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Biological and Ecological Studies of *Calliteara cerigoides* (Lepidoptera, Lymantriidae), a Polyphagous Defoliator of Southeast Asian Dipterocarpaceae

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Abstract Larvae of *Calliteara cerigoides* (WALKER) (Lepidoptera, Lymantriidae) were encountered as important herbivores of the dipterocarp trees *Shorea javanica* K. & V. and *Hopea odorata* ROXB. Feeding preference tests indicated that while *C. cerigoides* is polyphagous, it feeds preferentially on dipterocarps. The urticating effects of larval setae appear to be caused by the structure of numerous apically-directed tines. Eggs hatched in 10.4 ± 1 ($\bar{x} \pm \text{SD}$) days, and larval instars were 7–9 days in duration. Female *C. cerigoides* deposited masses of 283 ± 274 eggs on tree trunks in an experimental forest. The parasitoid wasps *Mescomys orientalis* FERRIERE (Eupelmidae) and *Tyndarichus navae* HOWARD ? (Encyrtidae) were reared from eggs. The rate of parasitism for eggs in a field study was 78%, suggesting that biological control of *C. cerigoides* is possible.

Key words: Herbivory; parasitoid; defense; tropical biology; Lymantriidae; Dipterocarpaceae.

Introduction

Dipterocarp trees are a major component of lowland primary forests in Southeast Asia, and are important natural resources (ASHTON, 1982). Though they contain defensive chemicals, which presumably protect against biological attack (RICHARDSON *et al.*, 1989), massive defoliations of dipterocarp trees by unidentified Lepidoptera have been reported (ANDERSON, 1961).

Information on insect herbivores which feed on dipterocarps is important not only to an understanding of insect-plant interactions, but also for management of dipterocarp plantations established to aid reforestation in tropical areas. This report presents biological data on the dipterocarp defoliator *Calliteara cerigoides* (WALKER) (Lepidoptera, Lymantriidae) gathered in the course of research on defensive chemicals of these trees.

Methods

Study localities. Moths were collected in cultivated *Shorea javanica* K. & V.

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(Dipterocarpaceae) agroforests (TORQUEBIAU, 1984) in Krui, Lampung Province, Sumatera, Indonesia. Resins, scraped from man-made holes in tree trunks of *S. javanica*, are sold for formulation into varnishes, paints, and other materials. Extensive observations were made of *C. cerigoides* in the Cikarawang experimental forest, Bogor, West Java, Indonesia. This forest contains about fifteen dipterocarp and forty other species planted in blocks. In profile, the Cikarawang forest is essentially open, because lianas and extraneous tree species are removed by the forest caretakers. There is dominant canopy of mature trees above, with a horizon of 1–2 m high seedlings below. Scattered through the forest are trees of intermediate (approximately 5–15 m) height.

The observations and experiments below were carried out during two heavy *C. cerigoides* infestations of the Cikarawang forest, during the periods June–August 1988, and March–May, 1989. Where possible, voucher specimens have been deposited in the Cornell University Insect Collection, Lot No. 1185, and at SEAMEO-BIOTROP, Bogor, Indonesia.

Laboratory methods. All insect materials were taken from the Cikarawang Forest. Eggs, larvae and pupae of *C. cerigoides* were collected from foliage and tree trunks. Eggs were held at ambient laboratory temperatures (28–32°C) in 5 cm diameter petri dishes lined with moistened filter paper. Larvae and adults were maintained in 50 cm square nylon mesh cages. Larvae were offered freshly cut leaves of host plant seedlings taken from the Cikarawang forest, or from a nursery; dilute honey solutions were offered on cotton to adult *Calliteara*. Pupal cases were removed from the surrounding sheath of setae, and examined for parasitoids. After emergence of egg or pupal parasitoids, these parasitoids were maintained in 5 cm petri dishes and offered honey solutions in the manner described.

