Observations on the early stages of *Archaeoattacus staudingeri* (ROTHSCHILD, 1895) in northern Borneo (Sabah, Malaysia) (Lepidoptera: Saturniidae)

Christoph L. HÄUSER, Dieter STÜNING and Wolfgang A. NÄSSIG

Dr Christoph L. HÄUSER, Staatliches Museum für Naturkunde, Rosenstein 1, D-70191 Stuttgart, Germany

Dr. Dieter STÜNING, Zoologisches Forschungsinstitut und Museum Alexander Koenig, Adenauerallee 160, D-53113 Bonn, Germany

Dr Wolfgang A. NÄSSIG[1], Entomologie II, Forschungsinstitut und Naturmuseum Senckenberg, Senckenberganlage 25, D-60325 Frankfurt/Main, Germany

Abstract: The early stages of *Archaeoattacus staudingeri* are described and illustrated in colour for the first time, based on a successful laboratory breeding from eggs obtained from a single injured female taken in July 1994 in Mount Kinabalu National Park, Sabah, on northern Borneo. Rearing took place indoors in Germany at ambient temperatures and light regime. From about 180 eggs obtained only 9 larvae hatched of which 4 died in first instar. *Ligustrum, Prunus,* and *Syringa* were accepted as substitute fooplants, and larval development (6 instars) took between 55 and 62 days. The pupal stage lasted about 4 months, and total development took about 6½ months. The larvae are white with black pattern in the first two instars, greenish blue in the last two instars, wax-covered, and show a characteristic arrangement of scoli. The cocoon was constructed in one of several drying leaves fastened with silk to the twig and consisted of three distinct layers. All stages are very similar to *Arch. edwardsii,* and differ at the same time from *Attacus* particularly in the arrangement of the larval scoli and cocoon construction. From the available records of *Arch. staudingeri* (10 from Borneo) it is concluded that the species has not very restricted habitat requirements but exists at extremely low population densities over a wider range of (primary) forest habitats.

Zu den Präimaginalstadien von *Archaeoattacus staudingeri* (ROTHSCHILD 1895) in Nordborneo (Sabah, Malaysia) (Lepidoptera: Saturniidae)

Zusammenfassung: Die Präimaginalstadien von *Archaeoattacus staudingeri* werden erstmals beschrieben und farbig abgebildet. Eine erfolgreiche Laborzucht fand statt mit Material von einem verletzten Weibchen aus Nordborneo, Mt.-Kinabalu-Nationalpark. Die Zucht fand im Zimmer unter Raumtemperatur und natürlichen Lichtverhältnissen statt. Aus ca. 180 Eiern schlüpf-

[1] 41st contribution to the knowledge of the Saturniidae.

ten nur 9 Räupchen, von denen 4 während des ersten Stadiums starben. Ersatzfutterpflanzen waren *Ligustrum, Syringa* (Oleaceae) und *Prunus* (Rosaceae). Die Dauer des Raupenstadiums (6 Stadien) betrug zwischen 55 und 62 Tagen, Puppenruhe etwa 4 Monate, die Gesamtentwicklung also etwa 6½ Monate. Die Raupen sind weiß mit schwarzer Zeichnung in den ersten 2 Stadien, blaugrün in den beiden letzten. Besonders die späteren Stadien sind stark wachsbedeckt und weisen ein besonderes Ausbildungsmuster der Scoli auf. Der Kokon wird in einem von mehreren vertrocknenden Blättern, die mit Seide am Zweig festgesponnen sind („Ablenkungsblätter"), gesponnen und besteht aus 3 unterschiedlichen Lagen. Alle Stadien sind der nah verwandten *Arch. edwardsii* sehr ähnlich und unterscheiden sich darin deutlich von der Gattung *Attacus,* insbesondere in der Scoliausbildung und dem Kokonbau. Nach den bisher vorliegenden Funddaten (darunter 10 von Borneo) läßt sich vermuten, daß die Art keine spezifischen Habitatansprüche aufweist, jedoch in nur sehr geringer Populationsdichte in einer Vielzahl verschiedener (Primär-)Waldhabitate vorkommt.

