BIOLUMINESCENT GLOW-WORMS:
IS THERE A DIFFERENCE BETWEEN CAVE AND RAINFOREST POPULATIONS?

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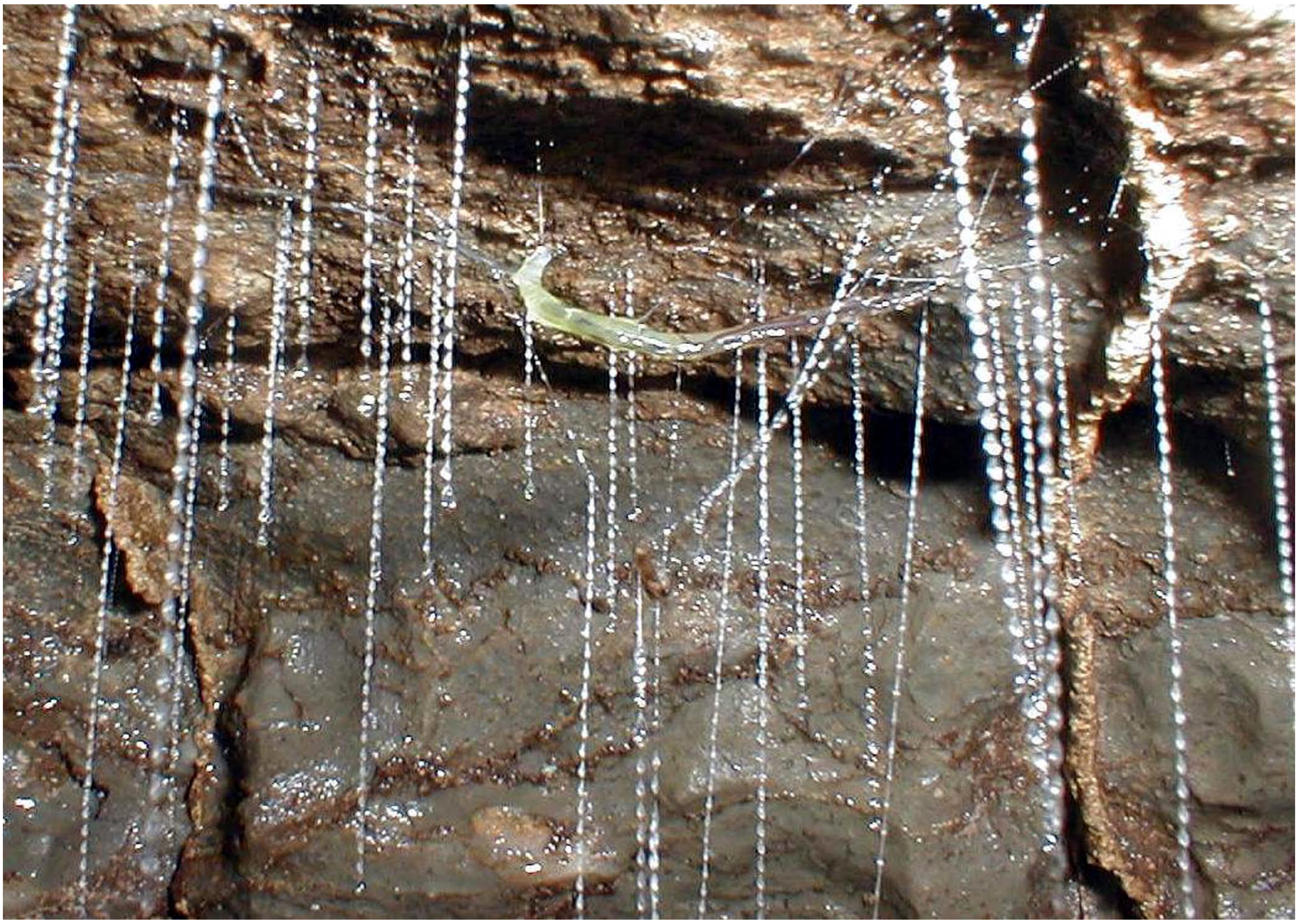

Arachnocampa tasmaniensis.

INTRODUCTION

Glow-worms are the larvae of a fly from the family Keroplatidae. The unique feature of glow-worms is their ability to bioluminesce—to produce light. Because they are not very mobile the larvae must trap flying insects in their webs, and they use light to bait the trap. The larvae build a structure composed of a horizontal mucous tube suspended by a network of threads from the earth or rock substrate. The larva moves back and forwards in the tube and can turn in its own length. The larvae spend a considerable amount of time maintaining their "snares"—the many fine silken fishing lines that hang downwards, decorated by periodically placed sticky droplets. We have made artificial glow-worm habitats to keep larvae in the laboratory and used invisible infrared illumination to video record them as they maintain their snares through the night. Larvae bioluminesce and behave as normal while they are being observed. The production of fishing lines is a very stereotyped behaviour, originally described by Stringer (1967) for *Arachnocampa luminosa*, the New Zealand glow-worm. Larvae glow very brightly when an insect is caught in their web, although we are not sure exactly why.

