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RESULTS OF THE AUSTRIAN-CEYLONESE HYDROBIOLOGICAL MISSION 1970 OF THE 1ST ZOOLOGICAL INSTITUTE OF THE UNIVERSITY OF VIENNA (AUSTRIA) AND THE DEPARTMENT OF ZOOLOGY OF THE VIDYALANKARA UNIVERSITY OF CEYLON, KELANIYA

PART VIII: Larval Stages of Water Moths (Lepid., Pyralidae, Nymphulinae) from Torrents of Ceylon and some South-Pacific Islands

by

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1. Material

During the Austrian Indo-Pacific-Expedition 1970–71 there were collected altogether 30 samples containing larval stages of water moths. 26 samples came from Ceylonese mountain streams (" Sturzbäche " = torrents), 3 from the Solomon Island Guadalcanal and one from the island of Efaté, New Hebrides. All samples except one contained larval stages of moths from the sub-family Nymphulinae (Genus *Aulacodes* (*Paraponyx*) and perhaps other ones). But only one specimen in the imaginal stage could be caught, and it is doubtful whether this moth really belongs to the genus *Aulacodes*.

The whole collection consists of 76 larvae, 22 pupae and 15 empty, i.e., hatched, pupal cocoons. A list of the habitat conditions at the collecting sites gives further information and allows some interpretations (or speculations) about the ecological niche occupied by the larvae in the torrents.

I am very grateful to Prof. Dr. F. Starmühlner who gave me the opportunity to study the collection. The material was handed over to me by the Museum of Natural History, Zoological Department, Vienna, Austria (No. 898/71 Z).

2. Results

2.1 The Larval Types.

The lack of imagine made it impossible to determine species. Therefore it seems necessary to suggest a schematic " classification " according to some characteristical distinguishing marks of the larvae, especially the arrangement of the tracheal gills. To what extent the resulting larval types may be corresponding the systematic species classification remains undecided up to now.

As all larvae bear tracheal gills, it is very likely that they belong to the genus *Aulacodes* (and/or *Paraponyx* in one case), which had been described from India (SUNDAR LAL HORA 1928 and 1934 ; PRUTHI, H. S. 1928) and China (MUIR and KERSHAW 1909 ; IWATA 1930) as inhabitants of fast running waters. WESENBERG-LUND (1943) had summarized the most astonishing adaptations from these " aberrant " life-types in the Lepidoptera. Even in the Nymphulinae the development of tracheal gills represent the most advanced form of adaptation to the aquatic habitat. The (European) genera

