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Cover photograph: Aggregation of males and females *Chalybion japonicum*; see p.12 (photo by Christophe Barthélémy)

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Prionoceridae Lacordaire 1857 of Hong Kong and Guangdong Province, China (Coleoptera; Cleroidea).

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Abstract

Notes on the identification of the six species of Prionoceridae occurring in Guangdong Province and Hong Kong are given. Records, photographs and details of the male genatalia are provided for the Hong Kong species, together with remarks on the biology, flight period and mimicry.

Introduction

The Prionoceridae is a small family of three extant genera: *Idgia*, *Prionocerus* and *Lobonyx* containing around 150 species (Geiser 2007), and is confined to the old world. Six species of *Idgia* have been recorded in Hong Kong and Guangdong, and Mayor (2007) lists another 14 species from China. Two species of *Prionocerus* have been recorded from China; both have extensive distributions and could well occur locally (Geiser pers com.). *Prionocerus* differs from *Idgia* in having the third to tenth antennal segments greatly broadened, flattened and serrate (see Geiser 2010 for details on species identification). A single species of the genus *Lobonyx* has been recorded in China and differs from the other two genera in that the male has only two pectinate protarsal segments.

Historically theses genera have been placed in other family groupings; most recently as a subfamily of the Melyridae; prior to that in the large family groupings of Malacodermidae or Malacodermata. Champion (1919) revised the two genera *Idgia* and *Prionocerus*, but omitted many species (Geiser 2007). Gressitt (1939) treated the Chinese and Cochin-China species of the two genera, but due to limited material only incorporated 10 species of *Idgia* in his key and descriptions, which was biased towards the south China species.

Species of Prionoceridae are elongate with thin, soft elytra, normally with rows of bristle-like setae. The head is drawn forward of the eyes forming a flat rostrum. The pronotum always has a lateral costa and there are no costa on the elytra disk. Other features are emarginate eyes, tarsal formula 5-5-5, with simple tarsal claws and a single spur on the pro-tibia.

Methods and material.

All specimens were collected, and site records documented, by the author in Hong Kong, with a bias towards Lantau Island. The genitalia were dissected and were photographed in 100 % glycerine. All specimens are in the author's collection.

Mimicry.

Champion (1919) noted that the two Oedemeridae genera *Nacerdes* and *Xanthochroa* bear superficial resemblance to species of *Idgia*. In Hong Kong there is an unidentified species of Cantharidae (Figure 1) which is very similar to *Idgia flavicollis* Redtenbacher 1868. Also there are many species with similar colouration to the *Idgia* species with black tipped orange / yellow elytra, such as the oedmerid *Eobia chinensis* (Hope) (see Figure 1); the Lampyridae species *Luciola terminalis* Olivier, 1883; and at least one species of Alleculidae. Whether this similarity is mimicry, some form of parallel evolution or other mechanism would be speculative. These mimic-like species show few of the features of Prionoceridae given in the introduction above.

Figure 1. Some mimic-like species of *Idgia* species. Top: Cantharidae sp. 16 May 2009 Tung Chung, Lantau. Bottom: *Eobia chinensis* (Hope) an Oedemeridae.

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Sexual dimorphism

The males of *Idgia* and *Prionocerus* species have a pectinate black comb along the inner edge of the anterior tarsi (Figure 2), which is totally absent in the females. This is quite distinct in all species in Hong Kong, with the exception of *Idgia oculata* Redtenbecher 1868.

Figure 2. Protarsus of male *I. flavirostris* Pascoe1860.

Key to the *Idgia* species of Guangdong (modified from Gressitt 1939).

1. Elytra largely pale (testaceous or orange) with dark apices ……. 2
- Elytra dark, usually dark blue or green, never orange or testaceous……..... 3

2. Prothorax rather evenly rounded at sides, edged with long blackish bristles, surface smooth; head and apical halves of femora black; elytra with apical fifth blackish and external margins with black bristles……..***Idgia deusta*** Fairmaire 1878
- Prothorax strongly narrowed behind middle, edged with moderate brownish hairs, finely and sparsely granulose; head largely brownish or testaceous; only extreme apices of femora black; elytra with apical tenth or so black, margins with small pale brown bristles bristles……..***Idgia ungulata*** Champion 1919

3. Head posterior of eyes blackish, and anterior of antennal insertions light testaceous…….. ……..***Idgia flavirostris*** Pascoe1860
- Head anterior of antennal insertions mostly dark..... 4

4. Small species less than 12mm long ....***Idgia flavicollis*** Redtenbacher 1868
- Large species longer than 15mm..... 5

5. Pronotum with a pair of blackish spots each side of the disc, Femora basally testaceous and dark (purplish brown or bluish) apically .....***Idgia oculata*** Redtenbecher 1868
- Pronotum immaculate, smooth and shaped similarly at apex and base; Abdomen metallic green on basal two-thirds; femora entirely metallic green .....……..***Idgia hoffmanni*** Gressitt, 1939

Species accounts

Idgia flavicollis Redtenbacher 1868

Description: Length of Hong Kong specimens: 7-10mm. Shiny metallic green. Head green to shiny blue. Antennae ochraceous. Prothorax testaceous, more orange in older specimens. Pronotal disk smooth with a few bristles and margin with sub-erect black bristles. Ventral surfaces bronzy green, with the apical two abdominal segments and trochanter testaceous. Elytra micropunctate, thinly clothed with recumbent golden-brown hairs and with rows of short erect, black bristles.

Material examined: # 2 of 22.ii.09 Wang Tong on flowers; # 2 of 28.ii.09 Wang Tong on flowers; # 3 of 28.ii.09 Wang Tong on flowers; # 1 of 1.iii.09 Wang Tong on flowers. Female; # 2 of 1.iii.09 Wang Tong on flowers. Male; # 1 of 5.iii.05 Mui Wo, Lantau; # 2 of 5.iii.05 Mui Wo, Lantau.

Site records: 20.ii.09 Wang Tong, Mui Wo, Lantau; 2.iii.08 Wang Tong, Mui Wo, Lantau; 5.iii.05 Wang Tong, Mui Wo, Lantau; 7.iii.06 Wang Tong, Mui Wo, Lantau; 11.iii.06 Wang Tong, Mui Wo, Lantau; 13.iii.08 Wang Tong, Mui Wo, Lantau; 14.iii.08 Wang Tong, Mui Wo, Lantau; 17.iii.08 Wang Tong, Mui Wo, Lantau; 18.iii.06 Mui Wo, Lantau; 19.iii.06 Wang Tong, Mui Wo, Lantau; 21.iii.06 Wang Tong, Mui Wo, Lantau; 25.iii.06 Wang Tong, Mui Wo, Lantau; 26.iii.06 Wang Tong, Mui Wo, Lantau; 27.iii.06 Wang Tong, Mui Wo, Lantau; 28.iii.06 Ngong Ping, Lantau; 2.iv.06 Wang Tong, Mui Wo, Lantau; 5.iv.06 Wang Tong, Mui Wo, Lantau; 14.iv.05 Wang Tong, Mui Wo, Lantau; 17.iv.05 Wang Tong, Mui Wo, Lantau; 18.iv.06 Wang Tong, Mui Wo, Lantau; 26.iv.08 Wang Tong, Mui Wo, Lantau.

Biology: This is by far the commonest species of Prionoceridae in Hong Kong. It is abundant in the last 2-3 weeks of March with extreme dates of 22 February and 26 April. Invariably seen in large numbers and found on almost every indigenous blooming plant on the hillsides, most commonly on *Maesa perlarius* (Lour.) Merr.; *Ligustrum sinense* Lour.; *Celtis sinensis* Pers.; *Zanthoxylum scandens* Blume and *Rhaphioepis indica* (L.) Lindl.; *Phyllanthus emblica* L and *Lonicera* sp. *I flavicollis* seems to favour indigenous species and has been observed feeding on plants close to blooming, although this species was never observed visiting flowers of *Agaretum* sp, *Lantana* sp and *Bauhinia* sp. On 2 March 2006 during and after very heavy rain many beetles of this species were observed sheltering under green painted metal railings.

