# THE NEW ZEALAND GLOWWORM

by

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Cover Photo is of
Glowworm Lava and Threads
Photo: Malcolm Wood


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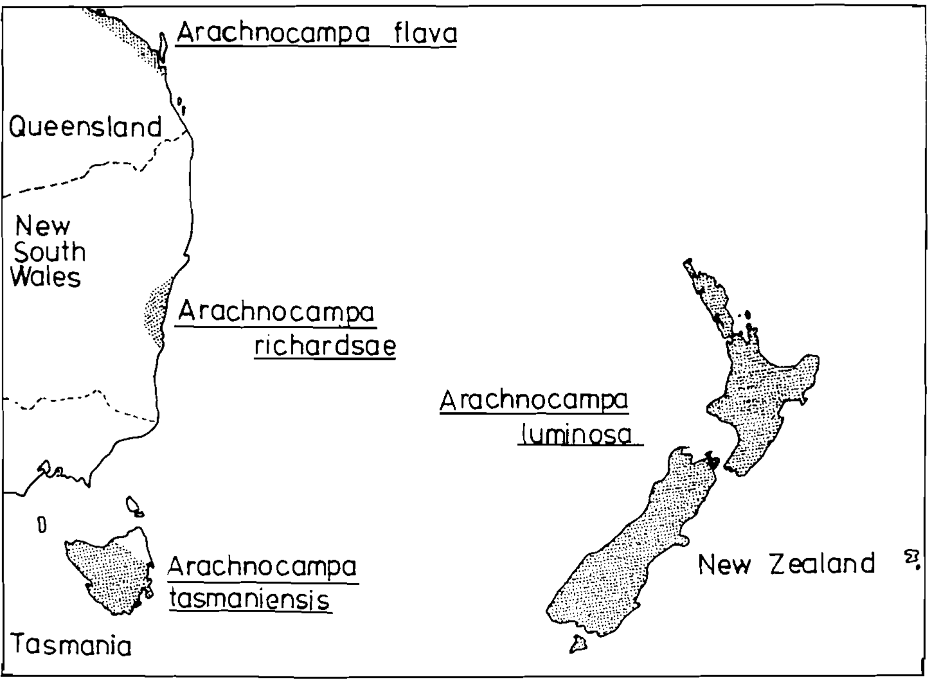
## INTRODUCTION

A feature of anyone's trip to Waitomo Caves is a visit to the Glowworm Caves, and in the Glowworm Grotto we feast our eyes on a wondrous sight. The cavern roof is dotted with thousands of tiny lights, each being produced by our New Zealand glowworm.

Our New Zealand glowworm is quite different to so-called 'glowworms' from other parts of the world. These others are mainly luminous beetles which use their lights only to attract the opposite sex. The New Zealand glowworm by contrast is the larval stage of a fly, and will use its light in different stages of the life cycle as a lure for food as well as to attract a mate.

The scientific name of the New Zealand glowworm is Arachnocampa luminosa. It belongs to the family MYCETOPHILIDAE or 'fungus gnats', most of which, as the name suggests, feed on fungus. 'Arachno' refers to the web it spins, 'campa' to its grub-like qualities and 'luminosa' to the light it emits. This species is found only in New Zealand, but it has three relatives within the genus Arachnocampa from Australia. Of these, Arachnocampa tasmaniensis, from Tasmania, is the closest relative. Two other smaller species are known from the Australian mainland, Arachnocampa flava and Arachnocampa richardsae.

This booklet attempts to present to the Waitomo Caves visitor a general knowledge of the New Zealand glowworm - including details of habitat, life cycle, snare, feeding behaviour and light.




Distribution of the genus Arachnocampa (after Kermode )

EARLY RECORDS OF THE NEW ZEALAND GLOWWORM

The first record of the New Zealand glowworm was by Rev. A.G. Purchas in 1871. He had collected the female fly and larvae of "one or two" species of luminous insect from mines on the Thames Goldfields.

In 1886, E. Meyrick observed that this luminous larva appeared to be a predatory beetle larva. He stated that the light came from the back of its neck, and thought it would be carnivorous, feeding on minute insects caught in the slimy network of its 'web'. Meyrick postulated that this beetle larva might use its light to attract its food.

Later in 1886, G.V. Hudson refuted the writings of Meyrick stating that the light came from a large sticky knob at its posterior end. Furthermore he thought there was little doubt that its food consisted of decaying vegetable matter as he had never observed flies or gnats captured in the webs. Hudson also disagreed with Meyrick's assumed function of the light. As the light was not shown regularly, he thought the larva used it to escape from enemies, for "when disturbed they nearly always gleamed very brilliantly for a few seconds, suddenly shutting off the light and retreating into the earth". He was also quite confident this larva bore no relationship to any beetle families, and was in fact a small 'gnat' or fly.

These early observations of the glowworm are very interesting when compared to what is now known about this creature. Meyrick was quite wrong about the positioning of the light and about the larva being from a beetle family. However his observations were correct on the feeding behaviour (carnivorous) and function of the light (prey attraction). Hudson, on the other hand, was accurate in describing the glowworm as the larva of a small fly and stating the posterior position of its light. He was incorrect however, on his other statements - the glowworm is not vegetarian, and nor is its light a means of escape.

In 1886, Osten-Sacken from Germany, assigned this insect to the family MYCETOPHILIDAE, but he was unsure about to which genus it belonged. F.A.A. Skuse (Sydney) in 1890 named it as Bolitophila luminosa. The Englishman, F.W. Edwards, 1924, noted that some of its characters were unlike those of the European Bolitophila which feed on the interior of fungi, form no web, and pupate in the ground. He considered that there were sufficient distinctive characters to establish a new genus, Arachnocampa. Edwards chose this name because of the spider like habit of the larva forming webs and using them to catch insects (spiders are scientifically referred to as Arachnids).