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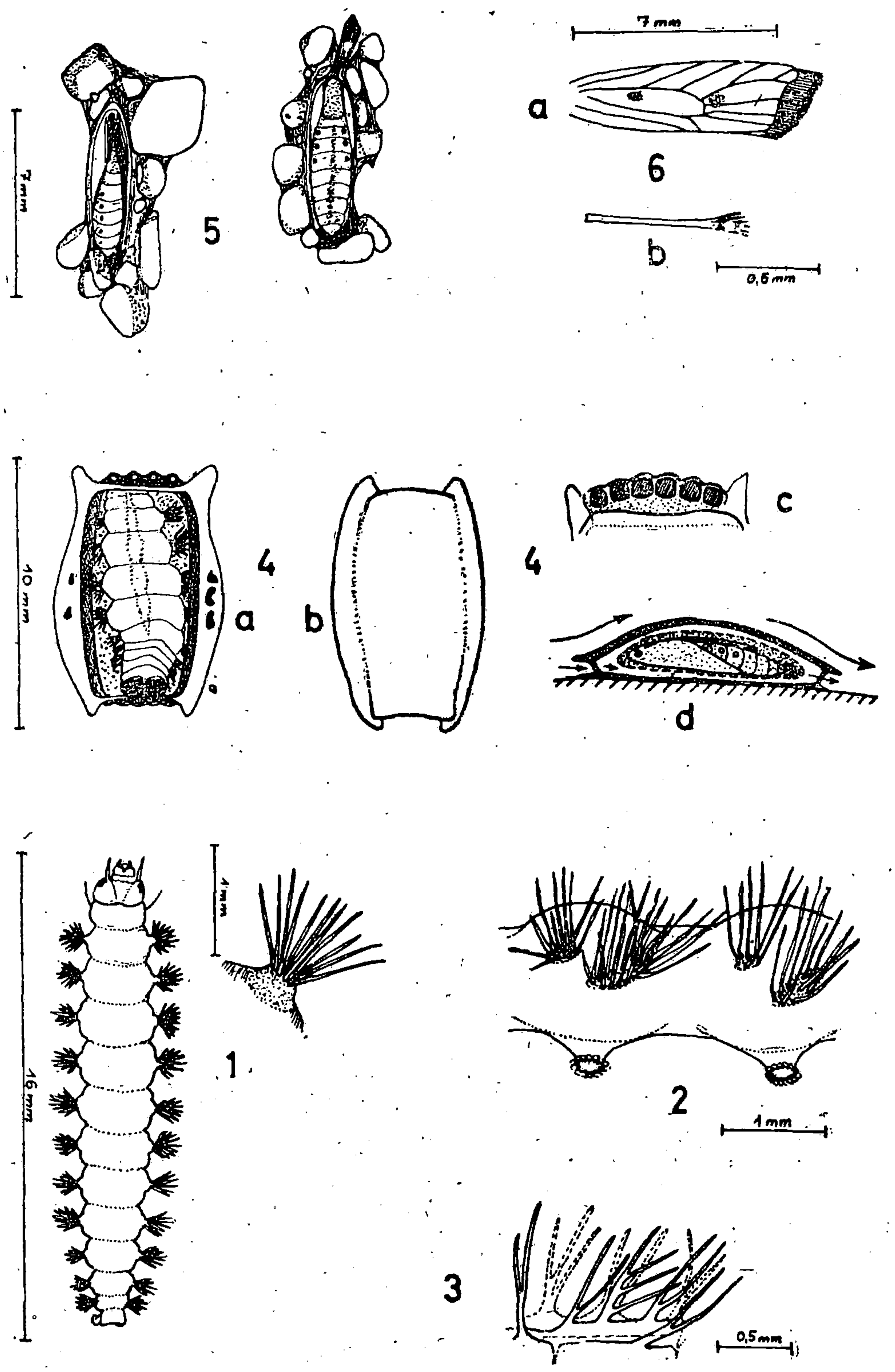

Fig. 1. Larva of the " Cupola -type " (Aulacodes) with a single " Cupola ".
Fig. 2. Arrangement of the tracheal gill-tufts in the " Dispersed-type ".
Fig. 3. Branched tracheal gills of the "Paraponyx-type ".
Fig. 4. Pupal cocoons of *Aulacodes* (?) (*a*) Ventral view with pupating larva.
(*b*) Dorsal view.
(*c*) Influx openings at the anterior end, ventral view. and
(*d*) Semi-schematic longitudinal section through the sucker-like pupal cocoon. Arrows indicate the direction of water movement.
Fig. 5. Two pebble-enchored pupae from the Solomon Island Guadalcanal.
Fig. 6. Wing venation and marginal scale from one imago collected in Ceylon.

Nymphula and *Cataclysta* have air-breathing larvae and only two species of *Paraponyx* develop tracheal gills. No European species is known to live in torrents, but according to LLOYD (1914) there are species of the genus *Elophila* in the Americas with tracheal gills in the larval instar. They also occur in running waters and their biology resembles that of *Aulacodes.* It is a case of convergence caused by similar ecological conditions. According to TSUDA (1936) the larvae of *Cataclysta midas* BUTLER develop tracheal gills, but WESENBERG-LUND doubts whether this is true, because there are no comparable structures to see at the figure.

The following larval types are characterized by the structure of the tracheal gills. Thus they are types of ecological adaptation. For our purpose to describe the habits of moths in adapting themselves to the very unusual habitat of the running water the classification based upon tracheal gill-structure may be sufficient. The results may indicate some ecological functions, but they must not be of classificational value. Furthermore the difficulty of describing the adaptive strategy of species, which you did not see in its real habitat is immense. The conclusions must be taken under this point of view. The limited material itself gives other limitations.