Distribution: Hong Kong and Taiwan. Redtenbacher (1867) described this species from specimens collected in Hong Kong by the Fregatte Novara expedition.

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Figure 3. *Idgia flavicollis* : Top 5 March 2005 . Bottom: 17 April 2005. Both Wang Tong, Mui Wo, Lantau

Figure 4. *Idgia flavicollis* Redtenbacher 1868. Left imago. Right from top. Male genitalia armature: A Lateral view B Lateral view with medium lobe pulled away from the lateral lobes. C Dorsal view D ventral view.

Idgia hoffmanni Gressitt, 1939

Description (from Gressitt 1939): Length 18.5mm. Metallic green and blue. Elytra, ventral surfaces and legs clothed in sub-recumbent short pale tawny hairs. Head and pronotum covered in longer sub-erect or oblique black bristles. Head steel blue with greenish tinge. Clypeus slightly purplish. Antennae pale ochraceous, base of scape piceous. Clothed in very short pale golden hairs. Prothorax orange yellow, sub-hyaline, slightly dark near apex and base, clothed with black setae. Scutellum bronzy purple. Elytra metallic blue-green. Ventral surfaces shiny blueish-green. Last 2-3 abdominal segments and the sides of the preceding sternites orange testaceous. Legs metallic green. Males: inner side of the first three segments of the anterior tarsi with distinct, close toothed black combs beneath.

Distribution: Known only from a few specimens (Geiser pers.comm.) from Lien district in north Guangdong.

Idgia oculata Redtenbecher 1868

Description: Length of Hong Kong specimens: 15.5-18.5mm. Head steel blue to purplish. Antennae testaceous. Prothorax testaceous with a round purplish-edged, black spot each side of the centre of the disk, sparsely covered with long semi-decumbent golden pubescence and sparse semi-erect and shorter black setae. Scutellum dark testaceous to bluish (brighter testaceous in one live specimen). Elytra metallic blue to greenish blue. Metasternum blue green. Abdomen testaceous. Legs purple to black with coxae and basal halves of femora testaceous.

Material examined: # 23 of 25.v.10 Ng Tung Chai; # 24 of 25.v.10 Ng Tung Chai; # 1 of 17.vi.08 Lam Tseun Valley ; # 6 of 22.vi.09 Ng Tung Chai # 2 of 26.vi.07 Upper Lam Tsuen valley. **Site records:** 1.vii.08 Shing Mun; 6.vii.08 Kap Lung.

Figure 4. *Idgia oculata.* 17 June 2008 Lam Tseun Valley

Biology: Flight period centred around June with extreme dates of 25 May and 6 July. Normally encountered in large groups, feeding on various flowering shrubs and trees. Observed on 17 May 2008 on leaves of *Mallotus paniculatus* (Lam) Muell. Arg.

Distribution: Hong Kong and Hainan. Redtenbacher (1867) described this species from specimens collected in China by the Fregatte Novara expedition (which at that time could have included modern day Kowloon or the New Territories). The first reference to this species in Hong Kong was made by Hill (1982) and Hill *et.al* (1982). Mayor (2007) lists only Hainan and not Hong Kong for this species. Geiser (pers.comm.) has noted that Pic (1923) had recorded this species from Tonkin.

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Figure 5. *Idgia oculata*. Left imago. Right from top. Male genitalia armature: A Lateral view B Lateral view with medium lobe pulled away from the lateral lobes. C Dorsal view D ventral view.

Idgia ungulata Champion 1919

Description: Length 8-10mm. Pale orange testaceous. Antennae, basal portion of head, extreme apices of elytra, tibiae and tarsi and apical one-tenth of elytra pitchy brown. Eyes almost contiguous on top of the head in males.

Material examined: # 3 of 22.iv.06 Wo tin, Mui Wo, Lantau; # 10 of 27.iv.08 Wang Tong , Mui Wo, Lantau; # 1 of 7.v.07 Wang Tong , Mui Wo, Lantau; # 3 of 9.v.06 Silver mine waterfall, Mui Wo, Lantau; # 12 of 16.v.10 Ng Tung Chai.

Site records: 12.v.09 Wang Tong

Biology: Always found singly. Attracted to lights. One specimen was netted at dusk in flight. Normally found in the daytime under leaves with no sign of feeding.

Distribution: Widely distributed in eastern China. Champion (1919) described this species from specimens collected in Hong Kong Kong by J.J. Walker and F.W. Terry, as well as specimens collected from Amoy.

Figure 6. *Idgia ungulata* 22 April 2006 Mui Wo, Lantau.

Figure 7. *Idgia ungulata*. Left imago. Right from top. Male genitalia armature: A Lateral view B Lateral view with medium lobe pulled away from the lateral lobes. C Dorsal view D ventral view.

Idgia deusta Fairmaire 1878

Description (from Gressitt 1939): Length 9.5-12mm. Orange testaceous. Antennae, head, tibiae and apical one-fifth of elytra, black. Elytra with longitudinal rows of black bristles.

Distribution: Widely distributed in south and east China and Vietnam. Gressitt (1939) recorded this species from Guangdong, but it has not yet been recorded in Hong Kong.

Idgia flavirostris Pascoe 1860

Description: Length of Hong Kong specimens: 9.5-11mm. The bicoloured head makes this species quite distinctive. Base of head to the posterior of the antennal insertions, dorsally, and to the anterior of the eyes ventrally, black with a green or purple tinge. Anterior of the head including palps and antennae, testaceous. Pronotum subquadrate with the posterior two-thirds slightly sinuate, all margins edged with erect black setae. Elytra green to bluish green, sometimes with a red or purple tinge, granulate, though shining. Each elytron with 6-7 rows of erect black setae, the rows becoming less distinct and confused in the posterior third. The antennae from segment four to apex, tarsi, meta and mesa tibiae are darker and have a reddish tinge, though in one specimen this is almost black. Metasternum dark greenish blue. The abdomen in the Hong Kong specimens is testaceous, the disc of the 3 basal segments being slightly dingier. This differs from Pascoe's (1860) description of the abdomen of the type, being black with yellow margins.

Material examined: # 1 of 21.ii.09 Tung Chung Uk, Lantau; # 5 of 26.ii.10 Po Lin, Lantau; # 6 of 26.ii.10 Po Lin, Lantau; # 7 of 26.ii.10 Po Lin, Lantau; # 1 of 8.iii.08 Tung Chung valley, Lantau; # 2 of 8.iii.08 Tung Chung valley, Lantau.

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Biology: Flight period from 21 February to 8 March. All records are in well wooded areas above 350m altitude. Mostly seen singly or in very small groups. Observed on blooming *Maesa perlarius* (Lour.) Merr. and *Ligustrum sinense* Lour.

Distribution: Southeastern China including Hong Kong. Mayor (2007) lists only southeast China for this species, even though Pascoe (1860) described the type from north China.

Figure 8. *Idgia flavirostris.* 8 March 2008 Tung Chung valley

Figure 9. *Idgia flavirostris*. Left imago. Right from top. Male genitalia armature: A Lateral view B Lateral view with medium lobe pulled away from the lateral lobes. C Dorsal view D ventral view.

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Notes on the biology of the conspicuous mud dauber wasp, *Chalybion japonicum* (Gribodo, 1883) (Sphecidae) a major predator of spiders in Hong Kong.