## HABITAT

The preferred habitat of the glowworm must include the following five major factors:

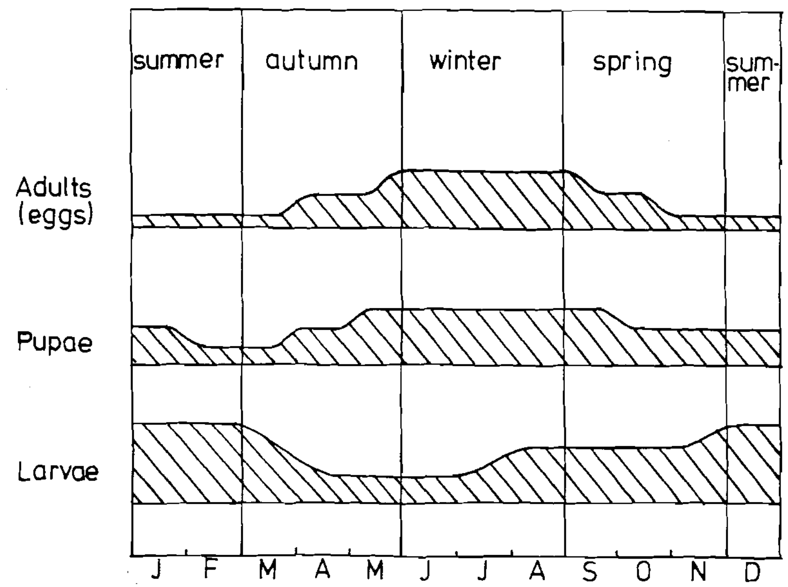
1) A humid atmosphere to prevent the glowworm from drying out.
2) A suitable hanging surface, such as the ceiling of a cave, from which the larva can suspend its fishing lines.
3) A relatively still (windless) environment to prevent the long sticky threads from tangling.
4) An adequate supply of small flying insects for food.
5) Darkness, in order that the glowworm's light shows.

The combination of these factors means that the glowworm has a very specialised environmental requirement. Suitable places exist in forests, tunnels and of course caves, habitats in which the glowworm may be found throughout New Zealand.



## LIFE CYCLE

Like that of most insects, the glowworm life cycle has four stages - egg, larva, pupa and fly - with the entire cycle taking approximately ten to eleven months. In the Glowworm Cave there is an underlying annual cycle with a new generation starting in late winter/spring (August - October) each year. However there is considerable overlap between each stage of development, with most stages being present throughout the year.

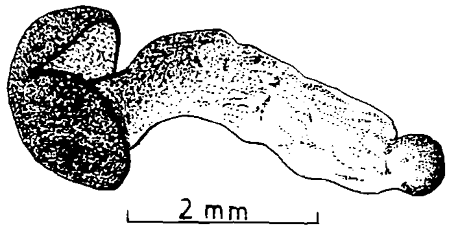



Seasonal frequency of stages in the glowworm life-cycle.

Egg:

The glowworm egg is spherical, 0.75 millimetres in diameter. When first deposited the egg is cream in colour, but will change to either light brown or orange-red within a few hours. The eggs are sticky and adhere to the substrate - in caves they are deposited directly onto the walls. The 'incubation' period is 20 to 24 days.

Luminescence does not occur in the glowworm egg. At hatching the larva splits the skin of the egg and crawls out.




Larva emerging from the egg (after Richards)

Larva:

When newly hatched the larva or worm is very small - three to five millimetres long and 0.33 millimetres across. The larva immediately commences the building of a nest and by letting down sticky threads and 'switching on' its light, is able to attract its first meal. It is hypothesised that cannibalism is quite important for the newly hatched glowworm, as very few insects are small enough for the tiny larva to handle. Other young larvae would be one of the few food sources of similar size.

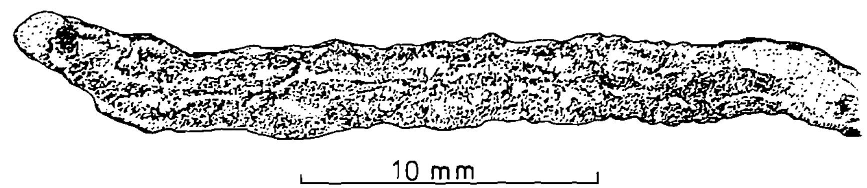
The larva grows over a period of several months, to reach a length of 30 to 40 millimetres. It is not necessarily confined to its nest being able to move 20 to 30 centimetres, and if greatly disturbed may move several metres. Movement is by waves of muscle contractions passing along its body - like the movement of an earthworm.

The only part of the larva that is hard is the head capsule, much like a 'crash helmet'. As the larva grows its 'helmet' becomes too small and has to be replaced by moulting. During total larval development there are four moults, with each larva stage being referred to as an 'instar' - first instar (newly hatched) to fifth instar (last stage before pupation). Larval development in total takes eight to nine months, but with considerable individual variation. The triggering factor is body



weight or size and this depends on the availability of food; an extreme example being a glowworm in Ruakuri near the rockfall which is about 18 months old. The 'annual' cycle starts in late winter/spring, so a plentiful supply of food for the larvae during this period may cause early pupation and adult emergence before the following spring.

The larva is the only stage of the life cycle that feeds. The pupa is a transitory stage, and the adult has no mouth. This is why the larval stage is so long relative to the others. The larva has to store enough food reserve to 'feed' the pupa, the adult, and if a female, the eggs of the next generation.

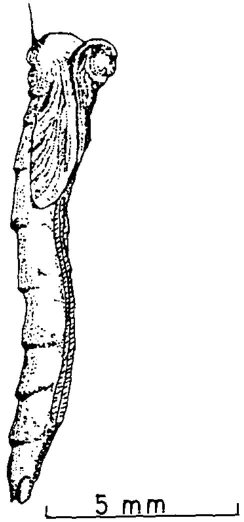



Glowworm larva removed from its nest (after Richards

Pupa:

Before pupation the larva shrinks and becomes opaque. It removes some of its fishing lines leaving an encircling barrier of shorter condensed lines. This may act as a protective shield to the pupa with the clear space preventing the fly becoming entangled after it emerges. The larva suspends itself vertically by a long thread, in this circle of lines, to pupate. The suspensory cord, formed from the larval nest and its supports, extends from the ceiling to a region of the thorax.

Sexual differentiation first becomes evident in the pupal stage. The female is larger and stouter than the male, and it possesses two prominent papillae at the end of its abdomen, which although present in the male, are smaller. The female pupae range from 15 to 18 millimetres in length and the males from 12 to 14 millimetres.



lowworm pupa (after Kermode)

Both the male and female pupae are luminescent, although the light is intermittant. Luminoscity in the male pupa stops during the last two or three days before emergence of the adult. In contrast, luminescence in the female becomes more noticeable in the latter stages of its development (a device to attract male glowworm flies).

