Glow Worms Tell The Time

BY DAVID MERRITT

Glow worms in forests adjust their light output, but what happens in caves where there are no time cues?

There is something completely alluring about glow worms. The clustered points of bluish light decorating the steep cliffs next to a waterfall, or covering the ceiling in the darkness of caves, is a fascinating and beautiful sight. Visitors that venture into caves or walk in the rainforest at night invariably come away wanting to know more about glow worms: what are they, why are they found in caves and rainforests, and why do they glow?

Glow worms are immature flies – the equivalent of the wriggler or larval stage of a mosquito. The larvae are quite long-lived, taking many months to grow large enough to pupate and then emerge as flying adults.

The adults resemble large, slow-flying mosquitoes. They are very short-lived, only surviving a week or so; just long enough to mate and for the female to lay eggs.

The adult glow worms of Australian species don’t glow, but adult females of the New Zealand species do produce a blue light. Once hatched, the tiny larvae are capable of glowing immediately. They make a small mucous tube and hang “fishing lines” from it. The fishing lines are made of silk and are coated with a series of sticky mucus drops that entangle any insect that flies or stumbles into the web.

The combination of bioluminescence and sticky webs is the key to the success of glow worms. The blue-green points of light emulate stars, causing flying insects to become disoriented and fly to the source in the same way that moths are drawn to light.

Another key attribute is their tendency to cluster in colonies, increasing their drawing power. In some caves they are very densely packed on the ceiling, resembling the milky way but much brighter.

A close look at a colony reveals a spacing pattern in their distribution. Individuals tend to be evenly spaced because the larvae are quite aggressive and mark out their territory with the extent of their snares. When larvae come into contact they fight until one backs away or is even consumed. Sometimes glowing larvae are found on
the floor of a cave where they have fallen from the ceiling due to their attempts to escape these aggressive interactions.

A single larva hangs down many silk lines, the length of which depends on environmental conditions. In still air, such as in caves, the individual lines can be 50 cm long while they are much shorter in the rainforest, where wind disturbs and tangles the lines.

Through the night, glow worms spend most of their time glowing and at the same time doing “housekeeping”: they move back and forwards in their snares, adding new suspensory threads, removing tangled lines and adding new ones. If an insect is caught, the larva immediately brightens and begins hauling up the line. It bites into the captured prey and consumes it completely, or just sucks out the juice and drops the body from the line. They resemble spiders in these habits, hence the inclusion of *arachno*, meaning spider, in their genus name, *Arachnocampa*.

Glow worms are found only in specialised habitats in eastern Australia and New Zealand. At Waitomo in New Zealand, the Glow Worm Cave has become an iconic tourism destination where thousands of visitors experience a cave tour followed by a boat ride through the dark glow worm grotto, with its ceiling and stalactites studded with glow worms. In Australia, the best-known glow worm tourism site is at Natural Bridge in Springbrook National Park inland from the Gold Coast. There, a cave behind a waterfall in the rainforest is prime glow worm habitat visited by many tourists at night.

Australian glow worms had been scientifically neglected until recently, when a study carried out by Claire Baker at the University of Queensland identified five new species of Australian glow worms, bringing the total to nine species, eight in Australia and a single New Zealand species named *Arachnocampa luminosa*. In Australia they are found in the rainforest of the Great Dividing Range from the Wet Tropics region in northern Queensland...
all the way to southern Victoria and Tasmania. They occupy a wide latitudinal and climatic range, from the wet tropics to the cool temperate regions of Tasmania and New Zealand and the Australian Alps. Species don’t overlap; rather, they are distributed in a north-to-south fashion in Australia.

Even in rainforests they are found only in specific types of habitat, and conditions have to be just right to maintain a colony. First they must be near running water. It seems that flying stream-associated insects such as chironomid midges are the most reliable prey. Even near streams they are only found where conditions are highly shaded, protected from wind, and there are steep banks to set up their hanging threads.

They dehydrate very quickly, so in times of drought they draw back into the most reliably moist areas in forests and caves. When conditions improve, populations expand to take advantage of the increased humidity and the increase in prey.

Glow worms are among a group of flies that are recognised as primitive, putting their date of origin perhaps earlier than the Jurassic – the time of the dinosaurs.

The evolutionary pathway to using bioluminescence as a lure for prey is fascinating, and while we can’t recreate history we can make inferences about possible evolutionary events leading to their peculiar habits. Their close relatives, the fungus flies, have larva that live on fungal fruiting bodies, such as mushrooms and bracket fungi. These larvae make slimy tubes and feed on the mushroom tissue.

It seems that an ancestral fungus fly evolved to become predatory and used its web to trap prey. Then the glow worms developed bioluminescence, increasing their chances of catching prey and freeing them from an association with mushrooms as a habitat.

In fact, rather distant relatives of glow worms have evolved many similar characters. These species are found in the caves of China and southern Asia. The larvae make horizontal tubes, hang down mucus-studded silk lines and are predators – but they have not evolved the ability to produce light. Otherwise, their habits show evolutionary convergence with glow worms.