LIFE CYCLE

The larval stage lasts many months, finally forming a pupa that lasts about a week. The pupa is suspended from the hardened thread-like remnants of the mucous tube that held the larva. One of the most obvious differences between *A. luminosa* and the Australian species is that *A. luminosa* pupae hang vertically from a single thread while all Australian species hang horizontally from a front and rear thread.

The adults look like large mosquitoes with very long legs. They are sluggish fliers and frequently rest on the walls of embankments or caves. They are very short-lived, surviving for only a few days after emergence from the pupa and apparently do not feed. The males will find a female pupa and wait for her to emerge so that they can mate. Males are more slender than the females that emerge from the pupa with an abdomen swollen with eggs. The female flies live only two days so mating and oviposition (egg laying) begin immediately upon emergence. Each female lays 130 eggs that take 7-9 days to hatch (Baker and Merritt, 2003).

BIOLUMINESCENCE

The bioluminescence is produced by internal cells located in a swelling at the posterior end of the larva. The blue-green light is visible through the transparent cuticle. The light producing cells are surrounded by a reflective structure composed of very fine air-filled tubes that appear as a white mass when examined closely. The light-producing chemical reaction is similar to the well-known firefly luciferin/luciferase reaction. However the enzyme and substrate are not identical to those used in fireflies (Viviani et al., 2002).

Bioluminescence output can be rapidly modulated, for example, when disturbed or exposed to bright light, larvae will douse their own light. In some caves of New Zealand the glow-worms can be made to increase the intensity of their light by splashing the water in these otherwise quiet caves. Glow-worms switch off their bioluminescence when exposed to daylight or intense torchlight. In caves they bioluminesce more or less continuously however one of our aims is to test this utilising time-lapse photography in a cave.

We have shown that their light output is temperature dependent. Within an acceptable range, light output increases exponentially with temperature, but at higher temperatures light output ceases and glow-worms show deleterious effects. Our experiments so far have used *A. flava* from south-east Queensland rainforest. It is likely that temperate species such as those from Tasmania will have a much lower range of acceptable temperatures.

GLOW-WORMS IN CAVES

In caves where the airflow is gentle the snares can reach 50 cm in length. In rainforest where they are exposed to stronger air movement they are usually shorter.

The distribution of glow-worms is determined by their sensitivity to desiccation. They quickly die when exposed to low relative humidity or excessive air movement hence they are found only in the most sheltered habitats such as heavily treed, shady, moist gullies or in caves. It is in caves that they reach their highest density, producing spectacular displays of bioluminescence. In most cases the caves that contain glow-worms are within or near rainforest patches or tree fern-lined gullies, suggesting that caves are a secondary, although very suitable, habitat for these insects. Not all caves have glow-worms. Our surveys show that they occupy only those caves with organic input from the outside environment, usually in the form of a stream. Glow-worms are common in wet boulder caves associated with underground streams. In Victoria and Queensland we have collected glow-worms from granite boulder caves in areas where we would not otherwise expect to find them because rainforest is not found nearby. These populations may be relicts of a distant past when the surrounding vegetation was more lush. In caves, glow-worm numbers can fluctuate depending on the season and the history of floods.

More research is needed to find out what characteristics determine their population levels in caves. They are rarely found deep in caves, rather they are usually found near cave entrances, and are true troglophiles.

They show some adaptations typical of cave animals, including reduced pigmentation. Glow-worms from the interior of caves are a creamy colour due to their visible internal organs. By contrast, glow-worms that experience daylight at the mouth of the same cave have brownish pigmentation of the hypodermis especially in the head region. The degree of pigmentation is due to the environment rather than genetically predetermined.

SPECIATION AND GENE FLOW IN GLOW-WORMS

At the start of our work three species of glow-worm had been described in Australia: *Arachnocampa flava* from south-east Queensland, *Arachnocampa richardsae* from the Blue Mountains region, and *Arachnocampa tasmaniensis* from Tasmania. Claire Baker, as part of her PhD project, has identified 5 additional species: *A. tropicus* from north Queensland, *A. girraweenensis* from northern New South Wales, plus *A. gippslandii, A. otwayensis and A. buffaloensis* from Victoria.

Despite the geographical separation of glow-worms within Australia and New Zealand, the different species are remarkably similar in appearance and life habits, however, there are regional differences. With the help of an evolutionary tree (termed a "phylogeny") based on DNA sequence analysis, indications are emerging that the most ancient species, namely the Tasmanian, Mt Buffalo and New Zealand species are more cave adapted than their relatives located in rainforest along the Great Dividing range. These species tend to be larger and have longer snares than their northern neighbours, even when found in rainforest. Our next series of experiments will involve collecting glow-worms from within individual caves of a karst region as well as from nearby rainforest. Using gene sequences called "microsatellites" we hope to discover how much migration has taken place between individual caves and between caves and rainforest populations. This information will be useful in managing threatened, relict populations and those under tourism pressure. ■

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