Reproductive potential. To determine reproductive potential of *C. cerigoides*, females and males which had emerged from field-collected pupae were paired in individual nylon mesh cages. The moths mated, and females oviposited in the cages. The number of eggs deposited was counted, and after the females had died, dissections were performed to determine the number of eggs remaining in the ovaries.

Measurements of eggs were made with a compound microscope equipped with an ocular micrometer; larvae and pupal dimensions were measured with calipers. All measurements are presented as $\bar{x} \pm S. D.$

Herbivory. Leaf preference studies were conducted with naive 1st instar larvae within three days after emergence. Freshly cut 2 cm × 6 cm strips of leaves were taped to the inside of a 30 cm glass arena. Twenty-five larvae were placed in the center of the arena. The amount of leaf damage was noted after 24 hours.

Studies of urticating setae. In this paper, the term setae is used *sensu* PETERSON (1956). Approximately 50 simple setae of 2–3 cm length were plucked from the dorsal surface of larvae in their last instar. The setae were extracted overnight in 5 ml 100% dichloromethane prior to gas chromatography. Extracts were

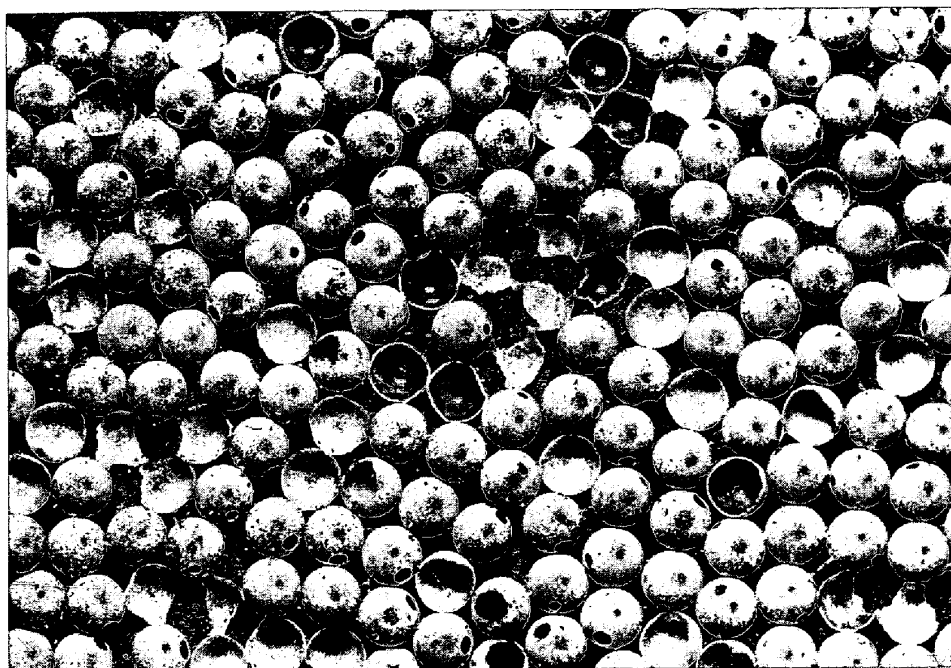


Fig. 1. Portion of egg mass of *Calliteara cerigoides*. Parasitoid exit holes are visible as small, rounded holes with smooth edges, offset from the micropyle. Larvae of *C. cerigoides* consume the eggshell, including the micropylar region, leaving a larger, jagged exit hole, or eggshell fragment.

analyzed with a Shimadzu GC-7A gas chromatograph, fitted with a $3\text{ m} \times 3\text{ mm}$ glass column of 3% OV-101 on GasChromQ, and a flame ionization detector. Samples were eluted with nitrogen, with the column oven temperature programmed to rise from 150° – 250° at 4° per minute.

For examination with the scanning electron microscope (SEM), dried larval setae were mounted on stubs, coated with gold, and observed.

