2016). Habitat loss and light pollution are two essential elements that the article effectively addresses.

Fireflies exchange information among themselves using light flashes. Every species has its distinct pattern that facilitates mating between both genders at the appropriate time. The flashing light is important to their reproduction process. But with the increasing use of artificial lights around the world, this group of pollinators faces the risk of extinction. Lights from streets, buildings, advertisements, and vehicles make the night environment brighter than it was before (Hölker *et al.*, 2020).

This kind of pollution can affect the communication patterns of the fireflies. In case the intensity of the artificial light is too high, the dim lights that are emitted by the fireflies become invisible. Therefore, both male and female members of this species cannot locate each other easily, hence reducing their mating rate (Faust *et al.*, 2017). The global warming and climate changes detection part makes the writing detailed, as it states about how world environment may change which can disrupt firefly's life cycle depending on their region.

A further factor that has contributed to the decline in firefly populations is the use of pesticides and agricultural chemicals. Firefly larvae live underground for find most of their early life and eat small creatures that likely include worm, snails, and other small insects. Because farmers use chemical sprays to protect crops these chemicals can leach into the soil and nearby bodies of water. Consequently, it has detrimentally impacted both the larvae and their food source (Perkin *et al.*, 2020). This knowledge gives the reader a global understanding that firefly decline is not just because of one reason but an outcome of several environmental factors that are interplaying.

### Climate Change Impacts

Climate change is thought to be impacting firefly population as well. Each species has its own distinct way of glowing which enable males and female to recognize each other when the mating season comes. Street light, building light, being in vehicle lights and advertisement boards offer us too much bright night spot than it was before. Fireflies, or lightning bugs, are members of the lampyridae family and live in warm and humid habitats including forests, wetlands and grassy areas (Faust *et al.*, 2020).

They breed and depend on water systems, forests and riverbanks. However, rapid urban natural ecosystem. Learning about these threats is important to fix fireflies and keep biodiversity. That geography has fragmented firefly populations in such a way that it restricts their movement and complicates finding appropriate habitats and mate partners. This may, in turn, have adverse effects on both the larvae and their food source (Seymoure *et al.*, 2018).

### Human Activities and Cultural Impact

Bioluminescence is primarily used for communication and the revelation of mates. Fireflies are a member of the lampyridae family and they are usually found in warm, humid places like forests, wetlands, or grasses. In the old days, fireflies in many parts of the world were an equally ubiquitous presence. When soil and water get polluted, the surrounding environment becomes

dangerous for growth and development. Such contaminated can disrupt their life cycle, adversely affecting their survival rate ultimately leading to slow extinction of their population (Cock *et al.*, 2009).

Fireflies are an important part of natural ecosystems and are known for their distinct

glowing abilities. But their numbers are under threat from habitat destruction, light pollution, pesticide use climate change and human activity. By reducing artificial light at night and practicing environmental care, we can conserve fireflies and sustainably restore biodiversity (Firebaugh *et al.*, 2020).

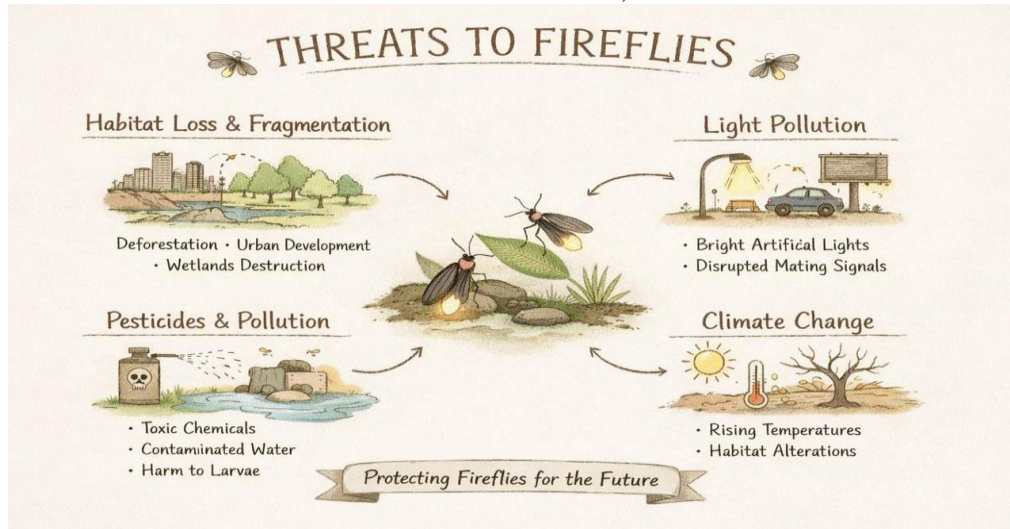


Fig. 02. Major Threats to Firefly Population

**Conservation Status**

The International Union for Conservation of Nature’s Species Survival Commission Firefly Specialist Group is attempting to determine which of the world’s approximately 2,200 firefly species are most threatened with extinction. They began this work in 2020 by compiling whatever information was out there about where these species are found, what kinds of places they live in, how they grow and behave and what threats they face (Lewis *et al.*, 2024).