Introduction

In the Indo-Australian region, the giant silk moth tribe Attacini is represented by four genera: *Samia* HÜBNER, [1819], *Archaeoattacus* WATSON, 1914, *Attacus* LINNAEUS, 1767, and *Coscinocera* BUTLER, 1879. The genus *Archaeoattacus* has been separated from *Attacus* based on differences in wing venation, wing pattern, and labial palps, and on the presence of spurs on the mid- and hind-tibiae (see WATSON in PACKARD 1914, HOLLOWAY 1987). Moreover there are differences in larval morphology: in *Archaeoattacus* larvae the lateral scoli are reduced, but the dorsal scoli, especially on meso- and metathorax, are very elogate and prominent, while these scoli are usually reduced in *Attacus;* and *Archaeoattacus* larvae do not possess defensive glands (NÄSSIG 1983). *Archaeoattacus* shares about as many supposedly apomorphic characters with *Attacus* as with *Samia* (see LEMAIRE & PEIGLER 1982, PEIGLER 1989), which gives reason to maintain *Archaeoattacus* as a separate genus.

The genus *Archaeoattacus* contains two species, *Arch. edwardsii* (WHITE, 1859) and *Arch. staudingeri* (ROTHSCHILD, 1895). While *Arch. edwardsii* occurs from the Himalaya valleys in northeastern India and Nepal to southern China and the Malay Peninsula, the latter species has a typical Sundaland distribution ranging from Peninsular Malaysia (there overlapping with its congener) to Sumatra, Borneo and Java (HOLLOWAY 1987, PEIGLER 1989, NÄSSIG et al., in press a); it has not yet been found on Bali,

Palawan and the smaller islands on the Sunda shelf. *Arch. edwardsii* has often been bred in captivity, and the early stages have been described several times (e.g., STEGER 1955, KUYTEN 1962, ARORA & GUPTA 1979, GARDINER 1982, NÄSSIG 1983, PINRATANA & LAMPE 1990). In addition, a lot of comparative information about Asiatic Attacini larvae is available from the recent literature (for reviews, see NÄSSIG et al. 1996 b, NÄSSIG & TASCHNER 1996). Apparently nothing has hitherto been published, however, on the early stages and life history of *Arch. staudingeri.*

This paper reports on a first successful laboratory rearing of *Archaeoattacus staudingeri* from the eggs obtained from a wild caught female, and gives some information on the habitat of the species in northern Borneo.

Field observations

Field work was carried out in northern Borneo by the first author during several visits totalling a period of six months at and around Mount Kinabalu Park (Taman Kinabalu), Sabah, Malaysia, during April 1993, February, March, July, and August 1994, and December 1995. Observations were made at a number of different locations in the park area, notably at Poring Hot Springs, 600 m, at Park Headquarters, 1200–1500 m, and at a park station near the village of Sayap, 1000–1100 m, located on the northern side of the mountain. In addition to the observations by the first author, single records were made in the same area between 1992 and 1994 by staff members of the ecology section of Sabah Parks, and during regular light trapping sessions by Christian SCHULZE, University of Würzburg, during August and September 1993. Reference specimens are deposited in the collections of the Entomology Section of Sabah Parks, Mt. Kinabalu Park Headquarters, and at the institutional collections of all three authors.

All moths observed were attracted at night to light sources including UV-light traps and normal street-lamps between 19.30 and 23.30 hours. During all observation periods spent in the area *Arch. staudingeri* was always rare, and only single individuals were found or observed at any one night. In total, only eight specimens of *Arch. staudingeri* have been recorded during the entire time period: 1 ♂, Park Headquarters, 19. IX. 1992; 1 ♂, 8. IX. 1993, Park Headquarters; 1 ♀, 28. IX. 1993, Park Headquarters; 1 ♂, 9. XII. 1993, Kiau village; 1 ♂, 11. V. 1994, Park Headquarters; 1 ♂, 20. III.

