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Bioluminescence
Learning from glow-worms

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All over the world, on land and in the sea, living things have been making light for millions of years. From the glow of the sea on a dark night due to myriads of phytoplankton, to the dance of the male fireflies trying to attract a mate, this phenomenon, bioluminescence, has fascinated people for thousands of years.

In Australia I study insects known as glow-worms which live in our caves and out in the forest, giving a display which entrances tourists and scientists alike. But I am the really lucky one because I get paid to observe and study these fascinating insects in the Australian outback.

What is bioluminescence?

Bioluminescence, or 'living light', is a remarkable phenomenon in the plant and animal kingdoms where light is produced by a chemical reaction inside a living organism. One of the amazing things about bioluminescence is the end product of the reaction is almost 100% light. When this is compared to human light production it is easy to see we have much to learn! When humans create light, we waste enormous amounts of the energy just producing heat. For instance, most incandescent light bulbs give out over 97% heat and only produce 3% light. Fluorescent light bulbs are up to 15% efficient, but this is still not in the same ballpark as bioluminescence.

How does an insect create bioluminescence? The reaction occurs when luciferin (a substrate) is oxidized by luficerase (an enzyme), to make oxy-luciferin, which in turn gives off light photons and carbon dioxide. ATP (adenosine tri-phosphate) powers the reaction.

The stunning bioluminescent display of a colony of glow-worms.

What are glow-worms?

The common name 'glow-worm' is used to describe many different species that use bioluminescence. The glow-worms that I study in Australia and New Zealand are the larvae of a delicate fly. These fascinating insects undergo a holometabolic life cycle, i.e. a transformation from an egg, to a larva, to a pupa, to an adult (see Figure 1) as do many other insect groups such as butterflies and moths (Lepidoptera), beetles (Coleoptera) and all other flies (Diptera) (Box 1).

Figure 1 *The life cycle of a glow-worm: from left to right adult female, adult male, eggs, larva, pupa. (Images Anthony O'Toole, University of Queensland)*

It is only in the larval stage that glow-worms can actively create light, as the chemicals required are produced in their digestive system. However, occasionally adult glow-worms have been observed to give off a very weak light if disturbed in the adult or pupal stage. This light is probably due to residual chemicals being present, as they lose their digestive system when they pupate to become adult flies and are thus unable to physically produce light. The larval stage lasts for between four months to one year, although this is dependent on environmental conditions and prey abundance. The adults are very short lived (females two days, males six days), as they are unable to feed due to the loss of their digestive system. It is during the short adult stage that glow-worms are able to find a mate and reproduce, thus ensuring the success of another generation.

An adult female Arachnocampa flava. *The adult stage is the reproductive stage of this insect's lifecycle. They must mate and lay eggs to ensure the survival of the species.*

Why do animals use bioluminescence?

There are many uses in the plant and animal world for bioluminescence. For instance some species use their lights for mate attraction. For example, adult fireflies (Coleoptera; Lampyridae) use their pulsing light to signal and attract a potential mate. Other organisms use light to communicate, scare off predators, illuminate their habitat and attract potential food. *Arachnocampa* glow-worms glow to attract small insects emerging from the leaf litter and water in and around which they are usually found. The glow-worms construct "snares" made from silk threads and sticky mucous droplets to capture insects so they can be devoured. Their scientific name, *Arachnocampa*, refers to their "spider-like" ability to make a web snare.

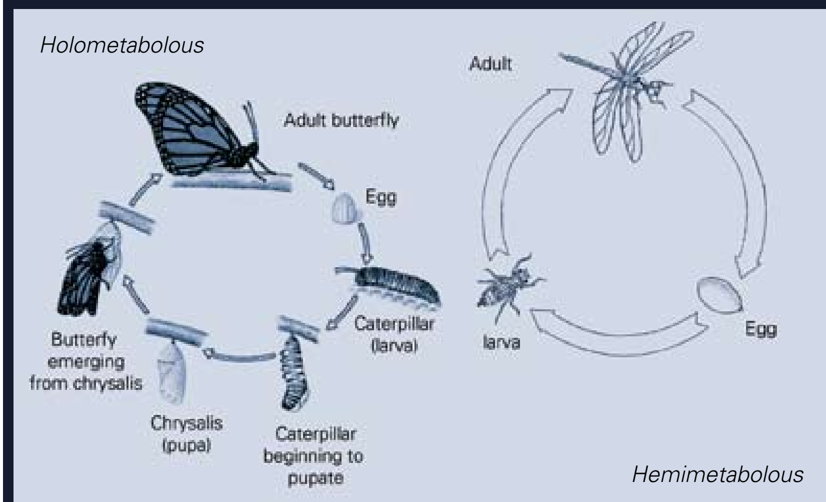
The individual light of one glow-worm is remarkable but easily missed unless specifically looking for it. When glow-worms congregate in large numbers in suitable forest habitat they make breathtaking displays of light that attract human tourists from around the world. These incredible displays serve as powerful lures for drawing insects towards their silken snares. Thus, by working as a team, they attract more insects to their snares.