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Abstract

The nesting biology of *Chalybion japonicum* was studied using nest traps in Hong Kong. It was revealed that (i) this wasp was very versatile in nesting site selection, (ii) it constructed few cells per nests (83% of the nests studied had one or two cells only), (iii) there was a variability in prey selection related to the seasonal abundance of prey, (iv) that nearly 40% of all brood died during development either from fungal infection or parasitism and (v) that this mud dauber was bivoltine in Hong Kong.

Key words: *Chalybion japonicum*; Sphecidae; Araneidae; nest-traps; parasitism.

Introduction

This paper describes the nesting biology of the common mud dauber wasp *Chalybion japonicum* in Hong Kong. Observations were carried out in 2010 using nest traps that were dissected and nesting behaviour was recorded *in-situ*.
The genus (sub-genus) was revised by Hensen (1988) who provided a grouping of the various species; *C. japonicum* was placed in the *C. bengalense* Group. Members of this genus have generally distinctive metallic hues of blue or green, only one member being black.
Chalybion japonicum is widely distributed from the Korean Peninsula, Japan, Taiwan and South East Asia (Yamane *et al* 1999).

Materials & Methods

The nesting behaviour of *Chalybion japonicum* was studied using nest traps that consisted of hollow bamboo canes of various length and diameters that were cut so that one end was closed by a nodal septum. Clusters of seven cut canes were bundled together and hung from roof beams in the author's office in Sai Kung Country Park, Hong Kong.

A total of 64 traps were set in April, May and June 2010 in the same location. The April and May traps were 155-185mm long (mean = 164.8; n = 50) with diameters of 6-10mm (mean = 7.6; n = 50), while the June traps were 165-230mm long (mean = 203.9; n = 14) with diameters of 6-10.5mm (mean = 7.5; n = 14). Upon collection, after completion of the nest by the wasp the traps were opened, prey, brood content and nest associates recorded and the traps then placed individually in Ziploc® bags for brood emergence.

Ten freshly completed nests totalling 12 cells were opened daily, the brood was measured, prey numbers and species determined and daily prey consumption measured until the larvae pupated, after which the nests were left undisturbed until emergence of adults. The daily growth was documented photographically.

Measurements were taken on scaled photographic enlargements for brood and with a precision stainless steel calliper for nest dimensions, cell partition and cocoon wall thickness.
Spider prey where identified by Dickson Wong Chi Chun, Hong Kong, based on my photographic records.

Additionally, I carried out *in-situ* observation of nest construction and prey provisioning on four traps, totalling 6hrs 08mns of observation.

Observations & Discussion

Nest & brood description

Nest architecture
Chalybion japonicum was extremely versatile with regards to nesting site selection, beyond the frequent usage of my obvious traps, the wasp selected any site that would present itself with a more or less tubular shape, whether it be the screw recesses in electrical appliances, cells of a nest of *Polistes gigas*, left on a table top, the cells constructed by *Sceliphron deforme* the previous year (Fig. 1) or even interstices between rafters and joists of the roof. It was also observed opening fresh *Sceliphron deforme* cells, empty the content, prey and brood alike and then furnish it with its own prey and brood.

The nests contained few cells generally, 39% of the nests were composed of one cell, 44% had two cells,14% had three cells and 3% had 4 cells, regardless of the tube length or diameter. As was noted by Iwata (1976) the wasp does not utilize fully the cavity at hand, leaving considerable empty space either in the cell or beyond it, as opposed to many other tube-renting wasps in the family which optimise space utilisation.

The nests could be characterised by the following: (i) the innermost cells did not necessarily start from the bottom of the trap, but could be initiated anywhere along its length, (ii) there were no intercalary cells, (iii) the outermost cell anterior partition formed the nest closure and (iv) when the first cell was initiated against the nodal septum the

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wasp generally did not add a plug of cell material at the posterior end of the cell. Figure 2 gives an illustration of a typical nest at opening.

The cell partitions were composed of a clayish material with inclusions of sand grains, in all cases the posterior side of the cell partitions had a rough finish while the anterior surface was smooth. A great variety of forms of closures where observed, from a simple clay partition maximum 3mm thick, with or without adjunction of a finishing layer, to complex multipartitions constructions, separated with narrow empty space and thick nest plugs, with or without a finishing layer. In 14% of the cases *C. japonicum* applied an additional layer of white material - likely uric acid from reptile faeces (*Gekko* spp) - on the last cell partition on both uni- and multi-cellular nests; in another 14% it would apply patches or even layers of a grey/black material likely to be faecal matter and in 14% it applied a layer of transparent resinous material (from an unknown plant source) to the same. Iwata (1964) noted that the usage of white material was an obligate behaviour on all nests of the specimens he observed in Thailand and that such was the case for uni-cellular nests in Japan (Iwata, 1976); however, as shown here this behaviour was more facultative in Hong Kong with a large degree of variability. The use of white material has been recorded for several other species in the genus (*C. bengalense* and *C. zimmermanni*) (Jayakar and Spurway 1963; Ward 1971). Iwata (1976) observed the wasp collecting gum from peach trees and applying it to the nest closure.

The nests had no vestibular cell, although one trap presented a succession of three partitions after the single cell. It may be possible that this was the consequence of an attempt by the original wasp or even another one to add additional cells to the cavity. All but two traps had no posterior partition to the first cell and two other traps had some cell partition material applied on or very close to the nodal septum of the hollow cane.

When multi-cellular nest were built the first cells were longer than the second which were longer than the third. The first cells were 22-190mm in length (mean = 104mm; n = 64), the second cells were 23-84mm (mean = 44mm; n = 38), the third cells were 26-116mm (mean = 33mm; n = 11) and the fourth cells were 19-32mm (mean = 25.5; n = 2).

Prey and oviposition

The vast majority (90%) of prey were in the Araneidae family,7.8% in Tetragnathidae (all represented by four species of *Leucauge*), 2% in Theridiidae and 0.2% in Uloboridae. In fact the majority of all prey were represented by two genera in Araneidae, 49% in *Neoscona* spp and 33% in *Cyclosa* spp. Males and females were provided although females represented 79% and males 21% of all prey taken. There were between 5 and 18 prey items per cell (mean = 10.5; n = 47). *C. japonicum* is a major predator of small spiders. Between the 12 April 2011 and 10 May 2011 the first adults (from overwintering pupa) took 251 prey items distributed over 21 recorded nests (12 prey items per nest) and between the 29 May 2010 and 17 July 2010 the daughters took 234 prey items on seven nests (33.5 prey items per nest).

A generational variation was noted in the major species of prey taken. The first active females of the year took a majority of *Neoscona* spp., while their daughters took a majority of *Cyclosa* spp. with *Neoscona* spp. completely absent from the prey records. This absence may be explained by two independent factors: the exhaustion of the prey stock after intensive hunting by the first generation, and/or the end of the seasonal presence of the spider species from mid to end of June onwards . David A. Landes (Landes *et al* 1987) noted that *C. californicum* in the Southern USA clearly selected prey according to their seasonal abundance and this may well be the case with *C. japonicum* in Hong Kong. The difference in prey number presented above may be explained by the distinctive seasonal prey preference between the first active females and their daughters: *Neoscona* spp. are generally larger than *Cyclosa* spp.; at least in the prey record and the nesting female would require more prey matter to sustain its brood.

The egg was attached dorso-laterally close to the abdomen and cephalothoracic junction of the prey, the anal end approximately median to the host body (Figure 4). On the 32 cells for which the position of the egg was ascertained four were found to be laid on the first prey, seven on the second, five on the third, four on the fourth, one on the fifth, three on the sixth, three on the seventh, three on the eighth and one each on the ninth and thirteenth prey. This clearly shows that *C. japonicum* lays its eggs after provisioning the cells as is the case with many apoid wasps, but there was no particular determinism in the egg position.

On five nests for which prey and sex of brood was determined it was noted that the mother provided fewer prey for males than for females (Table 1).