1994, Poring Hot Springs; 1 ♂, 9.-10. IV. 1994, Sayap station; 1 ♀, 31. VII. 1994, Park Headquarters.

The female recorded on 31st July 1994 was actually taken on one of the last nights spent at the park prior to a return journey to Europe, but eggs were obtained from this female which resulted in the successful rearing of the species described below. The specimen was found severely injured on the ground below a lamp at the outside wall of an building at Park Headquarters, at about 23.00 hours. The injuries had probably been caused by someone stepping on it or through collision with a car as the thorax appeared partly crushed and internal organs including part of the ovaries were protuding from a lateral rupture at the posterior end of the abdomen. As the female was still alive and had already started to deposit a few eggs through the ovipositor, it was placed with closed wings in a folded plastic freezer bag. The bag was kept moist inside with wet tissue paper, but movement of the specimen was restricted through light lateral pressure, and it was stored indoors in the dark. Under such treatment the female not only survived the following days but continued to lay eggs adding to the ones already deposited and sticking out from her abdomen. When leaving Mt. Kinabalu Park on 4th August for Germany, the bag with the specimen alive was taken along and transported for the entire journey inside a plastic box kept in the hand luggage. The female was still alive upon arrival in Germany on 8th August, and continued to live there until 11th August 1994. About 180 eggs were collected afterwards from the plastic bag including some which might not have been properly deposited but had originated instead from the rupture of the abdomen.

Rearing records and behavioural observations

The entire rearing was carried out by the second author in Bonn between August 1994 and February 1995. All stages were kept at ambient room temperatures (ca. 20-22° C) and light regime in an office room inside the museum building. During the winter months, the room temperature was lowered to 14-15° C at nights and weekends.

The first caterpillar hatched on 12. VIII. 1994, 3 on 13. VIII., 3 on 14. VIII., 1 on 15. VIII., and the last one on 18. VIII.; in total, only 9 larvae from ca. 180 eggs were obtained. A number of unhatched eggs examined later contained almost fully developed larvae. In comparison to the developmental times of *Arch. edwardsii* and several *Attacus* species, the hatched larvae

Table 1: Development times and size development for the different stages.

Instar	Date	Size, comments
L_1[2]	hatching out of the ova 12.–18. VIII. 1994	4 of 9 larvae die
L_2	first moult 19.–23. VIII.	ca. 10 mm long at moult
L_3	second moult 25.–29. VIII.	ca. 15 mm long
L_4	third moult 1.–9. IX.	ca. 19–21 mm
L_5	fourth moult 7.–13. IX.	ca. 35 mm, moulting took two days
L_6	last moult 17.–26. IX.	ca. 50–60 mm, moulting took two days
Cocoon construction	4.–13. X.	larva at maximum ca. 95–110 mm long, weight ca. 30 g
Hatching of imagines	5 ♀♀: 9. II. 1995, 18. II., 20. II., 23. II., 25. II.	

presumably originated from the ova deposited during the first days after the ♀ had been collected.