2.1.1 The "Cupola Type"

Fourteen Ceylonese samples contained only larvae whose tracheal gills are arranged laterally in one fascicle-like set. The filiform gill-tufts arise at every segment from cupola-like protrudings, which are more sclerotisized than the surrounding cuticle (figs. 1, and 8). They give the appearance of a *Rhyacophila*—larva (Trichoptera), a fact, which is also stressed by WESENBERG-LUND (1943) for the larva of *Aulacodes.* The gill tufts are composed of 3 to 20 filae. Except of the prothoracal segment all following segments of the larval body bear these gill tufts and thus form a lateral line which is very typical for these torrenticole larvae. The filae are relative short and thick, which may be explained by the habitat preferences of this species (see section 3).

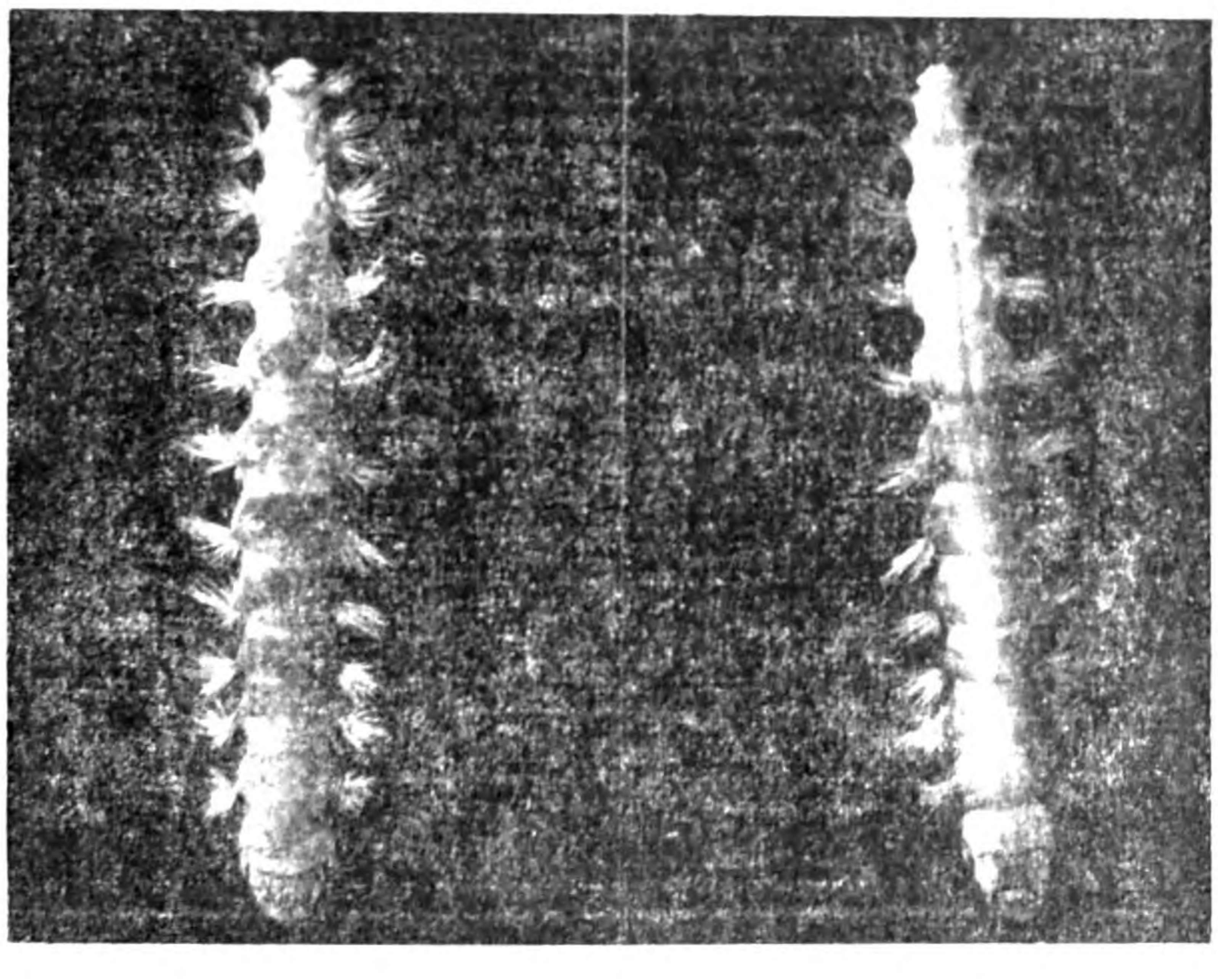

Fig. 7. Dorsal view of larva of the " Cupola-type " (Aulacodes).

Fig. 8. Ventral view of the larva of the " Cupola-type " (Aulacodes).

2.1.2. The " Dispersed-Type "

Another se t of five samples from Ceylon contained exclusively larvae of the " Dispersed-Type ". In this type the filiform tracheal gills are arranged in 2 to 3 (or even 4) single groups instead of one cu ola. This leads to the formation of an irregular double or triple line along the body sides.

But the single tufts are well defined and surrounded by lesser sclerotisized cuticle (see fig. 2). They comprise 1 to 18 single filae which are longer and thinner than those of the " cupola-type". Table I shows the distribution of the numbers of filae in the single groups along the 12 segments of one larva (length : 8 mm.).

TABLE I

Number of filae in the groups of gill-tufts

	Thorax			Abdomen										
Segment	1	2	3	1	2	3	4	5	6	7	8	9	10	Σ
Dorsal serie	0	4	6+8	3+12	3+8	8	3+10	3+1	5+10	12	18	15	0	129
Median serie	0	3	10	10	12	3+5	4+3	4	5+4	12	0	0	0	75
Ventral serie	0	2	5	2	1	1	0	0	0	0	0	0	0	11
Total/segment	0	9	29	27	24	17	20	8	24	24	18	15	0	215