Trap ref.	No. of prey Male cell	No. of prey Female cell
PSO-100. A7	4	7
PSO-101.A5	6	8
PSO-102.A3	9	12
PSO-102.A5	7	14
PSO-104.A2	7	9

Table 1: Prey item count relative to the sex of the brood

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Brood and brood development
Brood development was monitored at 24 hour intervals on 10 traps totalling 12 cells, until the brood reached pupation period (Figure 3).

The egg was creamy in colour slightly arched, with hemispherical ends and a more or less constant diameter of 0.8-0.94mm (mean = 0.86mm; n = 29), it was 2.9-3.6mm long (mean = 3.20mm; n = 27). It hatched in approximately four days after oviposition (mean = 3.80 days; n = 12). The first instar larvae remained attached to the prey and fed ventrally on the prey abdomen until it was emptied; it then reached for other food items moving about in the cell. At first the larvae only consumed the abdomens of the prey leaving cephalothoraxes and appendages, however, when all prey had been fed upon the larva consumed what was left, leaving nothing save for a few hard chitinous elements such as the chelicerae. The larvae fed continuously for about 7 days (mean = 6.80 days; n = 10). In the first four days, the number of prey consumed daily increased and on the fourth or fifth day it suddenly decreased. The daily mean larval growth and prey consumption is expressed graphically in Figure 4. When feeding was completed the larvae groomed themselves, removing foreign objects such as prey setae and hard chitinous parts from their bodies. On the first day after completion of feeding the larvae would spin lose strands of silk in an apparent random fashion binding them to the cell walls; they then proceeded at the construction of the cocoon proper within the tangle of the loose strands, this time spinning a dense film of fine silk forming a continuous layer for about two days. It took 3-4 days (mean = 3 days; n = 10) to complete a cocoon and start pupation. The silk of the cocoon was at first creamy-white and gradually darkened in three days to become dark brownish-red, barely translucent. It was fragile and easily torn. The cocoons were oblong, with a basal hard and dark capsule and were 17.50 - 25.20mm long (mean = 21.20mm; n = 24) with a maximum diameter of 4.50 – 6.70mm (mean = 5.60mm; n = 24) the wall thickness was 0.08mm thick.

Pupation time was measured untill emergence from the nest and lasted 39-42 days (mean = 40.80 days; n = 9). However, from casual observations it seems that after breaching the cocoon the wasp remained inside the trap/nest for a day at maximum and then emerged.

As a rule males emerged before the females, and females cells were always constructed before (posteriorly) to that of male, although in one instance the mother constructed a male cell before the female one.

Voltinism
Observations on nesting patterns revealed that *C. japonicum* had two generations per year. The first generation emerged from overwintering brood in May and the second emerged in June. Two distinct ovipositioning activity periods were noted, the first in May and the second from end of June to Mid-July. The larvae entered a long diapause in July, overwintering as pre-pupal larvae until end of April of the following year when pupation started.

Sex ratio
Sex ratio was obtained on 37 active cells and was determined to be 25 females for 12 males or an approximate ratio of 2:1.

Natural enemies, *nest associates and brood death*
A number of enemies and associates were reared from cells of *C. japonicum*. Twenty-eight cells out of 105 (27%) were parasitised. The most common enemy was a cleptoparasitic phorid fly which was present in 19 cells, seven cells were infested by *Melittobia* sp (Chalcidoidea, Eulophidae), one cell was parasitised by a cleptoparasitic miltogramine fly and the brood in one cell seemed to have been destroyed by an infestation of small Psocoptera.

and fresh prey was noted on several nests (Figure 5), this indicates that the fly gains access to the cell while it is being built, it remains trapped inside at cell closure, and is then at leisure to lay eggs both on the prey and the cell walls. The wasp egg is likely consumed by the adult fly as no eggs were ever found when the parasite was still at egg stage. The maggots never consumed the entire food store and left a great volume of prey matter.

On the other hand *Melittobia* sp. attacked only mature larvae, pre-pupae and pupae, therefore the Chalcidid must have gained access much after the nest and its closure had been completed.

Small Psocoptera were found in 10 nests. They were present from the beginning untill much after brood emergence. They seemed to feed on debris in the nest rather than on the wasp brood save for the single case mentioned above.

Mites were recorded in two instances on the brood and later on the adult wasp when it was collected at emergence.

The brood died for reasons not related to parasitism in 12 out of 112 active cells (11.7%). Fungal infection was present in nine of these cells and is the presumed cause of mortality, although in some instances despite the presence of mould on the prey, the brood developed, pupated and emerged. When combined with parasitism the total brood failure reached approximately 39%. O'Neil (2001) provides a summary of brood mortality for a few species of Sphecidae and in particular for four species of *Sceliphron*, a close relative to *Chalybion*. This ranges from 36% to 43% which coincides with the brood mortality observed in this study.

In-situ observations
In-situ observation totalling over six hours of activity on four traps was carried out in May-June 2010. Behaviours

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were time recorded. Five major activities were identified: (i) cell material foraging: (ii) prey foraging; (iii) applying cell material; (iv) placing prey and (v) other activities, referred to as unknown. Table 2 details the time spent on each of the above activities, Table 3 provides the duration of each activities for the construction of one cell and Figure 6 graphically illustrates the nesting activities sequences.

Work started soon after sunrise around 0700h locally (in May) and stopped before sunset around 1800h, the wasp sheltering for the night away from the nesting site.
On a cell the wasp spent 60% of her time foraging for prey, 28% foraging for cell material, 9% applying this material to the cell partition, 0.5% placing prey in the cell and 2.5% as unknown time spent. To construct and provision one cell the wasp took on average 3hrs50min and could therefore construct a 2-3 cell nest in one day. The cells were never closed by a temporary plug when the wasp left for foraging.

Activity	Time Spent (s)	Max (s)	Mini (s)	Mean (s)	Mean (mns)	e =
Material Foraging	7470.00	960.00	60.00	339.55	5.66	22
Prey Foraging	11580.00	1350.00	270.00	723.75	12.06	16
Applying material	2475.00	265.00	25.00	112.50	1.88	22
Placing prey	190.00	25.00	5.00	14.62	0.24	13
Empty	360.00			360.00	6.00	1
Total	22075.00					

Table 2: Recorded activities, time budget.

Activity	Time Spent (s)	Time spent (mns)	%
Material Foraging	3840.00	64.00	27.61
Prey Foraging	8405.74	140.10	60.44
Applying material	1230.00	20.50	8.84
Placing prey	72.00	1.20	0.52
Empty	360.00	6.00	2.59
Total	13907.74		100.00

Table 3: Activities durations for the construction of one cell.

Nest construction
The cell partition material was formed into a small pellet and was carried solely with the mouth parts, mandibles and possibly palpi/bristles (?). One wasp, using bundle PSO-104, procured the mud from an old *Sceliphron deforme* nest, approximately 1m away, a fact that had been observed with *C. californicum* and *C. zimmermanni* on nests of *Sceliphron* (Bohart & Menke 1976). The use of a dry source of material requires water to render it plastic, therefore it can be confirmed for *C. japonicum* (Bohart and Menke 1976) that water is procured first and then applied to a source of dry mud. When the material was applied inside the nest, the wasp produced a stridulating noise similar to that of other Sphecoidea, caused by the contraction of the longitudinal wing muscles of the thorax.

Upon completion of a cell partition the wasp always lingered at the nest entrance (2-10s), grooming and often re-entering the trap (up to five times) as if inspecting the workmanship.

In some cases when provisioning was incomplete at the end of the day the wasp would leave the cell open for the night resuming work the following day.