Two or three days before emerging, eggs become visible through the transparent pupal skin of the female.

upa development takes between 12 and 13 days.

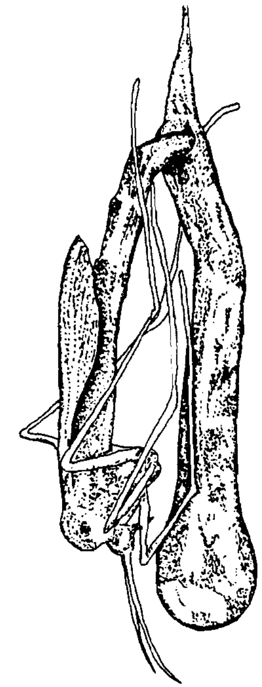
dult:

he adult fly may emerge from the pupa at any time of the ay, coming head first, pulling its wings and legs after t. The fly 'escapes' from its pupa case by muscular ontraction and expansion of the body, and wriggling of he legs. After emergence, which may take up to an hour r more, the fly hangs head down from the pupal case unil dry, then turns up the other way until its wings are trong enough for it to fly.

he sexes are quite distinct, the female's body being enarged by eggs which are visible through the body wall, nd the male's body much smaller and narrower. Both lies are sluggish in flight and move only short disances, one to two metres at a time, with the male being he more active of the two. In flight they make a buzzng noise. When at rest their wings are folded over the



thorax and abdomen. Both sexes are also intermittantly luminescent, with the female light being rather larger and brighter than that of the male, again a reproductive factor. The eye of the glowworm fly is very well developed taking up 90 % of the head. They are thus very sensitive to the lights around them.

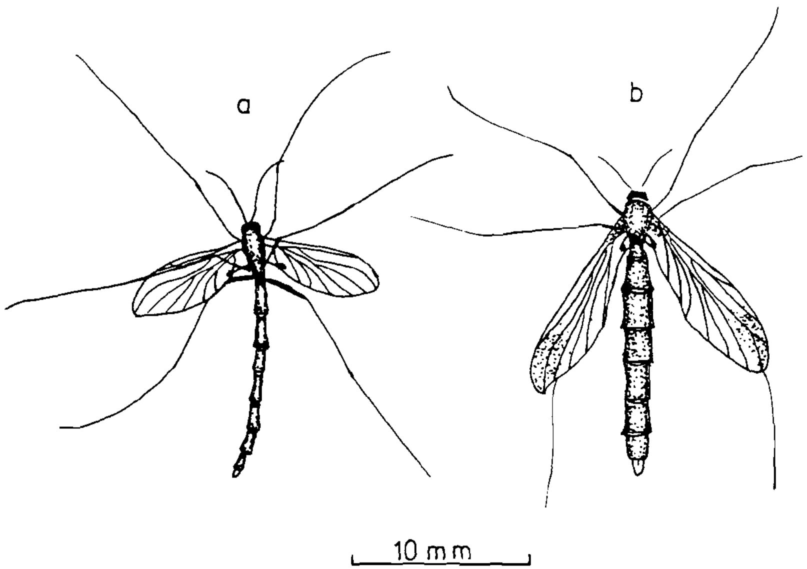


Adult fly emerging from the pupal case (after Richards)

Below is a table that shows the size differences between the male and female. The male is smaller in both body length and wing length. It also compares the bush glowworm with the cave glowworm, showing that adults in the former are some 20 % smaller.

The adult flies have two purposes to their life. Firstly reproduction and the continuation of the species. A second function is dispersal of the species; the adults being the only stage that can move easily over a significant distance.

| | MALE | | FEMALE | |
|---|---|---|---|---|
| | Bush | Cave | Bush | Cave |
| Body length | 9 - 11 | 12 - 15 | 10 - 13 | 13 - 16 |
| Wing length | 6 - 7 | 7 - 8.5 | 7.5 - 9 | 9 - 12 |
| | millimetres | | | |




Adult glowworm flies: a) male fly, b) female fly (after Richards)

Mating:

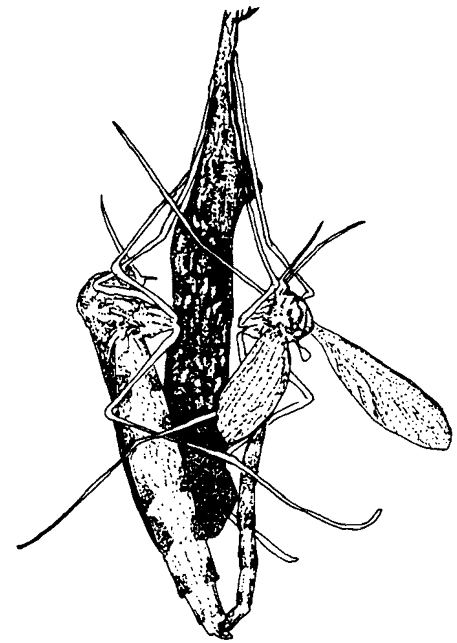
During the latter stage of its development, the female pupa is luminescent, a device to attract a mate. When gently rocked, as when a male fly alights on her, she 'lights up' (this action can also be brought about by 'tickling' the two papillae at the end of her body). It is not uncommon to see one or more male flies 'sitting' on the female pupa waiting for the fly to emerge.

Mating usually takes place as soon as the female emerges. However it may be delayed for several hours if there is no male fly immediately available, in which case the female will continue to glow. With the female light being larger and brighter, it is possible for the flies to distinguish between the sexes while in flight. It is thought that tactile (touch) and olfactory (smell) organs may also be involved in this attraction of the opposite sex.



When more than one male is waiting for the female to emerge from the pupa, each attempts to fertilise her the moment the tip of her abdomen is free. The successful male has to fight off the attempts of the others.

After mating the female lays her eggs. She has a short life span, from less than one day up to three days. On the other hand the male usually lives for up to four days being capable of fertilising more than one female.