Parasitoid field studies. Tree trunks were systematically examined for *C. cerigoides* egg masses during March–April 1989. When an egg mass was located, its height on the trunk, and the diameter at breast height (DBH) of the tree were measured. The total number of eggs in each mass was counted, and the egg mass was examined *in situ* to determine the extent to which egg masses had been parasitized. Pilot observations made in the laboratory during the 1988 outbreak established that parasitoids made smaller, distinct, round exit holes with smooth edges at an angle to the micropyle, while *C. cerigoides* larvae partially consumed the eggshell, including the micropyle, resulting in a larger irregular hole or leaving only a partial shell (Fig. 1). Exit hole sizes were not measured in the field study.

It was not possible to determine when parasitized egg masses were deposited. Egg masses were counted after all emergence had ceased. By this time, virtually all of the eggs in the masses had some sort of exit hole. When encountered, intact masses were left undisturbed until emergence had taken place.

Results

Extent and consequences of defoliation. Specimens of *C. cerigoides* were collected as larvae from trunks of *S. javanica* trees cultivated for resin production near the village of Gunung Kemala, Krui, in February, 1987. Resin harvesters stated that the larvae of *C. cerigoides* were responsible for massive defoliations of *S. javanica* agroforests, with a loss of resin flow resulting.

In the 1988 infestation of Cikarawang experimental forest, *C. cerigoides* larvae were concentrated on the canopy of *Hopea odorata* ROXB. Though it was not possible to measure larval density, the frass fall from the canopy was great enough to be clearly audible, and the entire ± 1 ha block of *H. odorata* canopy was defoliated by the herbivore. However, seedlings of the same species remained largely undamaged. Examination with binoculars of canopy cover in adjacent blocks, including an adjoining block of *Hopea mengerawan*, did not reveal any detectable defoliation of other dipterocarp or non-dipterocarp species.

Feeding preferences. In feeding preference tests, naive first instar *C. cerigoides* showed a preference for leaf strips of *H. odorata* (Fig. 2). Though other species were eaten, none showed as much damage as *H. odorata*.



Fig. 2. Feeding preferences of *C. cerigoides*. Tests were conducted as described in Materials and Methods. The figure shows experimental results of two herbivory bioassays 24 h after larvae were placed into arena. The leaves of each row represent a single bioassay conducted with five species. Top row: 1, *Hopea mengerawan*; 2, *Shorea javanica*; 3, *Shorea selanica*; 4, *Shorea pinanga*; 5, *Shorea seminis*. Bottom row: 6, *Hopea odorata*; 7, *Vatica* sp.; 8, *Szygium* sp.; 9, *Altingia excelsa*; 10, *Shorea stenoptera*.