In several instances although the terminal partition had been constructed, it was re-worked upon several days after the nest had been completed, with the addition of a layer of white material, assuming it were the same wasps. Also, in two instances it was observed that wasps could breach the terminal partition of a completed nest, extract some of content of the last cell – never more than 1-2 prey items, and later reseal the nest. Usurpation of nests of *S. deforme* was a common occurrence, the two species co-existing in the same locale. *C. japonicum* re-used either breached cells or simply breached an occupied cell, extracted the content, either pupa, larva or prey and furnished it with its own prey and egg, sealing the cell upon completion of provisioning. Not having marked live specimens and despite the incident related above, it was unclear if *C. japonicum* showed defined intraspecific nesting site usurpation. Species in the genus have a tendency towards interspecific nest usurpation such a *C. californicum* upon nests of *Sceliphron* spp. (Bohart and Menke, 1976) and this was confirmed with the present study by *C. japonicum* upon nests of *S. deforme* although from casual observations it seems that *C. japonicum* may prefer pre-existing cavities over old nests.

Prey transportation and provisioning
The mode of transportation varied according to the prey size. While in general all prey were of similar size, occasionally the wasp would carry exceptionally small items (*Cyclosa* sp1). Large prey were carried venter up, the front legs seized by the mandibles and the body held with the wasp fore-legs. Small prey were carried similarly but held only by the mandibles, un-assisted by the forelegs.

The wasp entered the nest head first, dragging the prey under her body and always exited metasoma first being unable to rotate herself within the cavity.

On several occasions the wasp delivered additional stings to the prey before entering the trap, as if it had assessed that the item was insufficiently paralysed, behaviour that might have been confused with oviposition by Yamamoto (1942).As with cell partition construction, the wasp always lingered at the nest entrance upon completion of prey provisioning, often re-entering the tube for some kind of inspection.

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Interactions with conspecifics
Chalybion spp are known to form “sleeping” aggregations (Bohart and Menke 1976) and this was observed for *C. japonicum* in one instance where males and females aggregated on a loose hanging piece of rope (Figure 7).

The wasp was fiercely defensive of her nesting site and individuals would actively grapple and chase away intruding con-specifics that came to close to their nest.

Mating
Mating was witnessed in May 2010. A Ficus tree covered in Honey suckle overlooked by my office was a favourite resting/foraging(?) ground for many of the specimens that nested in the office. Here I saw several females being swarmed by males; the encounter lasted for about 10 seconds.

Conclusion

The observations that were made seem to conform to what is known about the biology of this wasp. However, it was noted that not all nest plugs were finished by a layer of white material contrary to the assertion by Bohart and Menke (1976) that “all” species save for *C. californicum* do so.
The variability of prey choice from one generation to the other warrants further analysis in order to ascertain the life cycles and abundance of the chosen prey.

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Figures

Figure 1: Nesting site versatility in *C. japonicum*. Top left: re-usage of cell of *Sceliphron deforme*. Top right: screw recess as a nesting site. Bottom: Cells constructed in an old comb of *Polistes gigas*.

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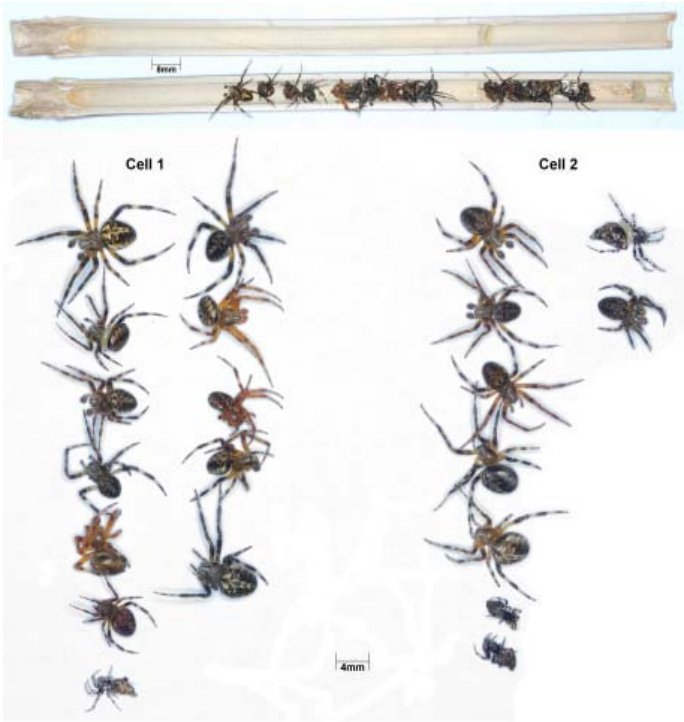

Figure 2: Typical nest content a opening. Top: trap PSO-102.A3 composed of two cells. Bottom: the prey and brood content of the same trap (photo author).

Figure 7: Aggregation of males and females *C. japonicum*.