Male and female flies mating (after Richards)

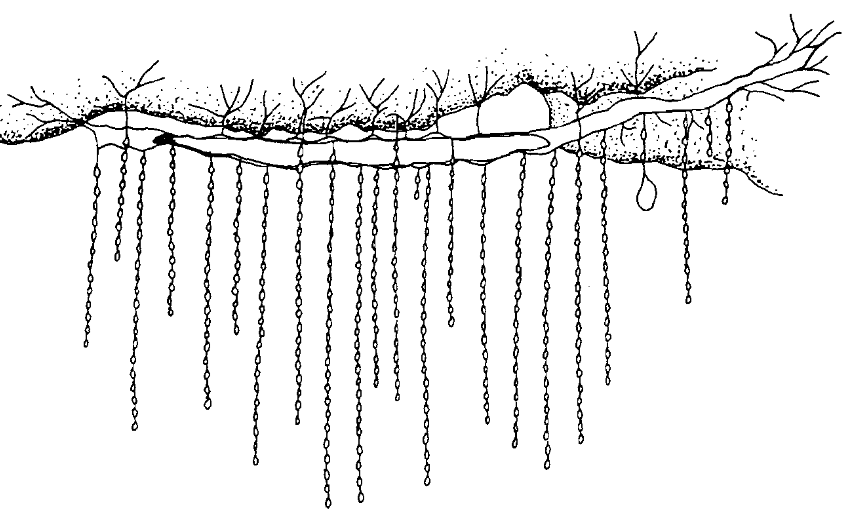
Oviposition:

Immediately or shortly after fertilisation, the female lays her eggs. When about to lay an egg, she feels for a suitable spot on the substratum with the tip of her abdomen. She then brings her abdomen under her body followed by violent contractions and flexing movements of her body. Her abdomen is then brought back to a normal position, and the tip gently touches the substratum to deposit an egg. Each egg is deposited singly. Egg laying is either continuous or sporadic over a period of from one to 24 hours until all eggs (on average 130) are laid. The eggs are found in clumps of 40 to 50, usually on the fringe of an existing colony. The female usually dies immediately afterwards.

## THE NEST AND FISHING LINES

The glowworm larva builds a hollow, tubular nest of silk and mucus which it suspends from the cave ceiling by fine silk threads. The silk and mucus is exuded from glands in the larva's mouth.

The larva lifts the front part of its body into the air to search for a suitable nest site. It will bend forward with a sudden darting movement, and then gently, but deliberately, deposit a drop of silk onto the rock, forming a fine thread that will act as a brace. This process is repeated, with the larva moving forward into the droplets, until mucus and silk have passed down the whole length of the body and the nest is complete and hollow. The tube or nest appears as the larva moves forward within it, and is left behind rather like a snail's trail. The nest is approximately 2.5 times the length of the larva, that is about ten centimetres. The nest is very plastic enabling the larva to move easily. It cannot



Glowworm larva in its nest.



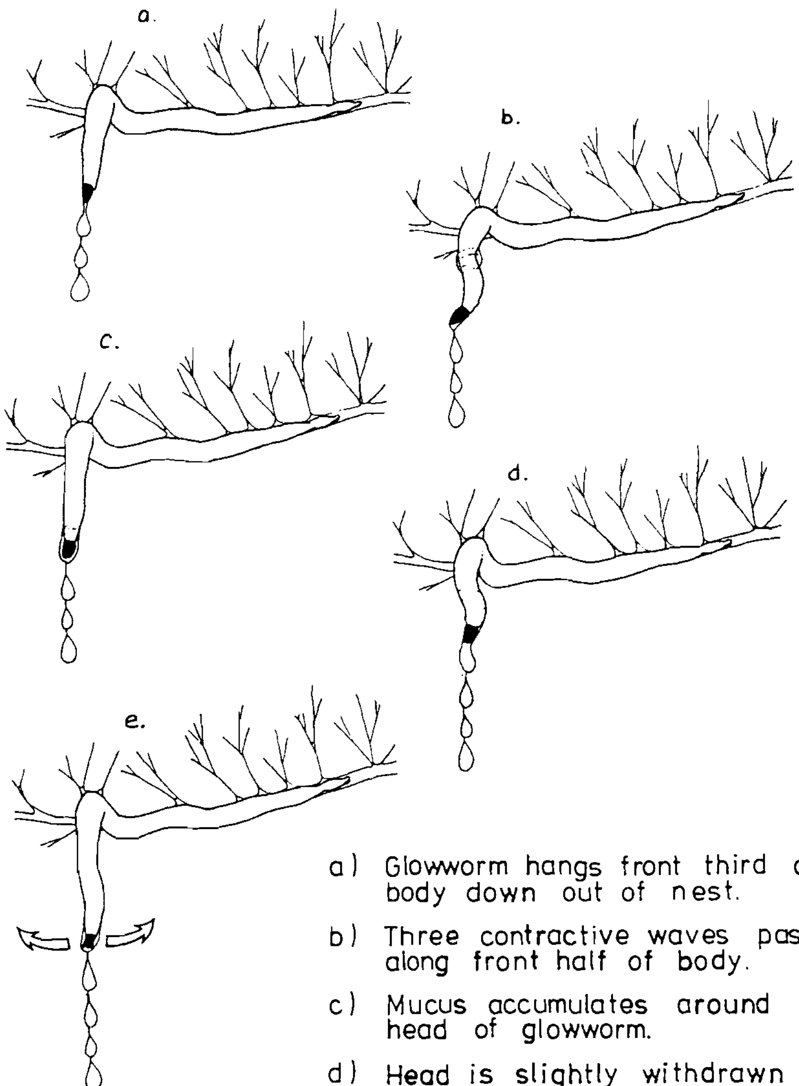
however, move backwards as it has small bristles on its body that 'catch' on the nest. To overcome this, the larva folds back on itself and moves in the opposite direction. When at rest the larva lies on its upper side, that is on its 'back'.

From this nest the larva lets down up to 70 strings of sticky droplets. These are the 'fishing lines', composed of a long thread of silk with a series of droplets arranged at regular intervals. These droplets vary in size, but the average is one millimetre in diameter and 1.5 millimetres in length. The length of each individual fishing line varies also - with extremes from one centimetre to 30 centimetres, but usually around 15 centimetres. These long lines show the great tensile strength of this silk. The fishing lines require a lack of air currents to be effective, otherwise they would tangle and break.

To form these fishing lines, muscle contractions cause the head to move backwards and forwards three times, during which mucus can be seen to accumulate around the head. With the last contraction, the head is drawn slightly within the body causing the droplet to appear. The larva rocks its head up and down five times while opening and shutting its jaws, during which the droplet is lowered on its thread.