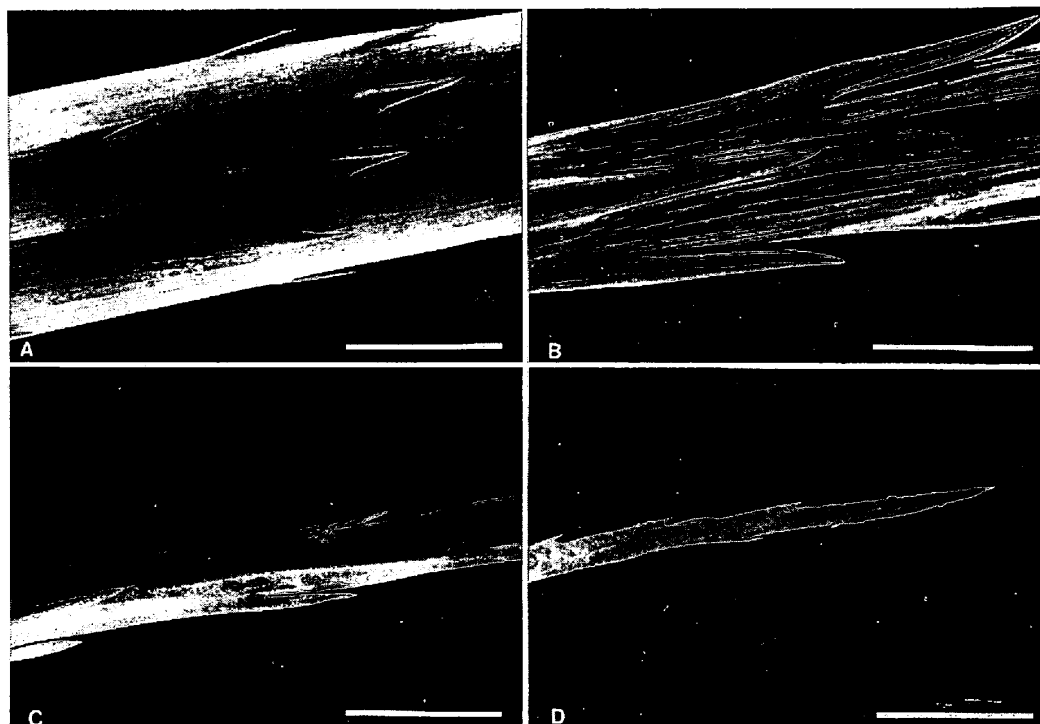


Fig. 3. Sections of urticating setae of *C. cerigoides* viewed with the scanning electron microscope. Setae are oriented with their origin to the left, thus the spines point in the direction of the apex. Bar=100 μ . A, Adjacent to base of seta, showing small spines 25–50 μ long; the shaft is cylindrical. B, At the midsection of the seta, spine length reaches approximately 150 μ , more than the width of the distinctly laminated shaft, which is cylindrical in form. C, Three-quarters of the distance to the apex, the shaft has assumed an angular aspect, and the spines are about 70 μ long. D, At the apex, viewed in profile, the spines are about 10 μ long and the shaft maintains its angular shape.

Urticating effects and structure of setae. Resin harvesters in Sumatera noted that the setae of the larvae were extremely irritating, a fact confirmed during work with *C. cerigoides* in the Cikarawang forest. To determine if organic chemical factors might cause the observed urticating effects, dichloromethane extracts of larval setae were analyzed with the gas chromatograph. Except for the solvent peak, no other chemicals were detected in the dichloromethane extract. Examination of the setae via SEM revealed that numerous, sharp, apically-directed tines project from the shaft along its entire length (Fig. 3).

Biological observations of C. cerigoides. Eggs of the moth collected in the field were $1.54 \pm .04$ mm in diameter ($n=45$); eggs deposited by females in the lab were $1.46 \pm .022$ mm in diameter ($n=66$). Eggs hatched in 10.4 ± 1 days ($n=18$). Attempts to rear *C. cerigoides*, on freshly cut leaves of dipterocarp seedlings, past the 5th instar were not successful, but to this point the duration of each instar was 7–9 days.