Major differences between the larvae of the " cupola " and the " dispersed " type occur only in the pattern of gill-tuft distribution. Some finer variations may show only adaptations to different niches in the same habitat, the torrents. But there is a clearcut exclusion between the two types. Therefore it might be possible that the two types represent two different species out of the genus *Aulacodes*. Unfortunately there is a lack of imagines in order to decide the question. But the two types are without any doubt two distinct forms of adaptation which inhabit separated ecological niches.

The larvae from mountain streams of Guadalcanal (Solomon Islands) may also belong to the *Aulacodes* group. The arrangement and structure of their tracheal gills resemble the " dispersed-type " from Ceylon very much.

2.1.3. The " Paraponyx-Type "

One little larvae (7 mm.) from the River Maat near Port Vila, Efaté (New Herbides), shows the branched tracheal gills of the type represented by the European *Paraponyx stratiotata*-larva. The tracheal gills are arranged laterally in three uninterrupted series without any groupings to tufts (fig. 3). This type has formed the comparable greatest increase in surface-enlargement by means of branching the thin and delicate tracheal filae in order to enhance the respiratory efficiency.

The little larva had spun together two leaves of water mints and thus formed a cocoon which resembles with its loose structure the cocoons of the European *Paraponyx* larvae. The collecting site, a region of mints and duckweed (Lemna) near the margin of the river, also proved to be very similar to the typical habitat of the European species. In a general sense one could typify the genus *Paraponyx* to be the hydrophil adaptation line to the conditions of stagnant and gentle flowing waters. The one larva dealt with may belong to this type.

2.2 The Pupae

While the collected pupae did not show any specific morphological differentiations except the well known general appearance of the Nymphlinae type, there were found on the contrary very nteresting features of adaptation to the rheophile habits in the structures of the pupal cocoons.