A nest can be built in as short a time as ten minutes. One larva that had its nest destroyed was observed to crawl along the wall to another spot a short distance away. Within 20 minutes it had built a new nest and let down two fishing lines, each three centimetres in length. The formation of fishing lines is a continuous process with the larva moving along its nest, gradually increasing the length of each fishing line, and also repairing those that are damaged.

## FORMATION OF THE FISHING LINE




a) Glowworm hangs front third of body down out of nest.

b) Three contractive waves pass along front half of body.

c) Mucus accumulates around head of glowworm.

d) Head is slightly withdrawn and droplet forms.

e) Head moves up and down while droplet is lowered on a thread.

(after Stringer and Kermode)



## FEEDING BEHAVIOUR

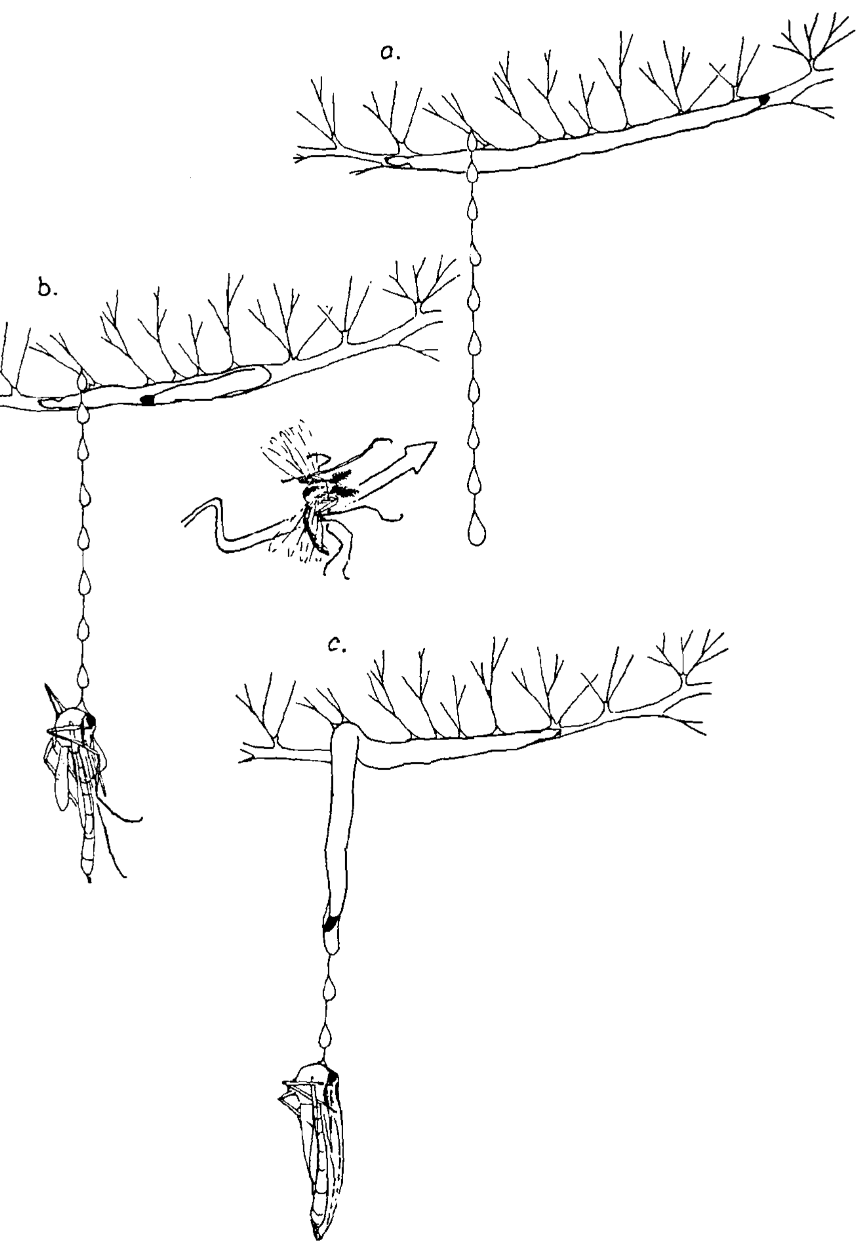
The larva is the only stage in the life cycle of the glowworm that eats. It uses its light to attract prey (insects) towards the sticky fishing lines, in which they become ensnared. The glowworm is not selective in what it feeds upon, eating anything that gets caught in its lines. In the Waitomo Glowworm Cave the main food is the midge Anatopynia debilis which breeds in the river mud. However other midge species, mosquitoes, caddis-flies, stone-flies and other insects also form part of the diet. In some circumstances glowworms have been seen to eat small snails and millipedes that get caught in the nest.

Studies of the glowworm anatomy show that the two papillae at the end of its body contain special sense organs that are designed to detect vibrations. They consist of an arrangement like an elastic thread on which are wrapped sense cells. With these special organs, the glowworm is able to register the struggles of an insect trapped in its fishing lines.

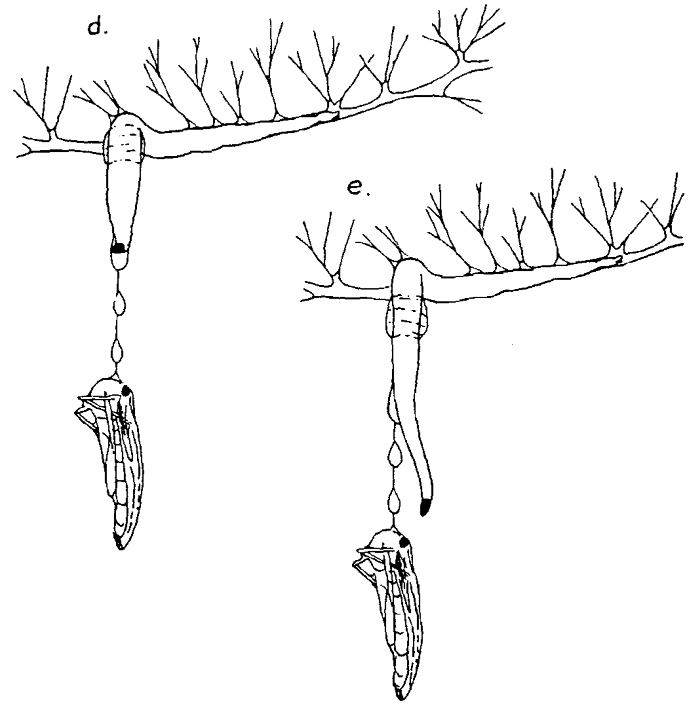
When the larva senses a 'catch', it crawls down the appropriate line until only its posterior half is left in the nest. Waves of contractions travelling along its body allow the larva to haul up the line. This is done by the larva reaching down and holding the line in its jaws. A wave of contraction raises the hanging part of its body along with the fishing line. The line is then held by bristles on its body, while the larva stretches down the next two or three droplets. This process is repeated with the complete cycle taking little more than a second. Large larvae can haul up a line at an average rate of two millimetres per second.