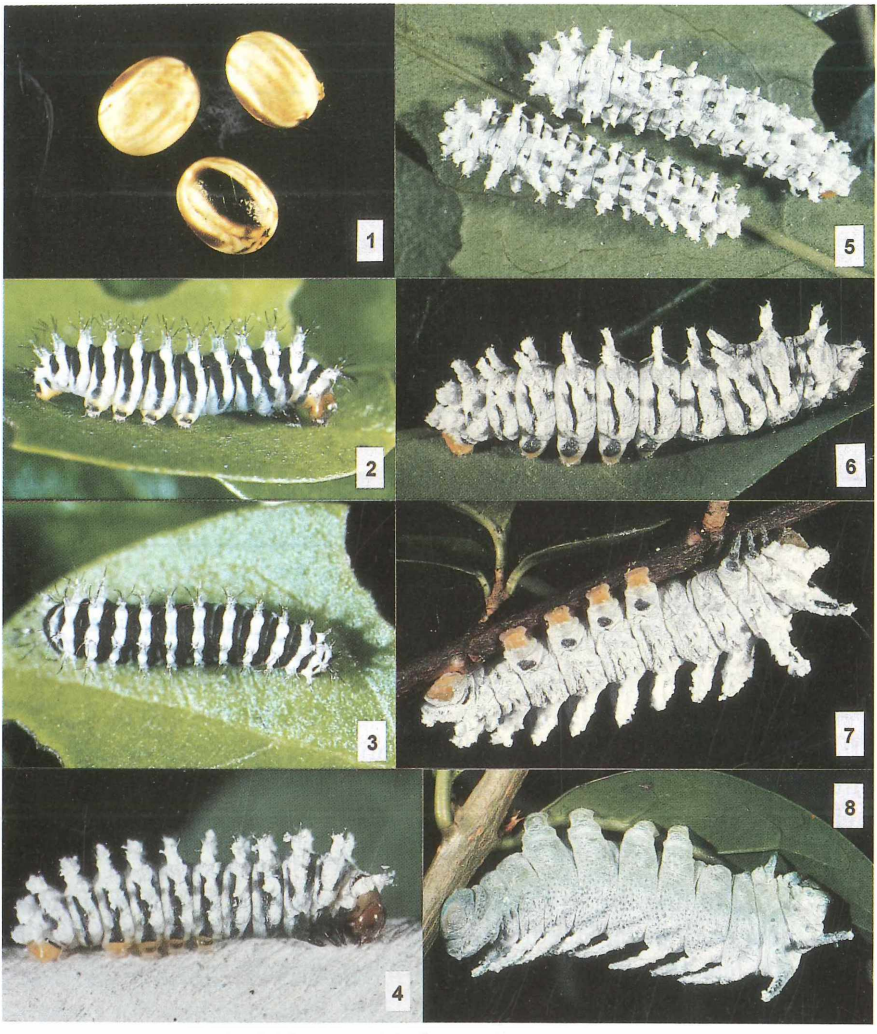
On their first day, the larvae started feeding only quite reluctantly. They were offered privet (*Ligustrum ovalifolium*, Oleaceae); feeding began often only on the second day. After accepting the food and cutting small, often triangular gaps into the margins of the leaves, the larvae gained weight quite fast. Occasionally the larvae were sprayed with water, and the caterpillars usually took up a few droplets.

Already in the first instar, the caterpillars showed no sign of gregariousness; their resting and feeding places were segregated, one caterpillar under one leaf (rarely two under big leaves), usually sitting on the midrip.