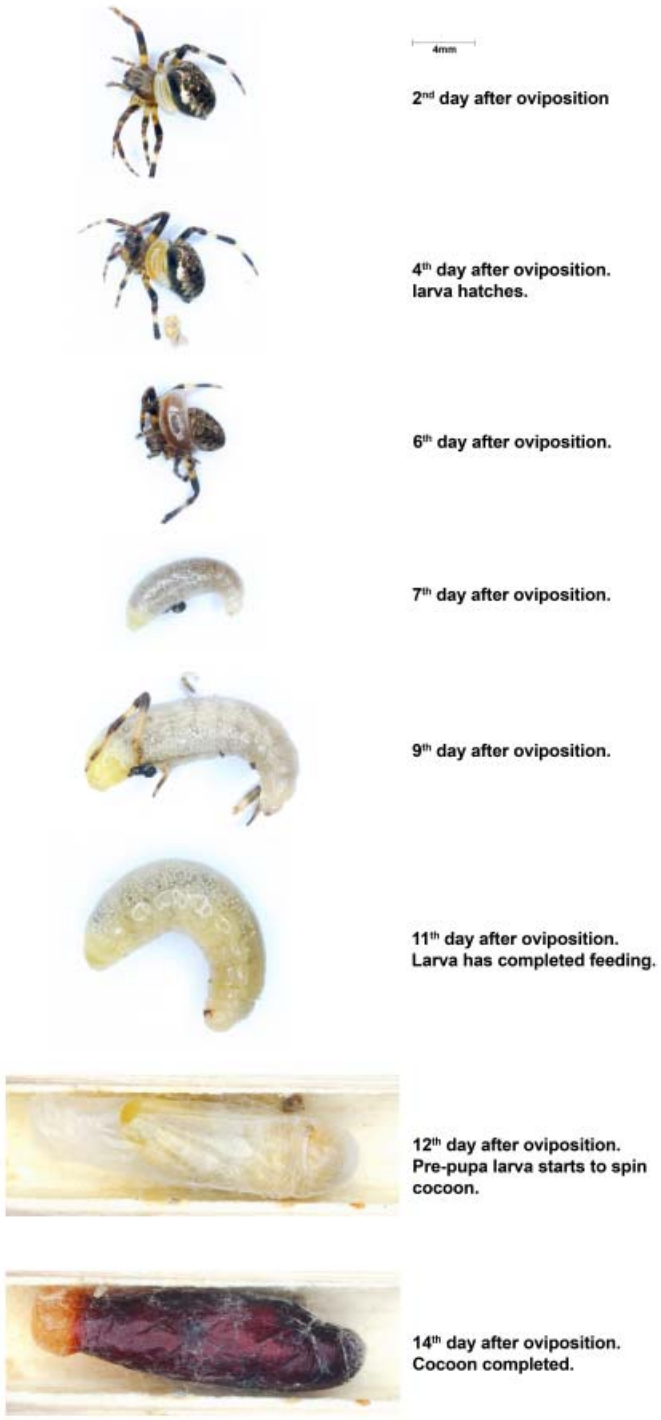

Figure 3: Brood development

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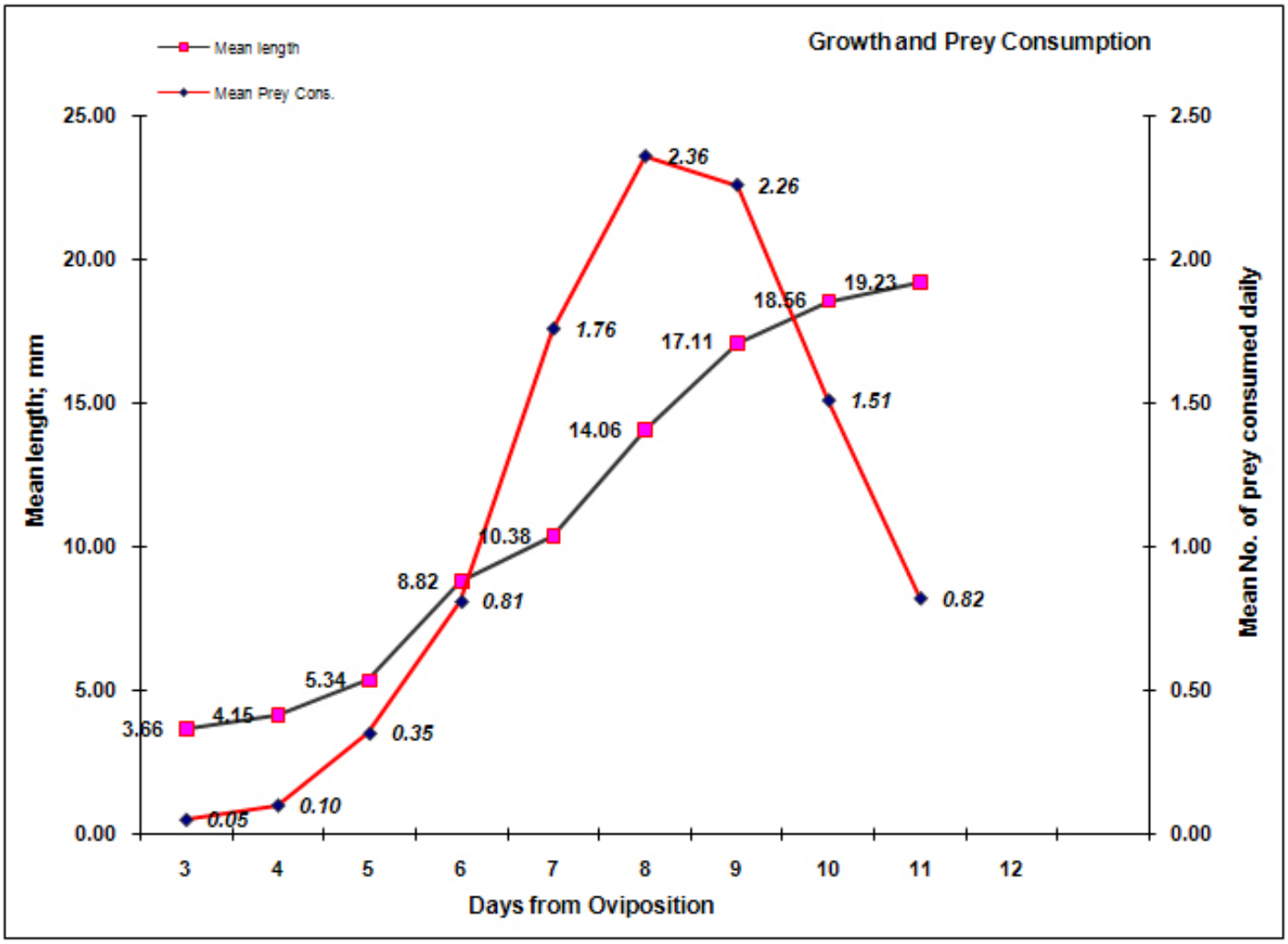

Figure 4: Prey consumption and brood growth.

Figure 5: Phoridae cleptoparasitism captured at trap opening (photo author).

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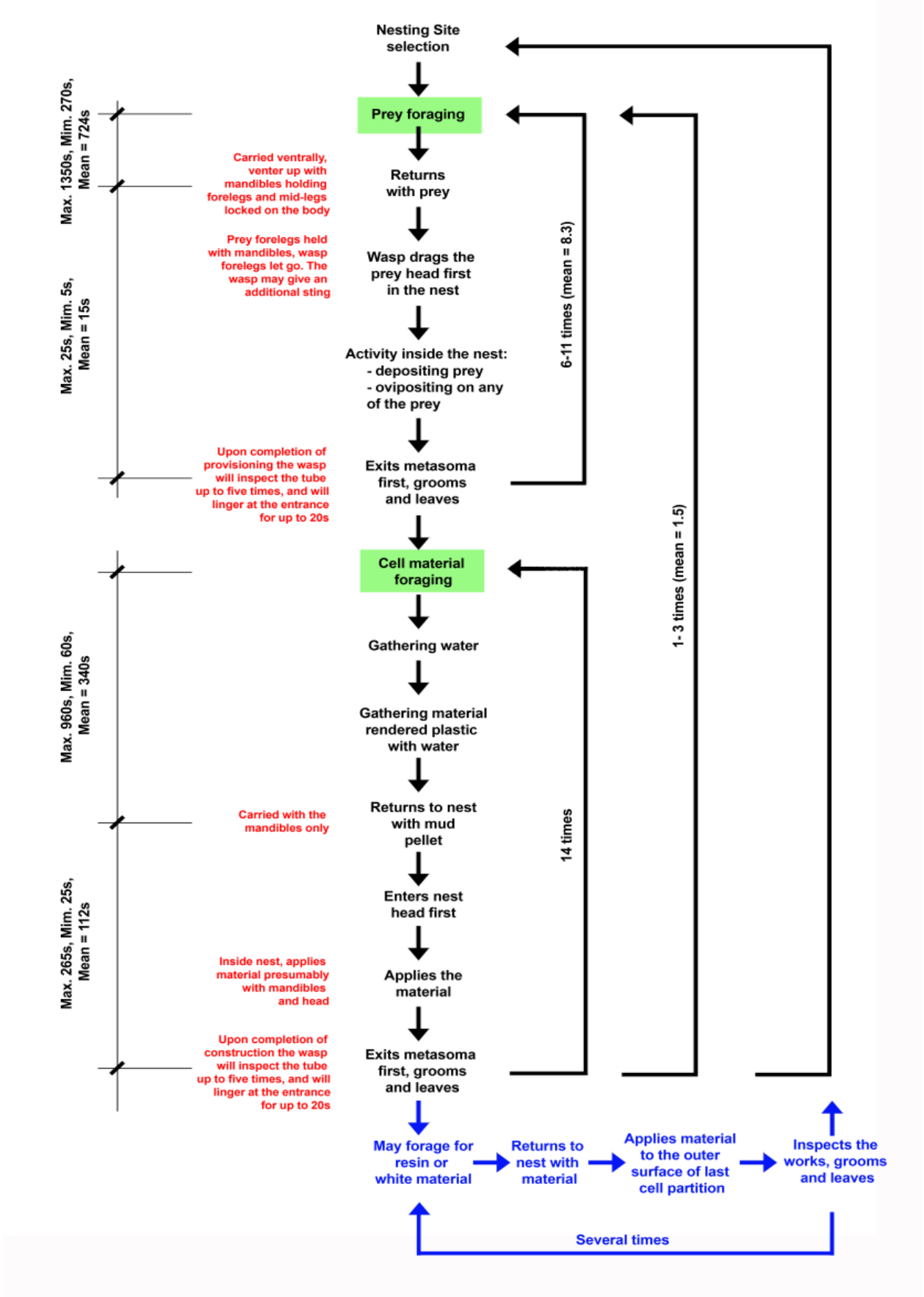

Figure 6: Nesting activities sequences

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A record of a group attack and occupation of a Vespine wasp nest by the hornet *Vespa ducalis* (Hymenoptera: Vespidae)

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Abstract

A record of an incident in which multiple workers of the hornet *Vespa ducalis* Smith, 1852 were found occupying a nest of another hornet species is reported. This behaviour is unusual in that this species has not previously been known to attack other vespine wasps, nor has it been recorded for more than a single forager to occupy a prey nest.