My speculation is that the glow worms of Australia and New Zealand are derived from a Gondwanan ancestor that evolved the ability to bioluminescence. Phylogenetic reconstruction of the glow worm family tree suggests that ancestral glow worms were adapted to cool climates. Maybe they evolved bioluminescence as a way of coping with the long, southern polar nights that prevailed when Gondwana was close to the South Pole but not covered with ice and glaciers.

There is no equivalent of a mild polar climate on our planet now, but fossil evidence indicates that Gondwana had a relatively mild climate and was covered with plants that must have had marvellous adaptations to survive the seasonal extremes of long periods of low light in winter and conversely long periods of sunlight in summer.

Polar night-adapted dinosaurs skeletons have been discovered in southern Victoria. Maybe glow worms evolved bioluminescence to enhance their ability to capture prey through the long nights of polar winters.

As Gondwana drifted north and split up, glow worms survived in the humid and dark conditions of rainforests and caves. Glow worm populations achieve their most impressive displays in caves. Here they rely not so much on the ecosystem of the cave – cave biota is somewhat limited in biomass and diversity – but the ecosystem outside the cave because they capture flying adult insects that drift into the cave as aquatic immature stages. It is well-known that freshwater stream invertebrates naturally utilise stream drift to disperse, even showing daily rhythms in drift times. In the rare situations where a stream "sinks" into a cave, their life cycle is completed in the cave. There they provide dinner for glow worms because there is no
natural light to compete with the glow worms' bioluminescent attractions.

Caves provide a natural laboratory for studying how animals cope with the absence of light. Glow worms are an ideal organism to study such adaptations because populations of the same species are found deep in the cave where they have never experienced natural daylight, as well as in the cave mouth and surrounding forest where they are exposed to natural day/night cycles.

Glowing of rainforest glow worms is restricted to night-time. We decided to investigate whether its onset and duration come under the control of an internal clock.

Light is produced in specialised cells at the tips of blind-ending tubes known as Malpighian tubules. The tubules have an excretory function in all insects including glow worms.

However, glow worms have adapted and changed the function of a small number of cells at the tips of the tubules. They have become enlarged and they produce light. This in itself is a fascinating adaptation.

But the glow worm was faced with the evolutionary challenge of regulating light. Presumably light uses energy, and there is no point in glowing during the day.

A number of researchers have shown that light output is modulated via the nervous system. Light intensity increases during aggressive interactions, when larvae detect vibration or are artificially exposed to anaesthetics. Not surprisingly, they douse when they detect bright light or when they are severely disturbed by a potential predator or curious human.

These and other clues and experiments led to the assumption that bioluminescence is controlled by the nervous system. To determine whether there is an innate glowing rhythm, we brought glow worms into the laboratory and placed them in individual chambers in humid conditions under constant darkness. The glow worms continued to cycle their glow intensity on an approximately 24-hour cycle, turning on and off for many weeks despite the absence of any cues as to what time of day it was. Thus they resemble many animals in possessing biological rhythms. In natural conditions in the forest where they are exposed to regular light/dark cycles, the rhythm is re-entrained (the clock is reset) naturally every day.

The next obvious question is what happens in caves where there are no cues as to what time of day it is? Do the glow worms maintain a glowing rhythmicity, or do they glow continuously?

In our discussions with seasoned glow worm watchers and people who run cave tours as well as earlier scientific observations we were told that they glow continuously, and maybe a bit more brightly at night. To test this we had to obtain equipment capable of photographing the glow worm lights at set intervals and sensitive enough to detect their glows, with enough battery power to last for several days, and withstand the wet, muddy conditions in caves. We were able to do this using digital cameras and time-lapse controllers and external batteries.

We discovered that glow worms do...
indeed show a rhythm of glowing in caves. Any single population is highly synchronised: all individuals show a similar phase in their rhythm. The period of the rhythm is exactly 24 hours, so there must be some external cue allowing the rhythm to be reset daily; otherwise it would drift out of period with the external day/night cycle. More on that later.

The most surprising result was that the glow worms in caves glow most intensely during the afternoon and dim to their low point late at night – quite the opposite to populations outside the cave in forests or in the cave mouth that all glow nocturnally. The most likely reason we could think of was that, away from the influence of daylight to repress bioluminescence, the peak phase of the rhythm could be adjusted to match the peak prey flight times in the cave.

As mentioned above, stream drift brings these prey insects into the cave. They could be emerging from their pupal stages or non-flying stages on a daily rhythm that was initiated in their life outside the cave. A periodicity in their time of capture could then provide the stimulus that causes glow worms to maximise their light output to anticipate the presence of prey.

To test this we set up an ultraviolet light-baited trap inside a cave and counted the flying insects attracted to the trap in 3-hour samples over several 24-hour periods. We found that the peak flight activity time closely matched the time at which the glow worms’ light peaks, so maybe the presence of prey has “entrained” the rhythm in the cave and shifted it out-of-phase with the natural external day/night rhythm.

Understandably, bioluminescence has fascinated scientists and lay people for many years. Glow worms have many more secrets to give up, especially as to how evolution has shaped the unusual adaptations that allow them to thrive in such specialised habitats.

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