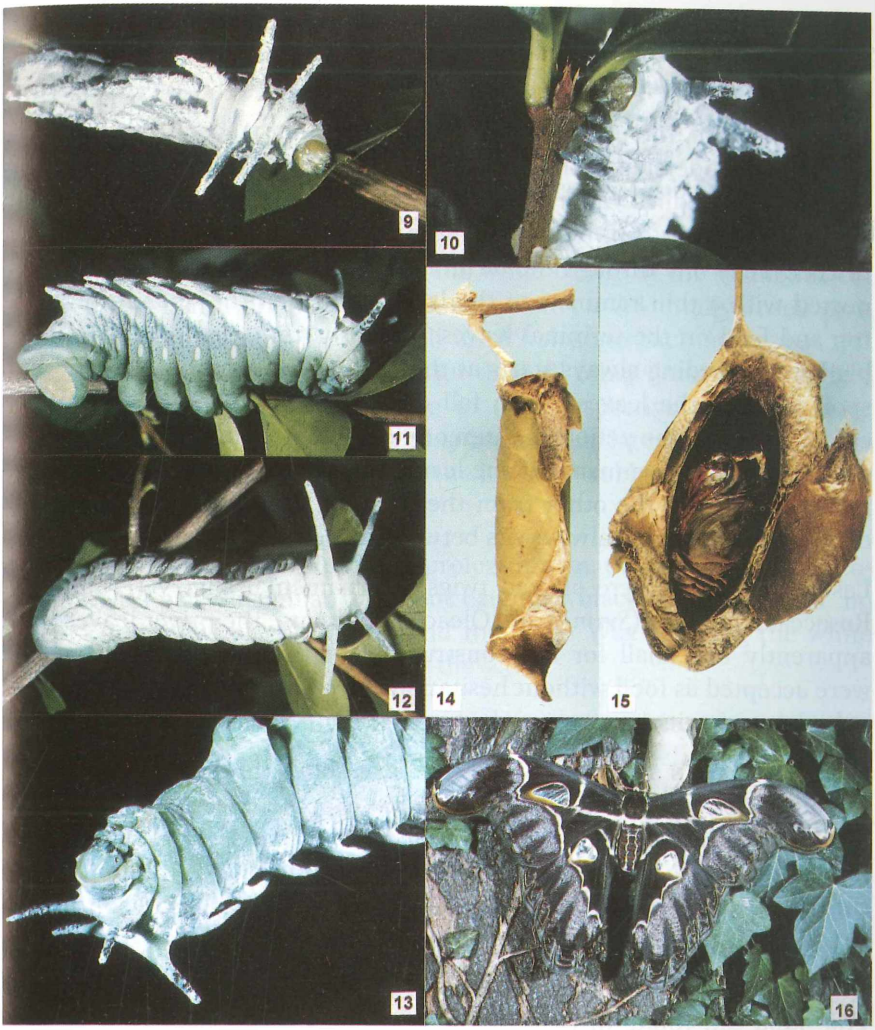
4 of the 9 larvae died during the first instar or at the first moult. The exuvia was always eaten by the larva after moulting; in the last two instars, the wax flakes often fell down while consuming the exuvia.

Rearing of first and second instar larvae took place in plastic boxes. Food was initially provided in form of cut leaves, later intact small twigs were

Abbreviations: L_{1-6} = larval instars 1–6. T1–T3 = thoracic segments 1–3. A1–A10 = abdominal segments 1–10.



Figs. 1–8: *Archaeoattacus staudingeri,* preimaginal instars. **Fig. 1:** Eggs. **Figs. 2–3:** L_1, lateral and dorsal view. **Fig. 4:** L_2, in moult to L_3, lateral view. **Figs. 5–6:** L_3, dorsal and lateral view. **Fig. 7:** L_4, lateral view. **Fig. 8:** L_5, lateral view.



Figs. 9–16: *Archaeoattacus staudingeri,* preimaginal development and imago. **Figs. 9–10:** L_5, dorsal view and ventrolateral view of head and front part of body. **Figs. 11–13:** L_6, lateral, dosal aspect and details of the front part of the body. **Figs. 11–12** are a freshly moulted caterpillar. **Fig. 14:** Cocoon. The petiole is biten through, and the leaf and cocoon are glued with silt to the stem. **Fig. 15:** Cocoon opened, with valve-like exit ("Reuse", top) and pupa visible within. **Fig. 16:** ♀ moth after emergence.

offered. After the second moult, the larvae were kept in a large glass box on twigs kept fresh in water; high air humidity in the glass box was attained with a wet sponge.