In the experimental forest, small groups (usually no more than 10) of larvae

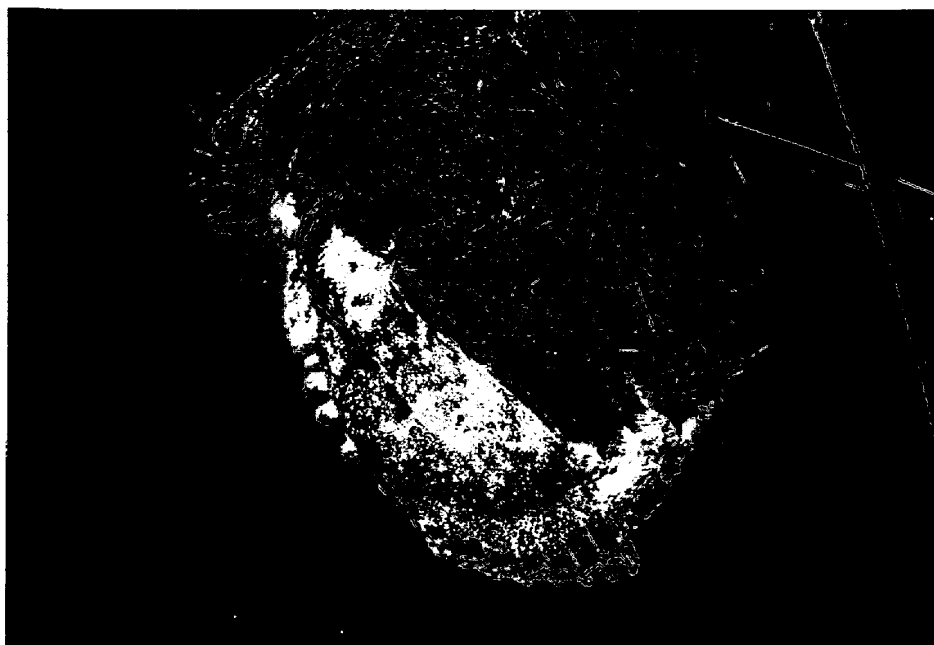


Fig. 4. Copulation of *C. cerigoides*. The insects are resting on the pupal case of the newly emerged female.

were often seen in aggregations on boles. The larvae were observed actively feeding and moving up and down boles during daylight hours.

Pupae were enclosed in a tightly webbed sheath, constructed out of tightly woven urticating hairs of the last larval instar. Pupal sheaths were found in low foliage and seedlings. Pupae were dimorphic. Those developing into females were 43 ± 1.8 mm long ($n=8$); pupae developing into males were 27 ± 1.3 mm long ($n=16$). The duration of the pupal stadium was not determined.

Adult female *C. cerigoides* observed in the field were never seen in flight, even after specimens in the field were disturbed. Laboratory reared females did not achieve full wing expansion following eclosion, but mated nonetheless.

Copulation was observed in progress in early morning hours in the field on two occasions (Fig. 4). In both cases, apparently newly-emerged females hung in a near vertical position from the webbed sheath surrounding the pupae, with the head up and the sternites and wings appressed to the sheath surface. Males were in a similar position, lower on the opposite side of the sheath, so that with the terminalia in contact the male was at right angles to the female (Fig. 4). Copulation was also observed in laboratory cages, with both insects on the same vertical surface, facing in opposite directions with the terminalia joined.

Deposition of eggs. Eggs were deposited on tree trunks ($n=126$) in masses ($n=236$). It was not possible to reach egg masses more than 2.5 m above ground level so the results below do not describe all egg masses located. Below this 2.5 m level, egg masses ranged from 4–222 cm above the ground, with the mean height