The animal usually ceases struggling soon after it is caught in the line although it is not dead. This is believed to be due to acid in the mucus of the lines actually paralysing the captured prey. This would be very advantageous as the less the insect struggles, the less

## CAPTURE OF PREY






a) **Prey** attracted by light of glowworm.

b) **Prey** becomes entangled in line. Glowworm detects struggling prey's vibrations.

c) Glowworm slides partly out of nest and down line.

d) Glowworm contracts body to lift line and prey.

e) Glowworm arches down next 2 or 3 droplets and **repeats** the lifting process.

(after Stringer and Kermode)

tangled the lines will become. When the prey is hauled up it is bitten whereupon it dies. The glowworm larva sucks out the juices, and if prey is less plentiful it eats the whole insect. When the glowworm is hungry it will glow more brightly.

Cannibalism is a fairly common occurrence, with larvae eating other glowworm larvae, pupae, and adult flies. Larvae have been observed to fight, especially when their nests are too close together, with the victor eating its opponent. When eating a pupa, the preying larva climbs down the suspended pupa to suck out its juices. Occasionally adult flies are caught in the larval lines and eaten.

To keep the fishing lines clean and in good repair, the larva removes the remains of its meals from the web. These remains are contained in a droplet which is lowered on a thread until it either breaks or is dropped. Similarly, the larva defaecates by lowering the posterior half of its body down a fishing line to make a large 'excretory' droplet (on the line) which is also lowered and dropped.

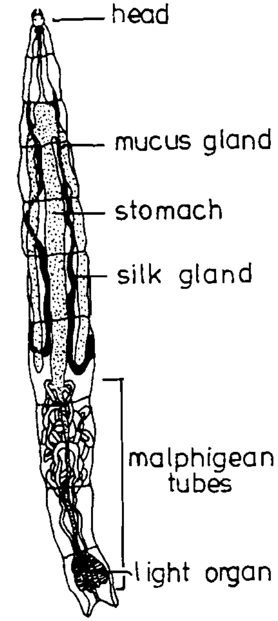
## BIOLUMINESCENCE

The light organ is formed from the swollen tips of four excretory tubes (malphigean tubules). This light organ lies within a layer of respiratory tissue which acts as a reflector, directing the light downwards. The respiratory tissue is composed of a network of fine tubes (tracheal tubules) which supply oxygen to the insects internal organs (the same function as our lungs). The large number of these tracheal tubes evident on the light organ show that it is profusely supplied with oxygen.

The chemical reaction producing this light involves several components:

1) Luciferin - a waste-product formed in the digestive






Anatomy of the glowworm larva (after Kermode)

system of the glowworm.

2) Luciferase - the enzyme that acts upon luciferin. An enzyme is a biological catalyst that is needed for the reaction, but is not itself altered.

3) The energy for the light comes from ATP (Adenosine triphosphate), which is a very important biological energy source.

4) Also required for this reaction is oxygen, which is the reason there is such an extensive system of respiratory tubes.

In the reaction, then, luciferase (the enzyme) acts upon luciferin to form an 'electronically excited' product which using the energy from ATP, emits light.

Luciferin + Luciferase + ATP + oxygen

↓

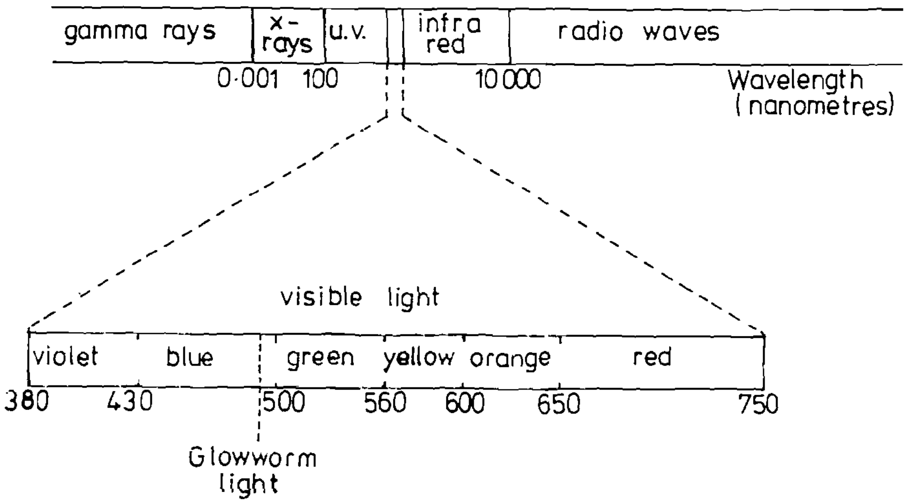
'excited product' + Luciferase

↓ ↓ ↓

LIGHT

This same system of light is used by all other luminescent organisms. Each organism however has its own kind of luciferin and luciferase (they differ slightly in their chemical make-up), but all give the same kind of light production. It is often termed 'natures cold light' as very little of the energy entering the system is lost as heat (compare with an electric light bulb which gets very hot). This biological production of light is perhaps the most efficient energy-emission system known.

The light of the glowworm is a blue-green colour, at a wavelength of 487 nanometres (nm).




Comparison of the glowworm light with other parts of the light spectrum.
[NOTE: 1 nm = $10^{-9}$ m = 0·000 000 001 m
u.v. = ultra violet]

The glowworm can shine its light continuously, but as noted by early observers can extinguish it quite suddenly or more slowly. It was earlier hypothesised that the sudden quenching was due to the glowworm retracting its light within a shield inside its abdomen. This is now disputed. The sudden dousing being explained as the larva rapidly retreating into a 'hide-out' in the substrate.

The slower quenching of the light (in about a minute) is



thought to be due to an ability to restrict the oxygen flow or other chemicals to the light producing organ.