In early instars, the larvae had a preferred resting place at the base of a leaf on the underside at the mid-rip for a few days where they aways returned after feeding. Older larvae (last two instars) sit on the twigs, usually not at the very tip, but somewhere downwards, where the twigs are thicker. They bite through the terminal twig-tips until these are only connected with a thin remnant to the basal part, then they bend down the top and feed on the terminal leaves. Similarly, they treat the petioles of big leaves. Feeding always starts at the tip of a leaf, and only rarely they spoil parts of the leaves which fall down. Usually a leaf is completely eaten, and even the petiole is eaten or cut through (thereby falling down) so that nearly no remnants of the leaves are left on the twig. While feeding one leaf after the other from the top of a twig downward, the larva crawls backwards and always sits between leaves.

Last instar larvae were offered twigs of ornamental cherry (*Prunus* sp., Rosaceae) and lilac (*Syringa* sp., Oleaceae), because the privet leaves were apparently too small for the construction of the cocoon. These plants were accepted as food without hesitation. *Arch. staudingeri* is obviously as polyphagous as its congener and most species of *Attacus*.

When starting to spin the cocoon, the larva bites through several of the surrounding petioles and twig-tips (at least 6–8; there were no more available in the rearing). These twig-tips and leaves are secured with silk to the main twig, so that they do not fall down. Into one of the uppermost cut-off leaves the cocoon is eventually spun. Thereby the cocoon is protected against predation by several empty „cocoon-mimics" of dead leaves nearby (see NÄSSIG 1983, PAUKSTADT & PAUKSTADT 1989).

The pupa can rotate in the cocoons and does so especially when being disturbed. This rotation produces sound and movements of the twig-tips, and probably serves a deterrent function.

Description of the early stages

Eggs (Fig. 1): Shape ovoid, not much flattened. Ground colour creamy white, covered with a striated dark brownish adhesive secretion. Chorion finely sculptured. Length 2.4 mm, width 1.9 mm, height 1.8 mm.

L_1 (Figs. 2–3): Head bright brown (honey-brown), thoracic legs deep shining black, prolegs and anal prolegs yellowish with lateral black patches. Ground colour of body white, thinly covered with white wax (no lose flakes), with two broad black rings per segment without wax, oblique at the sides (see Fig. 2). Dorsally a slight whitish stripe at the rear end of every segment. Length ca. 5 mm when hatching from the egg, ca. 10 mm in first moult.

scoli translucent whitish, located in the white centre of the segments, covered with bristles at their tops. Dorsal scoli on A8 totally fused to a single mid-dorsal scolus. Dorsal scoli on A9 close to each other, but not fused. Dorsal scoli on T1 much shorter than all other dorsal scoli, widely apart in the middle, but very close to their respective supraspiracular neighbour. The supraspiracular and subspiracular lateral scoli small, decreasing in size from top to bottom (the lowest – sublateral – row of scoli is largely reduced).

L_2 (Fig. 4): Similar to L_1. Head and prolegs brown, thoracic legs black. Coloration and pattern similar to L_1, but extent of black colour reduced: no longer continuous black rings around the body. Wax covering the white parts more densely, in lose flakes on the scoli.

L_3 (Figs. 5–6): Similar to L_2, extent of black pattern more reduced, with a row of small black patches (1 per segment) along the mid-dorsal line; lateral scoli much smaller than dorsal scoli. Head and prolegs honey-coloured, head with a greenish tint. Black dots above the prolegs very prominent. Dense wax cover, lose flakes in particular on the dorsal scoli.

L_4 (Fig. 7): Black pattern reduced except for the black dots above the prolegs, the black thoracic legs, a faint black line along every spiracle and, in addition, the meso- and metathoracic dorsal scoli. Anal prolegs laterally yellow. Wax cover of the thoracic dorsal scoli much less developed than in the previous instars. These scoli are laterally extended and start to appear bulky. Abdominal dorsal scoli still strongly covered with wax, bent backwards, overlapping. Supraspiracular scoli almost completely reduced; subspiracular and sublateral scoli totally reduced. Prothoracic scoli dorsally largely reduced, laterally still present. Head greenish yellow. Ground colour early in this instar pure white; just before the 4th moult turning to bluish white.