Pupation takes place under water and therefore there is first of all the necessity of a firm attachment at the bedrocks. All pupal cocoons from Ceylon are of one distinct type of construction : They are formed like a suction apparatus (fig. 4). The cocoon is attached to the overstreamed rocks like a flat cup. The current at that places reaches values up to 1 meter per second and even more. But a strong brown texture protects the fragile pupa and fastens the cocoons (length 15 mm, width 8 mm) like a sucker because of the reduced water pressure in the fast streaming regions. Thus the cocoon can be found even in the mountain torrents, but it remains nearly a miracle, how it is possible for the delicate and fragile moth to emerge out of these torrents when hatching.

The cocoon itself has a very interesting structure. The volume beneath the convex upper side of the cup is horizontally divided into two parts. The lower section is filled with water, which flows in through the anterior openings of the cocoon (fig. 4 a/c) and streams out through the likewise structured openings at the posterior end. Therein lies the pupa in a chamber filled with gas (air ?!). This air-filled section is surrounded by a thin but very dense silklike texture, which is impermeable or water. Even alcohol (70%) cannot pass through this web, for the pupal chamber remained gasfilled after more than one year of deposition in alcohol conservation.

But when fresh water is streaming through the system should act like a gas exchange chamber, where due to different partial pressures and solubility carbon dioxide can be exchanged against oxygen. In fig. *4d* the function is drawn schematically in a longitudinal section. There are some differences between the sucker like cocoons from Ceylon and those from Guadalcanal (Solomon Islands). The latter have a thicker convex upper side and the roof-like margin is attached as a whole to the bedrock. In those from Ceylon the margin is divided into additional chambers, which surrounded the large central " sucker " with the pupa as a circle of small ones. The attachment thus achieved is perhaps more solid.

The collection from the mountain creek of Guadalcanal delivered one additional type of aquatic cocoons. In the material (date : 16.2.1971) from the River Tenaru there are—besides 6 larvae preparing for pupation in the sucker like cocoons described above—also 4 pupae without this very typical cocoon. They are only embedded in a thin, air-filled tissue, which is fastened to the ground by little pebbles (fig. 5). It is, however, not clear, if they belong to the same or to a different species. This mode of anchoring-down is well known from the larvae of the Sericostomatidae and gives another example for convergent adaptations between aquatic moths and Caddisflies (Trichoptera).

2.3 The Imago

One female moth caught near Belihuloya, Ceylon, on December 7, 1970, may belong to the Nymphulinae group. With 5, 5 to 6 mm. body length, 15 mm. wingspread, 11 mm. length of the antennae, relative short legs and a well developed suctorial proboscis, there is a good morphological resemblance with imagines of *Aulacodes* or the European *Paraponyx*. Fig. 6 shows the venation of the right forewing. Two darker points are the only one signs of the wing pattern, which is almost totally destroyed by the alcohol. The fringe of the wing, especially the distal margin, is bordered with long, brush-like scales (fig. 6 *b*), which may have a similar function as those described for *Nymphula nymphaeata* L. (REICHHOLF 1970). In this species the brush-like scales protect the hatching imago from getting wet.

3. The Habitat of the Larvae

In Ceylon and also in the South-Pacific-Islands the larvae were collected mainly from torrents of the headwaters of little rivers and creeks. The general habitat of the Ceylonesian collecting sites is described elsewhere. For our purpose some physicographical features of the torrents may provide enough information to construct a rough picture of the environmental conditions of the larval habitat. With widths ranging from ·5 to 20 meters and depths from a few centimeters (or even only some millimeters at the overstreamed surfaces of the large bedrocks) to 1 meter the current certainly is the key factor in the abiotic environment of the torrents. Velocity reaches values of more than 1m/sec. but there is a great variety in the magnitude of water velocity in the bed of the torrent as a whole. There can be also reversing water movements in certain places of the riverbed and changes in water quantity caused by heavy rainfalls may alter the local conditions of the overstreamed rocks. As far as visible from the hydrological notes taken at the collecting sites the larvae prefer regions with high water velocity, i.e., the rocks amidst the torrents. Obviously they attach themselves to the surfaces of the granite boulders, which are covered only with thin layers of streaming water.

On what the larval feed in this habitat, we don't know exactly. But we can suppose that they graze upon the algal covers of the rocks or they catch their food by means of nets in a way known from the *Hydropsyche* larvae (Trichoptera).