Introduction

This paper describes observations on multiple individuals of the hornet species *Vespa ducalis* Smith, 1852 occupying a nest of *Vespa bicolor* Fabricius, 1787, a smaller species in the same genus. *Vespa ducalis* is usually a specialised predator which preys almost exclusively on nests of polistine wasps and attacks them individually. This is to the author's knowledge the first published record of *V. ducalis* occupying the nest of a vespine wasp, and also the first record of it occupying a prey nest in a group.

Notes on *Vespa ducalis*

Vespa ducalis is a widely distributed hornet species with a range including India, Nepal, Burma, Thailand, Vietnam, South China, Taiwan, East Russia and Japan. It forms the smallest colonies among all known *Vespa* species (Matsuura and Yamane 1984) and has the shortest colony cycle among all species in Japan (Matsuura 1991) and Hong Kong (Lee 2009), an attribute which is possibly linked to its very specialised feeding habits (Archer 1991; Matsuura 1984; Matsuura and Yamane 1984); new queens emerge and initiate nests only after various species of polistine wasps have already established their nests, and colonies die off earlier than other *Vespa* species as polistine colonies become void of immatures and food thus becomes unavailable.

V. ducalis is known to prey almost exclusively on polistine wasps such as *Polistes* and *Parapolybia*, and to attack singly, preying only on the brood and never harming the adult occupants. Its usual hunting method involves a single individual searching around locations where polistine wasps often build nests, such as in and around small trees, shrubs and under eaves and ledges of buildings (pers. obs.). When a target nest is found, the hornet lands on it and proceeds to pull out the brood, biting off cocoon caps in the process. Prepupae appear to be the preferred choice and are often taken first, followed by pupae, and lastly large larvae. Small larvae are usually either taken last or totally ignored. The adult occupants generally flee the nest, offering little or no resistance. They gather near the nest and return to it after the attacker leaves. *V. ducalis* is usually content to drive the original occupants away long enough for it to remove as much prey as it can; as a rule it does not harm the adult polistine wasps. This is in common with its close relative *Vespa tropica* (Linnaeus, 1758), which shows the same dependency on polistine wasp nests in Hong Kong. It must be noted that many older Japanese texts discussing "*V. tropica*" in fact refer to *V. ducalis*, as true *V. tropica* are not known from Japan.

Observations

A nest of *V. bicolor* was discovered at Kau Tam Tso (near Wu Kau Tang in the Northern New Territories) by the author in May 2009, as an embryo nest with several pupae. It was built within an old nest of the same species in an abandoned village house, a common habit with *V. bicolor* (pers. obs.). By August 2009, the nest was spherical and the envelope measured about 12cm in diameter and vertical length; when dissected and collected after the attack it was found to contain roughly 165 cells in two combs. The exact number of wasps in the nest was not known, though nests of similar size within the same time of the year often contained 50 to 60 workers (pers. obs.). The author regularly visited and observed the nest from May to August at intervals of one to two weeks.

On 23 August, accompanied by Chan Kam Wah, the author visited the locality and found the nest void of the original occupants. Instead, a few workers of *V. ducalis* had occupied the nest. There appeared to be a total of five or six individuals involved in the occupation. Shortly after we arrived at the locality, two individuals left the nest with their crops full of body fluids from the prey (see discussion below). Two wasps remained outside on the envelope, while another two were inside the nest, consuming the brood. Three of the wasps left shortly after, leaving one in the nest, but another two came to the nest; it is not clear if these were the two which we first saw leaving. The envelope was intact and in a good state of repair, apart from the entrance hole which appeared to have been bitten and enlarged, probably by the attackers. After observing and taking photographs for a period of approximately ten minutes, we broke the envelope to facilitate observation. While *V. ducalis* is an exceptionally placid species which often does not attack even when its own nest is disturbed (Matsuura 1984; Lee, 2009; pers. obs.), the wasps were

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visibly agitated when the envelope was broken, buzzing around it but refusing to leave. This clearly showed that they were in the occupation phase.

There were only a few smaller larvae left in the nest by the time the occupation was discovered. As it is normal for *V. ducalis* to attack pupae and larger larvae first, this isn't considered unusual. The following day, I returned and found the nest totally void of brood, with only eggs remaining untouched. The occupiers had completely abandoned the nest. This suggests that they had progressed to the final stage of the occupation phase by the time we came upon it. Two weeks had elapsed since the last time the nest was observed, and it was not possible to estimate the total length of the occupation phase. It is not clear how the *V. ducalis* came to occupy the nest, nor could we confirm that the slaughter phase took place or that the original occupants were in fact killed by the *V. ducalis* and not by something else. However, we did find numerous dead *V. bicolor* with mutilated bodies scattered on the ground below the nest, most with missing legs, wings and antennae and some even with severed heads and abdomens. Thus it is highly probable that the group of *V. ducalis* did actually attack and overpower all the occupants of the nest (see discussion).

Discussion

Many species of hornets have been known to attack honeybees at their nests (Matsuura and Sakagami 1973), and also to prey on other social wasps (pers. obs.), although most species hunt individually, capturing and killing individual foragers leaving their nests or at external food sources (Matsuura 1984; pers. obs.). However, some large species, notably *Vespa mandarinia* Smith, 1852 and *Vespa soror* du Buysson, 1905, are capable of launching coordinated attacks on nests of honeybees and other social wasps, killing off the majority of the adult occupants, and then occupying the nest over a certain period of time, during which workers shuttle back and forth, transporting the brood to their own nest. The process is described in detail in Matsuura and Sakagami 1973, and generally speaking consists of three distinct phases; namely the hunting phase, slaughter phase and occupation phase. In the hunting phase, the hornets attack individually, loitering around the nest entrance and catching individual workers of the target species one by one, bringing each one back to the nest upon capture. During this period several workers from the same colony may be present at the prey nest, but each one hunts individually. The slaughter phase commences when attackers from the same nest stop capturing prey individually, but instead attack and kill the defending workers one after the other, biting and maiming them with their mandibles. This phase ranges in duration from less than an hour to over a day, depending on the number of attacking hornets and the number of occupants in the target nest as well as the intensity of their defence. When most of the original occupants are killed or cease to defend the nest, the occupation phase begins, in which the attackers occupy the nest over a period ranging from several hours to two weeks, while the captured brood is transported as described above. Some hornets remain in the occupied nest at night, and the entrance is now guarded against intrusion by hornets from other colonies and other animals, including humans. While social wasps do not generally attack people away from their nests, *V. mandarinia* and *V. soror* will guard an occupied nest as ferociously as their own, and will attack and sting anyone who approaches the nest too closely (Matsuura and Sakagami 1973; pers. obs.).

Apart from *V. mandarinia* and *V. soror*, the only other species known to occupy nests of honeybees are *Vespa orientalis* Linnaeus, 1761 (Matsuura and Sakagami 1973) and *V. tropica* (Burgett and Akratanakul 1982; Ritter and Akratanakul 2006; pers. obs. unpublished).