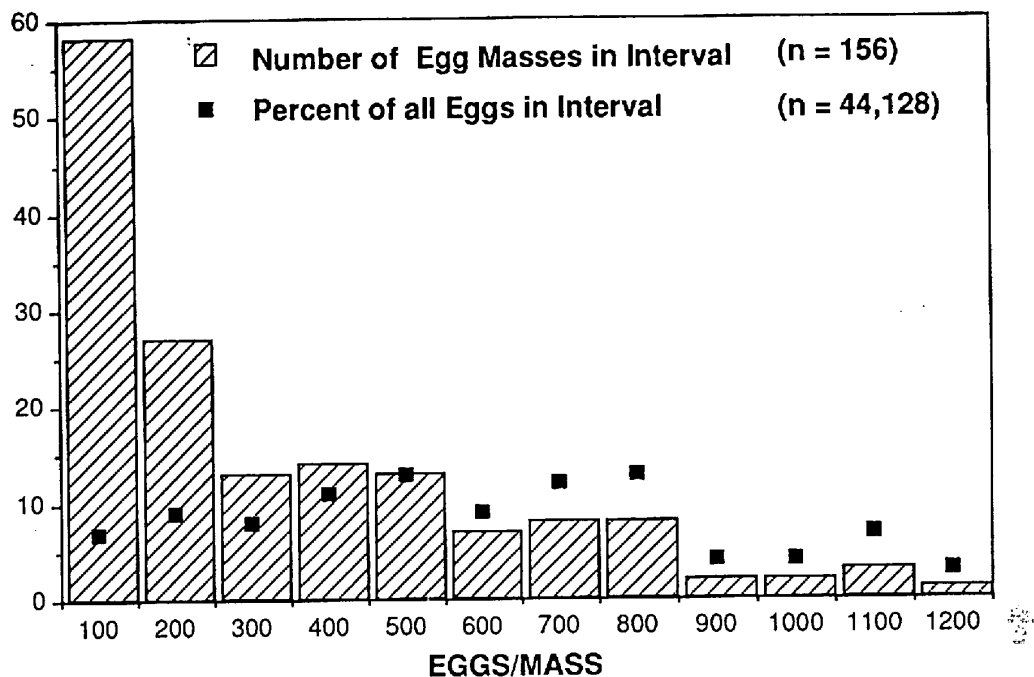


Fig. 5. Histogram showing number of egg masses in each interval. The percent of all eggs accounted for by egg masses in each interval is indicated by the dark squares.

of 132 ± 46 cm ($n=156$). The DBH of trees ($n=89$) with egg masses which could be counted ranged from 18–85 cm, with mean DBH of 41 ± 12.7 cm ($n=156$). Freshly deposited egg masses were off-white in color, and were not covered with any hairs. Egg masses contained 4–1174 eggs, with the mean mass size of 283 ± 274 eggs ($n=156$). The distribution of egg mass size is shown in Fig. 5.

The sum of the number of eggs deposited by females in individual cages and the number of eggs dissected from the same females after death indicated that ovaries of adult females contained a mean of 891 ± 254 chorionated oocytes ($n=14$).

Parasites and associates. Unidentified parasitoids were observed ovipositing singly, and in groups, on intact egg masses. Two parasitoid Hymenoptera species emerged from egg masses of *C. cerigoides*. These were determined to be *Mescomys orientalis* FERRIERE (Eupelmidae), and *Tyndarichus navae* HOWARD? (Encyrtidae). Parasitoid exit holes ($n=88$) in eggs held in the lab were divisible into two groups ($p < .001$, $t = -18.6$, 76 df). The smaller holes were $0.48 \pm .038$ mm ($n=53$) in diameter; the larger holes were $0.68 \pm .06$ mm ($n=25$) in diameter. The larger holes resulted from emergence of *M. orientalis*.

Dipteran larvae and pupae were dissected from pupae of *C. cerigoides*. The larvae were referable to Sarcophagidae and Tachinidae. Adult dipterans were recognized as belonging to an undetermined phorid species, and the tachinid genus *Carcelia*. Wasps emerging from the *Carcelia* sp. pupal cases were identified as *Brachymeria lugubris* (WALKER).