L_5 (Figs. 8–10): Ground colour greenish blue, after feeding more greenish. The black pattern elements reduced except for a few black hair bases on the meso- and metathoracic dorsal scoli. Wax cover thin, except on the dorsal abdominal scoli. Head yellowish green. Spiracles blue. Anal prolegs bluish, with a big reddish brown centre. Many small blue dots without wax representing basal cells of reduced bristles covering the body.

L_6 (Figs. 11–13): Very similar to L_5. Head greenish blue. Lateral patch on the anal prolegs much bigger, reddish brown, covering most of the lateral area of the sclerotized anal prolegs. Prothoracic scoli totally reduced, as well as all lateral scoli, only short blue cupolas left, without any defensive glands which are known for most mature *Attacus* caterpillars. Meso- and metathoracic dorsal scoli long and bulky, with a few black hair bases; dorsal scoli on A1–A7 paired, a single one on A8, bent backwards, shorter, without black dots.

Cocoon (Figs. 14–15): Brownish, consisting of three layers: Outer layer dense and papery, adjusted to the shape of the surrounding leaf, which covers about 70–80 % of the cocoon. Middle layer lose, thin, only some threads between the inner and outer layer. Inner layer dense, hard, papery, inner surface slightly shining. Exit preformed, valve-like ("Reuse").

Pupa (Fig. 15): Dark reddish brown, length ca. 40 mm, diameter ca. 20 mm after dried exuvias.

Imago (Figs. 16–17): (Only ♀♀ hatched.) Ground colour blackish brown, much darker than in the few ♀ specimens known from Sumatra or West Malaysia, almost completely without the violet or red colour known from these populations.

Discussion

Ecological considerations

From the data of the few specimens recorded so far in northern Borneo, it is difficult to deduct possible habitat preferences of *Arch. staudingeri*. At Mt. Kinabalu, the present localities cover an altitudinal range from 600 to 1400 m and include habitats, at least, in two distinctly different vegetational zones, i.e., lowland and lower montane forest (see KITAYAMA 1992). The only other published record of the species from Borneo are two specimens taken in September 1978 at Ulu Temburong, Brunei,

300 m, in an area of mixed dipterocarp lowland forest (ALLEN 1981). In Sumatra, where locality data for about 20 specimens are known, the collecting sites similarly extend from the lowlands (300 m) to the montane zone (1300 m) and include a variety of different habitats, but always inside or adjacent to areas of primary forest (see NÄSSIG et al. 1996 a).

These data suggest that *Arch. staudingeri* has not very restricted habitat requirements, and that the species might be adapted to a broader range of types of primary forest rather than being limited to specific vegetation zones or plant formations. This view can be further supported by the fact that the species is apparently not restricted to specific larval hostplants but rather exhibits a certain degree of polyphagy as judged from the acceptability of several substitute foodplants, which is also the case in *Arch. edwardsii* and most other Attacini (see, e.g., GARDINER 1982, HOLLOWAY 1987). In comparison to *Attacus atlas*, however, a species which occurs sympatrically but is generally more widespread and common, *Arch. staudingeri* appears not to occur in purely secondary forest or much disturbed areas or even inside urban areas.

