AUSTRALIAN GLOW-WORMS

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INTRODUCTION

Glow-worms are the larvae of a fly from the family Keroplatidae (Matile, 1981). While the biology of the New Zealand glow-worm, *Arachnocampa luminosa*, is well known (Gatenby, 1959), Australian glow-worms have not been studied in detail. The emergence of cave-based tourism featuring glow-worms has led to a demand for knowledge about their biology and potential tourism impacts. Also, the diversity of glow-worms in Australia is only partly known—no comprehensive survey has been carried out—and a knowledge of species identities is crucial for management of cave biota.

BIOLOGY

From our studies, the behaviour and habitat preferences of Australian glow-worms are very similar to those of *Arachnocampa luminosa* (Richards, 1960; Gatenby, 1960; Stringer, 1967; Meyer-Rochow, 1990). The worm-like larvae prey on flying insects, mostly small flies (Diptera) that are attracted to the larval bioluminescence. The larvae lie suspended in their "snares"—the complex structure composed of a horizontal mucous tube suspended by a network of threads from the earth or rock substrate. Many fine, silken fishing lines hang downwards, decorated by periodically placed sticky droplets. Flying insects are caught in the droplets and hauled up for consumption by the voracious larvae. The larval stage lasts many months. In contrast, the adults are very short-lived, surviving for only a few days after emergence from the pupa (Baker, 1999). The males may attach themselves to a female pupa waiting for her to emerge so they can mate. The female then flies off to lay her eggs. An obvious difference between the Australian glow-worms and the New Zealand species, *A. luminosa*, is that *A. luminosa* pupae are suspended from the substrate on a single thread (Richards, 1960) while all the Australian species are suspended horizontally by anterior and posterior threads (Baker, 1999; Baker and Merritt, personal observations).

BIOLUMINESCENCE

The glow-worm's bioluminescence is produced by cells at the tips of the Malpighian tubules, visible through the transparent cuticle at the posterior of the larva. The light-producing cells are surrounded by a reflective structure composed of very fine tracheoles. The glow-worm's bioluminescence is blue-green in colour with a peak in the spectrum at 485 nm (Lee, 1976). The light-producing chemical reaction is ATP dependant, indicating a similarity to the firefly luciferin/luciferase reaction. However the bioluminescent system is different to that of fireflies and different to that of a north American bioluminescent fly larva, *Orfelia fultoni* (Viviani, Hastings and Wilson, personal communication).

Bioluminescence output can be rapidly modulated, for example, when disturbed or exposed to bright light larvae will douse their light. They bioluminesce continuously under anaesthesia (Lee, 1976) or when the body is ligated, separating the terminal light-producing organ from the control centres in the brain (Gatenby, 1959).

GLOW-WORMS IN AUSTRALIAN CAVES

Glow-worms are found in caves or rainforest gullies, however it is in caves that they reach their highest density producing spectacular displays of bioluminescence. The hypogean and epigean environments expose glow-worms to different conditions. In the epigean environment they are exposed to climatic extremes. Experiments have shown that they are very sensitive to desiccation due to reduced relative humidity or excessive air movement hence they are restricted to the most sheltered habitats such as heavily treed, moist gullies. On the other hand, in the hypogean environment they are buffered from climatic extremes. However the food supply is less predictable and they are capable of going without food for many weeks or months (Meyer-Rochow, 1990). They occupy only those caves with organic input from the epigean environment, usually in the form of streams bringing in organic matter in which chironomids or other small Diptera breed. They are rarely found deep in caves, rather they are usually found near cave entrances, and are true troglophiles. Granite boulder caves or boulder in-fill caves appear to be prime glow-worm habitats. Boulder in-fill caves with active streams are generally short with a constant or periodic inflow of organic material or immature aquatic insects. The boulder jumbles form a series of chambers that trap the flying insects that form the glow-worms' prey.

TOURISM AND GLOW-WORMS

The incentive to pursue the study of the biology of glow-worms came from Queensland Parks and Wildlife Service (QPWS) officers who were interested in identifying possible threats to the glow-worm population at Natural Bridge in Springbrook National Park. A significant tourism industry has arisen based upon night viewing of glow-worms in a cavern lying behind a waterfall that has eroded its way through harder surface deposits forming a natural arch or bridge. Management practices to ensure sustainability have historically been based on the biology of the well-known New Zealand glow-worm *Arachnocampa luminosa* that has been studied in some detail, especially at Waitomo Caves (Pugsley, 1984). Information on the southeast Queensland glow-worm *A. flava* was needed so that management practices at Natural Bridge could be based around the glow-worms' specific requirements and the unusual environment at Natural Bridge.

Claire Baker carried out a BSc honours project through 1999 to determine tourism impacts on glow-worms. The project was sponsored by QPWS as well as tourism operators and the Cooperative Research Centre for Sustainable Tourism based at Griffith University Gold Coast. Time exposure photography at Natural Bridge and quadrat counts at a nearby, unvisited site provided estimates of the numbers of larvae glowing. Monitoring extended over 8 continuous months of 1999. Her conclusions were that climate fluctuations account for the major variations in glow-worm numbers experienced throughout the year (Baker, 1999). To be confident that long-term protection of the colony is ensured, further issues are under investigation. A watch is being kept for the appearance of fungus disease, a major cause of mortality in New Zealand glow-worms (Pugsley, 1984). To ensure a bright display the torches of visitors could be fitted with filters so currently we are carrying out experiments to determine the sensitivity of glow-worms to artificial light of different colours. The prime times of prey capture will be assessed and the response to climate will be assessed with the aid of a weather station to be installed at Natural Bridge.