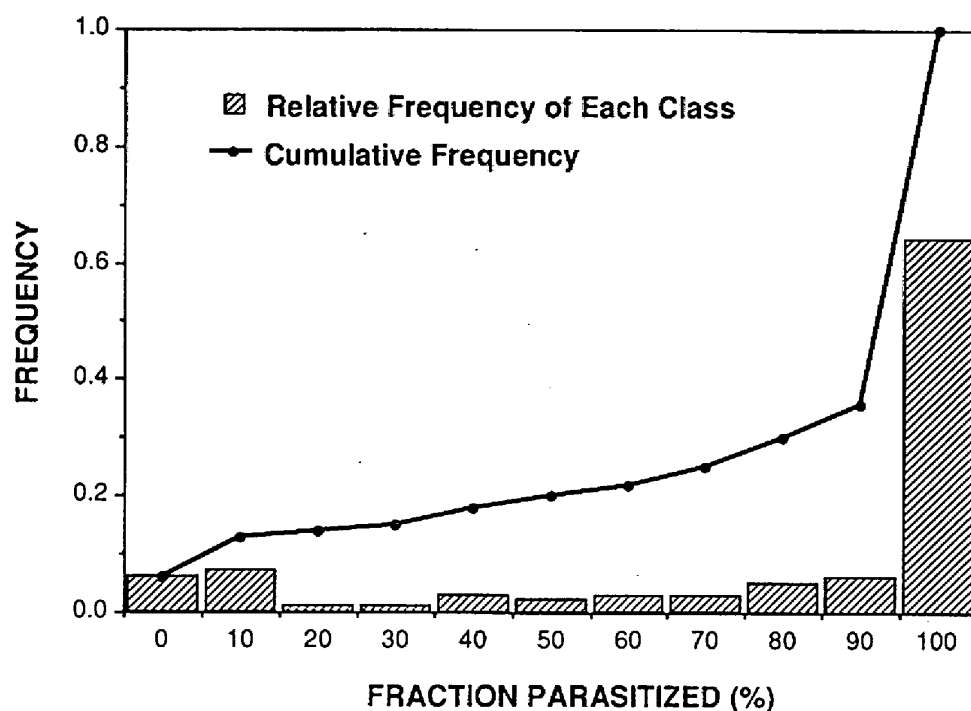


Fig. 6. Relative and cumulative frequency of parasitism of *C. cerigoides* egg masses. The histogram shows the relative frequency of percent parasitism of egg masses, the curve indicates the proportion of the total of all egg masses parasitized.

Parasitized pupae of *C. cerigoides* also contained other insects, which appeared to be feeding on decaying tissues. These insects were identified as adult *Aleochara postica* WALKER (Coleoptera, Staphylinidae), and adults and larvae of *Eporus?* sp. (Coleoptera, Rhizophagidae).

Quantitative aspects of parasitism. The parasitism rate for all egg masses ($n=156$) ranged from 0–100% (Fig. 6), with a mean of 78%. For the mean parasitism rate, the 95% confidence limits were 72.5% and 83.5%. Two-thirds of the egg masses ($n=100$, 64%), were parasitized at a rate which placed them in the interval of highest parasitism rate (91–100%). For these 100 egg masses, the mean parasitism rate was 99.2%. There was no correlation ($r=-0.038$, SPEARMAN Rank Correlation) between the number of eggs in a mass, and the parasitism rate of the mass.

Data relating to rates of parasitism of *C. cerigoides* pupae were not collected.

Discussion

A survey of the literature pertaining to *C. cerigoides* revealed no previous records of feeding on dipterocarps (HOLLOWAY, 1976). In the experiments reported here, *C. cerigoides* was shown to be polyphagous. Related lymantriid species are also polyphagous, and have been shown to feed on a variety of cultivated

and wild plant species (DUPONT & SCHEEPMAKER, 1936; MEHRA & SAH, 1974; MATHEW, 1978; ISLAM & JOARDER, 1983; ZAMAN & KARIMULLAH, 1987; REDDY *et al.*, 1988). That *C. cerigoides* may feed preferentially on *H. odorata* parallels the finding that *Dasychira mendosa* HUBN. form *fusiformis* WALKER is polyphagous, but shows a distinct preference for *Mohgania macrophylla* (WILLD.) O. KTZE (MEHRA & SAH, 1974).

Perhaps of more interest than the polyphagous behavior of *C. cerigoides* is that it eats dipterocarp species. Though chemical data is not available for the *Shorea* sp. and *Hopea* sp. studied here, dipterocarp leaves possess tannins (WATERMAN *et al.*, 1988), and dipterocarp resins in general contain terpenoid chemicals known to be toxic and repellent to insects (RICHARDSON *et al.*, 1989). These resins circulate through the leaf laminae in canals which lie beside vascular bundles (METCALFE & CHALK, 1979). Toxic and inhibitory effects of some of the chemicals found in dipterocarp resins (β -caryophyllene, and caryophyllene oxide, for example) have been demonstrated for the generalist herbivores *Spodoptera exigua* (Lepidoptera: Noctuidae) (LANGENHEIM *et al.*, 1980) and *Heliothis virescens* (F.) (GUNASENA *et al.*, 1988), as well as for leafcutting ants (HUBBELL *et al.*, 1983; HOWARD *et al.*, 1988). Such toxic chemicals might have been a factor in causing the mortality of *C. cerigoides* larvae in laboratory culture; other lymantriids cultured on toxic host plants (castor, *Ricinus communis* L.) in the laboratory showed substantial (<60%) mortality by the fifth instar (ISLAM & JOARDER, 1983).