The glowworm douses its light when the light level around it is too high, or when it detects severe vibrations due to especially loud, prolonged or unusual noises (The glowworms of Te Anau live in a very noisy cave).

Glowworms have a two-fold purpose for their light. They use it to attract insect prey, which become entangled in the sticky lines. The female pupae and adults use their lights to attract the opposite sex for mating. In the darkness of the cave this is a very practical attractant system. (The lights of the male pupae and adults seem to have no practical function and may just be relic genetic or larval characteristics.)

## POPULATION REGULATION

There are both biological and physical factors controlling the size of the glowworm population. These biological factors relate to other organisms or interactions between glowworms. Physical factors are those of the environment.

### Biological Factors

Predators:
Inside caves, the glowworm is fairly safe from predators. However, there are two species of harvestman that have been observed to attack glowworms. Hendea myersi cavernicola is a small, orange harvestman that is a permanent cave dweller. It preys on the eggs and young larvae of the glowworm. Megalopsalis tumida is a larger harvestman with very long legs. It differs from Hendea in being a cave visitor, entering only in search of food or shelter. Being bigger, Megalopsalis preys on the larvae, pupae and adults.

Parasites:
A common parasite in the Glowworm Cave and other caves is

a fungus - Tolypocladium sp. This fungus has been observed in both larval and pupal stages of the glowworm. The fungus enters through the skin and the gut of its host. A glowworm larva or pupa infected with fungus takes on a pink colour in the latter stages before its death. Once the host dies, the fungus spreads throughout all the body feeding on the dead tissues. It can then be seen as a white fluffy cylinder hanging in the cave (fungal cadaver).

The rate of fungal infection is very low, as dispersal of the fungal spores requires air currents which are normally at a minimum in the cave environment. However, the temperatures reached in the Glowworm Cave are within the optimal range for growth of Tolypocladium (15 - 25°C) so infection can occur easily.

In 1892, Hudson published a paper, describing a 'wasp' that was parasitic on the glowworm. Several pupae were collected from the Wellington Botanical Gardens, "which from their shrivelled condition, appeared to have been killed by a parasitic insect". When the adult insects emerged from these, they were described and named as Betyla fulva. There is only this one record of insect parasitism, but little work has been done in this area so its significance cannot be gauged

Interaction Between Glowworms:
Most species of animal have natural population regulating 'devices'. Often this is done by controlling the spatial distribution of individuals to ensure that each has a sufficient food supply. In glowworm populations it has been observed that when individuals get too close one may attack the other - a conflict often resulting in cannibalism. Thus direct competition between glowworms for space must also regulate their population.

Food Supply:
Food shortage does control population size, but this tends to be a seasonal phenomenon - during the winter there are fewer flying insects. However, it has also



been found that the glowworm larva is able to survive long periods (several months) without food.

Physical Factors

Environment:
One component is flooding. Because of the need to be close to the food supply (generally emergent aquatic insects) and physical factors (see below) glowworms often live in areas prone to flooding. After heavy rain the water in the Glowworm Grotto can rise two metres in four hours, causing the glowworms to be washed away. Most glowworms are situated high enough in the Grotto roof to escape rising waters and on occasions those lower down have been observed to survive several hours submergence. However, a major flood will reduce population numbers in caves considerably. Despite this there is also a good side to floods. They bring into the cave fresh silt and organic matter - a suitable habitat for the insects that make up the glowworms diet.

Temperature and Humidity:
Temperature is not a crucial element in the distribution of the glowworm. They can be found living over the whole range of temperatures recorded in the Glowworm Caves.

A more important physical factor is relative humidity. As the glowworm is very prone to desiccation, it requires a very humid atmosphere. In the Grotto, relative humidity ranges from 94 to 99 %. It is thought that the tolerance range of the glowworm is above 90 %.

The importance of the individual effects of the above components is hard to gauge due to the difficulty in assigning reasons for the disappearance of the glowworms. The only factor that can be judged accurately is fungal attack - the white fluffy 'cadaver' (glowworm corpse) left is quite distinct. With other forms of population regulation, we simply have the disappearance of a glowworm egg, larva, pupa or adult. Was it eaten by another glowworm or by a harvestman?

## EVOLUTION

Why such an organism should have evolved is an interesting question on which to ponder. The glowworm is well adapted to its environment, as is shown by the thousands of glowworms that can be seen in the Glowworm Grotto at Waitomo Caves and other caves in New Zealand. There are two main questions that can be asked about the evolution of the glowworm from the ancestral insect.

Did the 'present' glowworm gain its characteristics of line building, bioluminescence and carnivorous behaviour gradually, or did they happen suddenly? Previously this unique behaviour was considered so strange that some biologists suggested a 'macro-mutation' occurring. This would result in the ancestral 'glowworm' gaining all these characteristics at once. Now that other members of the family MYCETOPHILIDAE are described from around the world, many of these features have been observed singly or in combination. There are species that construct webs, others that have the carnivorous habit and others that are luminescent. The acquisition of all these factors in the glowworm has resulted in a species superbly adapted to the damp cave environment.

The second question is, if these characteristics developed gradually, then in what order did they appear? Again we look to other members of the MYCETOPHILIDAE. Some species, a few of those living inside fungi, build sticky webs but are not carnivorous, instead they use the web to trap fungal spores which are ingested along with the web. In another fungus inhabiting species minute bugs are also caught in the web and eaten along with the spores. Many species actually build webs either on a single plane or in three dimensions and are of carnivorous habits. Several of these live in cave habitats. Another species has bioluminescence which appears to be associated with fat cells but an actual light producing organ is absent. At least one other species related to the glowworm uses a luminescent organ to attract prey which are then trapped



in its web. This species differs in that it spins a flat web.

Thus it seems probable that web building developed first followed by adaption to a carnivorous diet. A later specialization to facilitate trapping of prey was the development of a light organ.

## MAN AND THE NEW ZEALAND GLOWWORM

The glowworm displays in the caves at Waitomo attract thousands of visitors each year, and as such are an important economic resource providing both revenue and employment. We have seen how the glowworm has very specialized environmental requirements. How is this environment affected by man and how is this habitat maintained?