We found that the core burnt areas and both the burnt sites and burnt perimeter were most similar in species composition. It indicates both species turnover in burnt areas and changes in their abundance. *E. tenax*, *E. corollae* and *E. lucasi* mainly drove differences this year. These migrated species were plentiful on burned sites but other almost non-existent on unburned sites. Smaller, medium-sized *Eupeodes* species were more prevalent along the periphery whereas *E. tenax* already dominated the core (Nakas *et al.*, 2023).

Some 19 firefly species inhabiting the Highlands of northern Thailand demonstrate their incredible diversity. For example, lower montane forest with rich and diverse vegetation supported many species whilst monoculture plantation harbours only few suggesting they provide limited resources; some fireflies exhibit strong habitat preferences. *Pyrocoelie* is restricted to lower montane forest and *luciole* clears upper montane forest (Wattanachaiyingcharoen *et al.*, 2016). Greater emphasis on collecting reliable population data will improve understanding of the conservation needs of lesser-known firefly species.

**Monitoring and Future Direction**

We demonstrate that the use of a single assemblage to monitor fire response may be misleading, unless sensitivity and complementarity have first been determined. It emphasizes the importance of including a diversity of taxa to more accurately represent trends in overall biodiversity. For the CFR we recommend a generalist species, such as butterflies, ants and scarab beetles for monitoring arthropods in post

fire recovery and conservation programs (Pryke *et al.*, 2021).

Firefly abundance peaked mid-summer at most sites. All but one location peaked from June to August, while the other reached its maximum earlier in May. In the year 2006, most of the sites showed their peak in June; however, site 5 reaches it a month later. For the peak in 2007 it shifted to events occurring between April–August. Besides the major peak, secondary smaller peaks of incidence were noticed from December to February annually (Khoo *et al.*, 2012).

This study is critical for preserving fireflies and their habitat in order to maintain their long-term conservation while simultaneously promoting sustainable ecotourism in the area. Researchers now had a clear view of the mangrove ecosystem for a period spanning many years, through satellite imagery areas that are difficult to access and monitor otherwise. Translate these insights into ensuring careful management and rigorous protections of their habitats to preserve the ecological and tourism value of these areas (Idris *et al.*, 2025).

The role of the IUCN SSC firefly specialist group is to assist stakeholders at firefly tourism sites in developing conservation wise strategies. Information on firefly ecology and protection is also being improved, drawing from scientific research such as De Cock *et al.* (2015) And Fallon *et al.* (2019) and practical guides for visitors, such as firefly- watching in Taiwan. While the events provide a great benefit for the population of safeguard fireflies, we also see an unprecedented opportunity to capitalize on their popularity in order to increase public awareness and ultimately accelerate greater appreciation for the conservation of all invertebrates (Lewis *et al.*, 2021).

### Conclusion

The firefly (order *Lampyridae*) is an extraordinary insect that embodies a rare blend of biological uniqueness, environmental significance, and cultural value. The ability of these insects to emit bioluminescence through communication, mating, and defense strategies is one of nature's

best examples of evolutionary adaptation. From the protracted predatory life cycle of the larvae to the brief reproductive adult phase, fireflies display a unique life cycle that is highly dependent on environmental factors. Fireflies can be found in abundance globally and have been around for millennia. However, these insects are facing significant threats to their existence. Factors like habitat destruction, light pollution, pesticide use, climate change, and human encroachment have contributed to the endangerment of several firefly species. It is vital to know that fireflies are bioindicators, which mean that their appearance shows the state of the ecosystem. Thus, their extinction indicates a greater issue within the ecosystem, which might have a negative impact on other organisms too. Nonetheless, measures are still not taken towards conserving fireflies since there is an inadequate amount of data available on most firefly species especially in their larva form. In order to conserve fireflies, it becomes necessary to monitor them constantly, protect their habitat, minimize artificial lighting, and adopt environmentally sustainable practices. Moreover, educating people about fireflies through ecotourism can make a huge contribution to their preservation.

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