The silken snare of one glow-worm larva, used for prey capture. Each snare is made from a thread of protein (silk) with sticky droplets of water affixed. The terminal segment of the glow-worm is where the glow is produced.

Box 1

From egg to adult

There are two major ways in which insects develop from egg to adult: Holometabolous and Hemimetabolous.



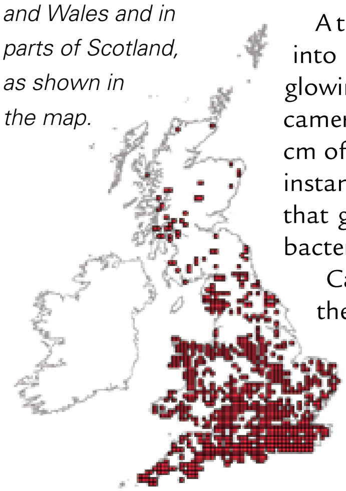
What other organisms can bioluminesce?

Many organisms glow in our natural world. Bioluminescence evolved separately in different groups including single celled organisms, earth and sea worms (the *real* 'glow-worms'?), insects, centipedes, millipedes, sea sponges, jellyfish, vertebrates like deep-sea fish and even some sharks. Fireflies are major tourist attractors in Asia and North America, where large congregations on trees appear like giant sets of flashing fairy lights in the wild. There a number of beetle familes that have evolved the ability to glow. Railroad worms (Phengodidae) and click beetles (Elateridae) are examples of these. Outside the animal kingdom, a number of fungi and lichen species are known to glow. In a few rare instances, the glowing organisms rely on bacteria to create the glow. However, most organisms create their own glow through a similar enzyme-based reaction to glow-worms.

One tiny firefly larva in the leaf litter. Fireflies uses bioluminescence in the larval stage to attract food and a pulsing light in the adult stage to attract a mate.

Where to see bioluminescence in the UK

Unfortunately Arachnocampa *spp. are not found in the UK, but there is a bioluminescent insect called a glow-worm. This one is a beetle,* Lampyris noctiluca, *which is quite common. It can be found all over England and Wales and in parts of Scotland, as shown in the map.*



Glow-worms and biotechnology

Glow-worm DNA is now synthesized and used in the biotechnology field to 'mark' or 'tag' diseases, infections or other cells being studied Anyone in working in a genetics lab will use these tags as part of everyday work. The very first tag to be used was green fluorescent protein (GFP) from bioluminescent jellyfish.

A tag is a small piece of DNA that can be inserted into any living cell via a bacterial vector. The glowing cells are then monitored using a specialized camera that can read levels of light though up to 6 cm of body tissue. The tag can be spliced with, for instance, embryonic cells to make an entire animal that glows (every cell contains the DNA), or with bacterial or fungal cells to map infections.

Cancer cells are tagged for monitoring during the drug testing phase of drug design. The tagging does not kill the cancer, but it allows scientists to be able to see the direct response of the disease or infection to various drug treatments. The technology is not yet being used on human patients, but by using it in the drug design process, fewer animals are needed for testing (the same individual can be used multiple times as they do not have to be killed and dissected to observe growth or decline of the cancer cells) and it rapidly speeds up the entire process.

Learning more from bioluminescence

Could insects hold the answers to more efficient lighting systems for humans? The glow of a glow-worm is now inspiring scientists to make more efficient lighting systems. Organic light emitting diodes (OLED's) are being used as a more efficient way of lighting up television screens, PDA's, mobile telephones and computer screens. An OLED consists of an organic membrane that is powered by electricity. This type of technology is known as electroluminescence as it still requires an external power source. Phosphorescent technology works through the absorption of light photons that are then slowly released over time. Phosphorescence is used in items like glow in the dark plastics and safety work clothing.

Other products and ideas that have been inspired by or directly use bioluminescence technology include bioluminescent trees along highways to decrease electricity usage, christmas trees that use bioluminescence instead of electricity, agricultural plants that glow when they need water, using bioluminescent markers to assess contamination in food products and novelty pets such as glowing fish.

Glow-worm survival in the future

Glow-worms need very specific rainforest habitat or caves for survival. As our own species continues to expand, some of the more severe threats to glow-worm survival include: habitat loss and fragmentation, increased sedimentation in waterways, climate change, predators, parasites, fungal or bacterial infections, stream degradation and direct human impacts such as insecticides and other chemicals, insect repellants, vandalism, smoking? and soil compaction (shortcutting off walking tracks).

Special projects, like the glow-worm caves on Tamborine Mountain (see links below) and education are the two main ways in which these fascinating animals might be preserved for the future.

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Look here!

Bioluminescence web page:
www.lifesci.ucsb.edu/~biolum/

Caliper life sciences – imaging inside living animals using bioluminescent tags:
www.caliperls.com/products/optical-imaging/

Where to see Australian glow-worms:
www.cedarcreekestate.com.au/tmgw/index.html

Studying glow-worms in the UK:
www.uksafari.com/glowworms.htm