The two most important factors that can be influenced by man in the glowworm habitat are the climate, (humidity in particular) and the food supply of suitable flying insects. Changes to the morphology or shape of the cave can quickly alter the climate inside. In 1975 a solid air-tight door at the upper entrance to the Glowworm Cave was replaced with an iron grille door to improve ventilation over the busy summer period. In winter, however, warm air inside the cave was able to rise to the upper levels and escape from the cave at an unprecedented rate. These greatly increased air movements removed much of the moisture from both the cave atmosphere and cave walls. The glowworm habitat began to dry out and numbers dropped with each winter. In early winter 1979 the remaining glowworms began turning their lights off and the cave was closed to the public as an investigation began. In three months the display had returned but the cave was left unmodified while detailed research was done on its climate. It is likely that the greater movement of air inside the cave increased the distribution of spores of a fungus that kills glowworms and mortality from this agent also contributed to their decline. One of the research recommendations was to seal off the upper entrance again and keep the air tight door closed in winter and left open during summer. This was done early in 1981 and the cave climate immediately stabilized. Since the restoration of the high humidity in the cave the glowworm population has responded with each generation and numbers are now at a level consistent with a stable healthy climate. There has also been a reduction in the glowworm mortality caused by the fungus.

The total population level that the cave can sustain is limited by another component that man can influence - this is the glowworm food supply. Here it is not changes inside the cave but outside, in particular changes to the Waitomo River catchment upstream of the caves. The Waitomo that Tane Tinorau* knew was vastly different to Waitomo today, but already the great rainforests were being destroyed, first for millable timber then as grassland farming became established. Along the bottom of the Waitomo Valley the Waitomo River meandered through swampy wetlands rich in bird and insect life. Today almost all of the thick forests have gone as have most of the wetlands that provided the breeding ground for numerous species of aquatic insects. Many of these insects in the egg, larva or pupa stages are carried into the caves by rivers and as adult flies are attracted to the lights of glowworms. It is likely there has been a significant decline in the numbers of insects coming into the caves over the last 100 years. In 1983 new research was started to examine the ecology of these insects. The objectives of this research are to establish which species are important in the glowworm's diet, how far upstream they originate, how much their habitat has been altered, if they are at risk with oil, insecticide, or fertiliser runoff and whether anything can and should be done to restore or enhance their habitat.

* Tane Tinorau was a Maori Chief who in the company of Fred Mace, an English Surveyor, first explored the Glowworm Cave in 1887.

In the past the mantle of rainforest was able to absorb most of the rain falling on the Waitomo River catchment and then release the water slowly into the main river channels. With the removal of the forest cover rainwater moves quickly down the valley slopes often taking topsoil with it. It is likely that flooding has increased both in frequency and peak levels over the last century. The less frequent higher floods tend to scour the bed of the Grotto while the more frequent smaller floods deposit silt and mud. The top ten centimetres of the river bed is rich in oxygen and supports much aquatic life including the larvae of insects crucial to the glowworm food supply. Hence the scouring or purging of the riverbed adversely affects stream life and glowworms. If there is a long period between floods the glowworms colonise the lower walls of the Grotto and many are swept away when the water does rise. Some movement of the water level is essential to stream ecology. Storm events release much organic matter into the streams replenishing essential organic nutrients.

The question is sometimes asked, "Do large numbers of tourists passing through the caves have any effect on the glowworms?". This is unlikely. The occasional baby crying or boat banging sometimes causes the younger glowworms to extinguish their lights but it is difficult to imagine any 'people' factors affecting the glowworms on a long term basis. Carbon dioxide is breathed out by people and in some deadend passages this can have detrimental effects on the cave formations. Experiments have shown that glowworms have a higher tolerance to carbon dioxide than humans so they will be affected by carbon dioxide long before the glowworms. Measurements have shown that the $CO_2$ in the Grotto is sometimes slightly higher than normal but nowhere near levels dangerous to people.

For some years now a record has been kept of habitat factors in the Glowworm Cave. At several sites in the cave weekly records are taken of maximum and minimum air temperatures, rock and water temperatures and evaporation. Variations in air temperature and humidity are constantly recorded onto charts by thermohygrographs. Outside the cave, climate readings are taken weekly and the river level is continuously monitored at a station near Aranui Cave.

Inside the Glowworm Cave two sample colonies of glowworms are counted each week. Within this population the occurrence of larvae, pupae, and adult flies are noted, as is the incidence of fungal attack. The number and size of insects caught in the lines of a small glowworm colony are also recorded.

Recent research on glowworm ecology and the hydrology of the Waitomo catchment has given us a better understanding of how man influences the ecological and physical environment of the glowworms in the caves at Waitomo. Many of the research recommendations have already been implemented with positive results and from this understanding of the resource it is likely that the glowworms will be attracting visitors for many years to come.



## GLOSSARY

Abdomen - The tail part of an insect.

Anatomy - The study of the structure of the body.

Bioluminescence - The biological production of light.

Cannibal - An animal that eats its own kind.

Carnivore - An animal that feeds on flesh.

Desiccation - The complete loss of moisture.

Larva - The 'grub' stage in the life cycle of an insect. (plural - larvae)

Macro-mutation - A very large genetic change (mutation).

Oviposition - The process of egg laying in the insect.

Papillae - Small extensions of the insect body, usually containing sense cells.

Parasite - An organism that lives in or on another, with detrimental effects to the host.

Predator - An animal that hunts and kills other animals for food.

Pupa - The 'cocoon' stage in the life cycle of an insect. (plural - pupae)

Pupation - The process whereby the larva changes its body functions and shape to become the adult insect. The organism in this state is known as the pupa.

Spatial Distribution - The distribution of organisms or objects in a defined area.

Substrate/Substratum - The underlying surface.

Taxonomy - The scientific naming of organisms. The full taxonomy of the New Zealand glowworm is as follows:

- Phylum: Arthropoda - animals with external jointed skeletons.
- Class: Insecta - animals with six legs and three main parts to the body.
- Sub-Class: Pterygota - winged insect.

Glossary contd.

Order: Diptera - two winged insect (as opposed to four wings).
Family: MYCETOPHILIDAE - fungus gnats.
Genus: Arachnocampa - larva building a web.
Species: Arachnocampa luminosa - N.Z. glowworm.

Tensile Strength - Strength of stretching.

Thermohygrograph - An instrument that continuously measures humidity and temperature of the air, automatically recording this information onto charts.

Thorax - The middle section of an insect - has legs and wings 'attached' to it.



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