Time lapse video images of larval light output are being used to determine whether larvae glow at the same intensity throughout the night. Preliminary results indicate that larvae glow most brightly at dusk, gradually dimming their lights. Perhaps this rhythmicity reflects the activity of flying prey although this remains to be determined by prey trapping experiments.

Currently, commercial glow-worm tourism in Australia is focused on a few sites. Glow-worms are the prime focus of adventure cave tours at Mystery Creek Cave in Tasmania although the number of visitors is relatively low. Natural Bridge in Queensland provides easy access to a spectacular display because access involves a short walk from a car park along hard-surface paths. Consequently visitor numbers are high. Similarly, at Mole Creek, Tasmania a glow-worm display is featured as part of the guided show cave tour at Marakoopa Cave. One of the aims of our research is to provide biological information so that any future proposals for glow-worm tourism in caves can be assessed in light of the biological requirements of the insects as well as taking into account the requirements of the sensitive environments in which they are found.

HOW MANY SPECIES OF GLOW-WORMS?

There are currently 3 described species of glow-worm in Australia: *Arachnocampa flava* from southeast Queensland, *Arachnocampa richardsae* from the Blue Mountains region, and *Arachnocampa tasmaniensis* from Tasmania (Harrison, 1966). However it soon became obvious that glow-worms are more widespread than suspected and that more species could be present. Claire Baker is carrying out collections and identifying specimens from throughout Australia. She has visited sites in rainforests and in wet caves. Glow-worms from the wet tropics in the Cairns region of Queensland are likely to be a new species. There appears to be a large gap in glow-worm distribution along the coast of central Queensland. Glow-worms are known from Victoria, for example they are a popular tourist attraction at Melba Gully in the Otway Ranges National Park west of Melbourne. The Victorian glow-worm has tentatively been identified as *A. richardsae* (Harrison, 1966) however the possibility that southern Victoria could be harbouring an undescribed species will be investigated.

A most interesting glow-worm is found in a granite boulder cave at Mt Buffalo in the Victorian Alps. The population was first mentioned in scientific literature in 1978 (Crosby, 1978). The larva and adult show some very specific features indicating that it is an undescribed species. The wing venation of the specimens more closely resembles the New Zealand and Tasmanian glow-worm than any mainland Australian specimens. At the moment their known distribution is confined to a single cave, so we are working with Victoria's Department of Natural Resources and Environment and Parks Victoria to list the species as potentially threatened. It is possible that it is distributed further afield in gorges of the rugged alpine region however specific searches will have to be carried out.

Glow-worms are commonly found in the wet limestone caves of Tasmania. They are also found in tree fern filled gullies of Tasmania's rainforests. All Tasmanian glow-worms are reportedly the same species, although the epigean and hypogean specimens have very different pigmentation. Pigmentation differences between "bush" and "cave" glow-worms have also been reported in the New Zealand species *A. luminosa*. Allozyme analysis indicated that the cave and bush populations are closely related (Broadley, 1998).

The search for morphological features that distinguish species is underway. An analysis of nuclear and mitochondrial DNA sequences will also help determine the relationships among Australasian glow-worms. It will be interesting to examine the phylogenetic "distance" between the long-standing isolated cave populations such as the Mt Buffalo species and the mainland rainforest species. The relationships between the Tasmanian, Australian mainland and New Zealand glow-worms will also be of interest and may be integrated into the known biogeography of Australia and New Zealand and the history of rainforest contractions.

REFERENCES

Baker, C. (1999) A biological basis for management of glow-worm (Diptera: Keroplatidae: *Arachnocampa flava* Harrison) populations of ecotourism significance. B. Sc. Honours thesis. The University of Queensland.

Broadley, R. A. (1998). Behavioural ecology and prey attraction of the New Zealand glowworm *Arachnocampa luminosa* (Skuse) (Diptera: Mycetophilidae) in bush and cave habitats. pp. 121. Master of Science thesis, Massey University.

Crosby, D. F. (1978). Glowworms. *Victorian Entomologist* 8, 56-59.

Gatenby, J. B. (1959). Notes on the New Zealand glow-worm, *Bolitophila (Arachnocampa) luminosa*. *Transactions of the Royal Society of New Zealand* 87, 291-314.

Gatenby, J. B. (1960a). The Australian mycetophilid glowworms. *Transactions of the Royal Society of New Zealand* 88, 577-593.

Harrison, R. A. (1966). Australian glow-worms of the genus *Arachnocampa* Edwards. *Pacific Insects* 8, 877-883.

Lee, J. (1976). Bioluminescence of the Australian glow-worm, *Arachnocampa richardsae* Harrison. *Photochemistry and Photobiology* 24, 279-285.

Meyer-Rochow, V. B. (1990). *The New Zealand Glowworm*. Pp. 55. Waitomo Caves Museum Society Inc.

Matile, L. (1981). Description d'un Keroplatidae du cretace moyen et donnes morphologiques et taxinomiques sur les Mycetophiloidea (Diptera). *Annals of the Socieyt of Entomology (France) (New Series)* 17, 99-123.

Pugsley, C. W. (1984). Ecology of the New Zealand glowworm, *Arachnocamp luminosa (*Diptera: Keroplatidae), in the glowworm cave, Waitomo. *Journal of the Royal Society of New Zealand* 14, 387-407.

Richards, A. M. (1960). Observations on the New Zealand glow-worm *Arachnocampa luminosa* (Skuse) 1890. *Transactions of the Royal Society of New Zealand* 88, 559-574.

Stringer, I. A. N. (1967). The larval behaviour of the New Zealand glow-worm *Arachnocampa luminosa*. *Tane* 13, 107-117.