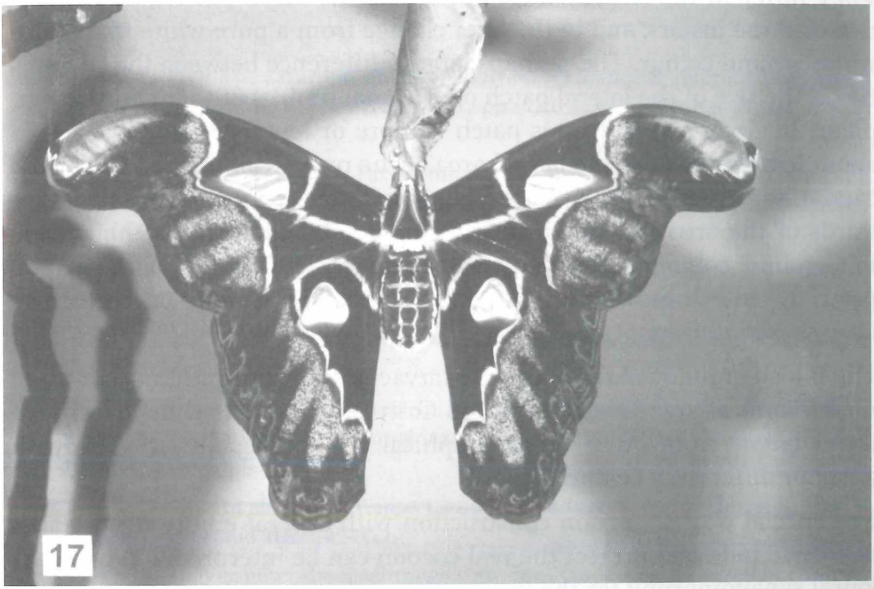


Fig. 17: ♀ of *Archaeoattacus staudingeri* in resting position, clinging to the cocoon. See antennae in resting position.

Considering a possibly wide range of acceptable habitats, it is remarkable that *Arch. staudingeri* seems always to be very rare, and has never been observed or taken in larger numbers. Apart from the low number of the present observations, the rarity of the species at Mt. Kinabalu is documented by the fact that it was apparently not found at all during three months of regular light trapping at various elevations and habitats in the area by members of by the Cambridge Expedition in 1965 (HOLLOWAY 1976). The species seems similarly rare in other parts of its range, and, for example, the best known collecting place for this species on Sumatra yielded no more than six specimens over a time span of one and a half years (NÄSSIG et al. 1996 a). Thus, unless the species evades succesfully all present-day recording techniques, *Arch. staudingeri* can be expected to exist at very low population densities, with individual populations probably ranging over large areas.

Morphological considerations and comparison with *Arch. edwardsii*

The larvae of *Archaeoattacus staudingeri* are very similar to those of *Arch. edwardsii* (see NÄSSIG 1983, PEIGLER 1989, PINRATANA & LAMPE 1990). They differ in the slightly larger extent of the black pattern of the first two or three instars, and in the later change from a pure white to a bluish white ground colour. The perhaps largest difference between the two species is the size of the lateral patch on the anal prolegs of the mature caterpillar: In *Arch. edwardsii* this patch is more or less oval and covers only about less than half of the lateral area of the prolegs along the ventral and caudal border, while in *Arch. staudingeri* it covers much more than two thirds of the area and fills it nearly completely, with only a thin rim in the ground colour of the body encircling it. The colour of the lateral patch[3] is reddish brown in *Arch. edwardsii,* while it is more orange brown in *Arch. staudingeri.*

The bluish ground colour of mature larvae is known from some *Samia,* all *Archaeoattacus* and most *Attacus* and *Coscinocera* larvae, while mature Attacini larvae from other zoogeographical regions usually are yellowish green or differently coloured.

The special way of cocoon construction with several empty dead leaves nearby to hide and protect the real cocoon can be interpreted as a behavioural synapomorphy for the two species of the genus *Archaeoattacus* (see

[3] This round patch is sometimes called "Attacini patch", because most species of the tribe, where the larva is known, possess this often quite colourful pattern.

NÄSSIG 1983). PAUKSTADT & PAUKSTADT (1989) observed traits of a similar behaviour in some *Attacus* caterpillars, but in these it is not as sophisticated as in both *Archaeoattacus* species and does not occur so regularly and obligatory.

From these results the separation of *Archaeoattacus* as a genus separate from *Attacus* can be supported, containing two similar and closely related species.

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