The high water tempereatures of the tropical streams, which were measured during the expedition to range from 19 to 27°C with a median daily maximum of 26°C, should cause a relative low oxygen content of the water. But the " eutrophicating action " of the turbulence in the torrents produces in fact an oversupply. Therefore the filae of the tracheal gills can be relative short and thick compared with those from larvae living in stagnant waters. The respiratory efficiency is enhanced by the high turbulence and thus the respiratory active surface of the larval body can be relative small. But in the down-stream regions, where turbulence decreases and turbidity increases, the more unfavourable oxygen conditions should cause an enlargement of the respiratory surface. Indeed the more downstream living larvae of the second type (the " dispersed-type ") show a greater number of longer and thinner filae and additional a " dispersion " of the gill-tufts. The " *Paraponyx*-type " finally is characterized by very long, thin and even branched filae, which are distributed along the whole length of the body sides. The larvae of this genus feed on submerged flora in lenitic regions of gentle flowing rivers and, of course, mainly inhabit the zones of submerged flora in ponds and lakes. One single specimen of this type was caught on February 21, 1971, in a dense stand of water mints mixed with duckweed (*Lemna*) at the bank of the River Maat, Efaté, New Hebrides. Inhow much the chemistry of the water may have influences on the structure of the tracheal gills is not yet evident. But by comparing the pH values, for example, there could be an adaptional connection between the regions inhabited by the " Cupola-type " and weak acid waters (pH values around 6), while the " Dispersed-type " obviously lives in more neutral regions of the river. But there are too little data for sound comparisons.

4. Age Structure of the Ceylonese Population

4.1. Members of the " Cupola-type "

Seventy stages of this type were collected in Ceylon between 10th November and 27th December 1970. They comprised 38 larvae ranging from 2 to 20 mm. (cf. table II), 3 larvae preparing for pupation, 16 pupae and 13 hatched pupae (=empty cocoons with exuviae). Except eggs, which were not sought for, all stages of metamorphosis could be collected within the six weeks exploration. It can be stated that there is no distinct seasonal distribution of stages in this species.

TABLE II

Length distribution of 38 larvae from the " Cupola-type "

length (mm.)	0—2	—4	—6	—8	—10	—12	—14	—16	—18	—20	Σ
number of larvae	1	5	5	6	8	3	5	3	1	1	38

4.2. Members of the " Dispersed-type "

From this type there had been found 19 larvae ranging from 4 to 12 mm. The samples contained no pupating larvae and also no pupa. The very regular distribution of the length classes of the larvae (Table III) and the fact that no other developmental stages could be collected in November and December, 1970 in the habitat of this larval type may indicate, that there is a distinct seasonal distribution on the contrary to the " Cupola-type ". One single (hatched) pupal cocoon can indeed have its origin from this species, but this remains uncertain because of the difficulty to age an empty cocoon and on the other hand it could belong to the very similar cocoons of the "Cupola-type" species. Since one would presume that the upstream dwelling species should live in a more temperate—and therefore more seasonal—environment than the downstream one, the appearant seasonality of the " Dispersed type " is so much the more astonishing. But there must be caution in drawing conclusions because of the small magnitude of the total sample. Furthermore the investigations of the Austrian Indo-Pacific Expedition were centred on other problems than the ecology of aquatic moths.

TABLE III

Length distribution of 19 larvae from the " Dispersed-type "

length (mm.)	0—2	—4	—6	—8	—10	—12	—14	Σ
number of larvae	0	1	2	9	5	2	0	19

5. Summary

In the collections of the Austrain-Ceylonese mission there were found three distinct types of larvae from water moths (Nymphulinae) which represent types of adaptation to the aquatic environment of the torrents. The larval types are described as the " Cupola-type ", the " Dispersed-type ", and the " Paraponyx-type ", according to the typical structure of the tracheal gills. The (possible) function of the high developed structure of the pupae-containing cocoons is reviewed briefly and there are given some notes on the habitat conditions and the age structure of the Ceylonese population in November and December. Unfortunately there was no possibility to determine species because of the lack of imagines.

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