The sexual dimorphism and urticating setae are consistent with descriptions of other Indonesian Lymantriidae (DUPONT & SCHEEPMAKER, 1936). No organic molecules soluble in dichloromethane were found in extracts of the larval setae. Though the chemical techniques used would not have detected the presence of any proteins possibly responsible for urticating effects (LAMY *et al.*, 1986), there is no evidence that this defensive function does not have the same physical basis described for other lymantriid larval setae.

The morphology of the setae (Fig. 3) is interesting because it suggests that a complex process may underlie their development. Tines do not bear a monotonic relationship to diameter of the setal shaft. The relationship between tine length and shaft diameter at a given point can be approximated with a second order polynomial which describes a parabola.

The number of eggs deposited by female *C. cerigoides* in egg masses overlaps that reported for other lymantriids (MEHRA & SAH, 1974; HÉRARD, 1979; BELLINGER *et al.*, 1988). The mean number of chorionated eggs in gravid females, determined by adding the number of eggs deposited to the number of eggs dissected from the same dead female (891 eggs), is 3.15 times larger than the mean number of eggs per mass (283 eggs), indicating that female *C. cerigoides* may deposit more than one egg mass. Though direct field observations are necessary to confirm this, an indirect corroboration of this result is provided from examination of the mean number of egg masses per tree, 1.9 ± 1 , and the fact that the females appear to be

flightless. A single female moth might thus oviposit more than once on the same tree.

On the basis of exit holes, it was determined that a mean of 78% of the *C. cerigoides* eggs in masses located in the experimental forest had been parasitized. Holes originating from exit of parasitoids were distinguishable from exit holes of *C. cerigoides* by their shape, size and position on the egg. These criteria were established on the basis of laboratory observations.

The high rate of parasitism seen in *C. cerigoides* eggs may result from the apparency of egg masses in the experimental forest. Compared to natural primary or second growth forest, the Cikarawang forest is much less heterogeneous, and much more open in profile, perhaps making it easier for parasitic wasps to locate egg masses.

It is possible that the restriction of our study to egg masses below 2.5 m above ground level influenced the rate of parasitism determined for *C. cerigoides*. However, *Lymantria dispar* (L.) egg masses above the 2.5 m level experienced greater mortality due to predators and parasites than those below (HÉRARD, 1979).

The exact number of species of egg parasites attacking *C. cerigoides* was not determined in our research, nor were we able to study the biology of *M. orientalis* and *T. navae*?. Surveys of *L. dispar* egg parasites in Asia revealed that six primary parasites attacked eggs (SCHAEFER *et al.*, 1988). *Tyndarichus navae* was recorded as a hyperparasite. Regardless of whether or not the *Tyndarichus* sp. reared from *C. cerigoides* is a hyperparasite, the fact remains that *C. cerigoides* eggs are subject to a high degree of parasitism.

The observations and experimental results presented here indicate that *C. cerigoides* may feed on at least eight dipterocarp species. This suggests that *C. cerigoides* has overcome chemical defenses of these trees. As such *C. cerigoides* is of potential economic importance as a defoliator of dipterocarps, both in naturally occurring and cultivated environments. The discovery and identification of egg parasites, and the finding that eggs sustain high rates of parasitism, indicate that biological control alternatives may be valuable in controlling *C. cerigoides* infestations.

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