The observations reported above therefore represent a valuable record of a presumed group attack by *V. ducalis* on the nest of another social wasp, leading up to the annihilation of the colony and occupation of the nest. In close to nine years of observing social wasps in Hong Kong, I have never encountered any nests of *Vespa* species being attacked by *V. ducalis*. To the best of my knowledge, there are also no published records of such attacks. While it is not surprising that there have been no observations or reports on such behaviour, it is all the more interesting because *V. ducalis* is the species least likely to attack en masse, due to its small colony size, its hunting habits and the the manner by which it feeds its larvae (see below).

V. ducalis is unique among hornets in that it feeds its larvae exclusively with regurgitated crop contents and never with anything solid (pers. obs.). In several observation colonies I reared indoors, workers would ignore any whole insects presented to them, and while they would accept items such as the thoraxes of dragonflies or honeybees cut open to expose the flesh, the wasps would chew on them for a period of time, but would then drop them, and did not feed anything to the larvae at all. Through long periods of time spent watching my observation colonies as well as those in the wild, it was also apparent that workers returning to the nest never carried any solid food or fed any visible object to the larvae, but instead would return with their gasters distended by the engorged crop and feed the larvae through regurgitation. This is in contrast with *V. tropica*, which is recorded to have similar predatory habits throughout its range, although it is known to attack and occupy nests of honeybees en masse in tropical regions such as Thailand and Singapore (Burgett and Akratanakul 1982; Ritter and Akratanakul 2006; pers. obs. unpublished). Although *V. tropica* appears to prey exclusively on polistine wasps in Hong Kong, imbibing the body fluids of polistine wasp immatures and feeding its own larvae by regurgitation, workers in observation colonies reared indoors by the author readily took prey such as the thoracic

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flesh of dragonflies, crickets and even pieces of prawn meat, and fed these to the larvae after 30 to 120 seconds of mastication. Thus the aspect of the hunting phase in this instance is highly puzzling. It seems unlikely that the gathering of attackers from the same colony leading up to the slaughter and occupation could have developed without the hunting phase. However, while it is perfectly conceivable that *V. tropica* could first begin hunting honeybees or other wasps at their nests independently of each other before proceeding to the slaughter phase once enough individuals from the same nest are present, it is highly unlikely for *V. ducalis* to do the same. Since *V. ducalis* feeds its larvae only on liquid crop contents obtained from the larvae and pupae of other wasps, and unlike other hornets does not feed the flesh of insects to its larvae, it is highly unlikely that it would hunt honeybees or other wasps since the solid flesh would be useless to it.

Since I did not witness the original attack, I have considered the possibility that the *V. bicolor* nest was first attacked by another species such as *V. soror* or *V. tropica*. However, this is unlikely for three reasons. Firstly, it does not make sense that another species such as *V. soror* or *V. tropica* attacked and gained occupation of the *V. bicolor* nest only to have *V. ducalis* take over and take the prey for themselves; if another species were to have attacked and occupied the nest they would have remained in the nest till they consumed all the brood, and there would be nothing left in the empty nest which would warrant subsequent occupation by *V. ducalis* to obtain. Secondly, while I have also considered the possibility that the nest could have first been attacked and occupied by another species, which in turn was driven away by *V. ducalis*, this is also highly unlikely due to the fact that among the six common *Vespa* species in Hong Kong *V. ducalis* is always at the lowest level of the dominance hierarchy at external food sources such as fallen fruit and tree sap in Hong Kong (pers. obs.) and this also holds true in Japan, where it is the least dominant among five common species at sources of tree sap (Matsuura 1984). From numerous personal observations it is often chased away by workers of other *Vespa* species, and is always at the losing end of any physical combat. As hornets guard conquered nests fiercely during the occupation phase, it is unlikely that *V. ducalis* would be able to enter and take over a nest guarded by either *V. soror* or *V. tropica*. One might argue that if *V. ducalis* is presumed capable of overpowering a *V. bicolor* colony, it should also be able to take over a colony occupied by another species, but with *V. bicolor* being the smallest local hornet species, the size difference between the two species would make it far easier and more likely for individuals of *V. ducalis* workers to overpower *V. bicolor* than to overpower either *V. soror* or *V. tropica*. At food sources such as fallen fruit or tree sap, individuals of *V. ducalis* sustain no damage in combat with *V. bicolor*, which often gives up attempting to drive them away if they persist in attempting to feed from the same fruit or tree, but are often injured by *V. soror* and even *V. tropica* under similar circumstances (pers. obs.). Lastly, hornets generally forage individually; even in species like *V. mandarinia* or *V. soror*, they work independently of each other before the slaughter phase begins. If another species had first attacked the *V. bicolor* nest and taken the prepupae, pupae and large larvae, it is possible that a single individual of *V. ducalis* could find the nest and take the remaining small larvae, but it is highly unlikely that more individuals would be recruited to occupy and guard a nest with such a small remaining amount of prey inside. Therefore, although I cannot prove that *V. ducalis* was responsible for the original attack which led to the demise of the colony due to a lack of direct observations, these three reasons suggest that the group of *V. ducalis* were indeed the original attackers and not opportunists moving in only after another species first invaded the prey nest.

It should be noted that according to my personal observations covering the same localities over seven years, foraging individuals and nests of *V. ducalis* were atypically abundant in 2009. Therefore, there is a possibility that the need for food could not be met by polistine nests alone, triggering the wasps to attack vespine wasps instead. Due to the fact that vespine wasps are far more capable of defending their nests against another *Vespa* species, an individual *V. ducalis* would not have been able to invade the *V. bicolor* nest and gain access to the brood, thus necessitating several individuals to invade and overpower the original occupants.

Besides this particular incident, I observed a single worker of *V. ducalis* circling and landing on a nest of *V. bicolor* built in a small tree in September 2010. It did not attempt to attack or capture any of the *V. bicolor* workers, but instead landed and walked on the envelope as well as the branches surrounding the nest, taking flight and circling for brief periods before landing and walking again. Occasionally it was attacked and brought to the ground by the *V. bicolor* workers, which at one point became quite agitated, resulting in a group of 15 to 20 rushing about the envelope and preventing the *V. ducalis* worker from landing. The intruder appeared to suffer no damage from these attacks. The circling, landing and walking continued for nearly 45 minutes before the wasp flew off and did not return. Unfortunately I did not find out the result of this behaviour because the nest was destroyed by people the next day. Given that the *V. ducalis* individual in question showed a distinct interest in the *V. bicolor* nest, yet made no attempt to attack or capture any of the workers, it is plausible that *V. ducalis* bypasses the hunting phase and instead, by flying near and walking on the nest envelope or nearby objects, possibly leaves chemical trails which other individuals from the same colony pick up, entering directly into the slaughter phase. This remains an open question and further observations are certainly welcome.

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Figures

Figure 1: Individuals of *V. ducalis* at the occupied nest of *V. bicolor*.

Figure 2 & 3: Individuals of *V. ducalis* feeding on the larvae before returning to their own nest.

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Figure 4 & 5: Other individuals not feeding on the larvae but lingering around the occupied nest

Figure 6: A worker visibly agitated after the envelope was removed to facilitate observation

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Observations on the luminescence configurations of eight firefly genera and their immature stages

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Abstract

Long exposure photography was used for recording luminescence configuration of eight firefly genera in Hong Kong, namely: *Rhagophthalmus, Stenocladius, Lamprigera, Pyrocoelia, Diaphanes, Aquatica, Luciola* and *Pteroptyx,* all sampled in Hong Kong. It was found that luminescence configuration does not necessarily coincide with light organ configuration of the same firefly. Additionally, a large portion of the fireflies in this study are capable of displaying bipartite light spots from their obround or rectangular light organs. *Stenocladius* can display three different types of luminescence configurations, including diffused light from the whole body. This study also shows that male and female adult of *Lamprigera* retain their larval light organs while other species develop additional light organs with their larval light organs remaining intact. Possible implications of the luminescence configurations are proposed and discussed.

Keywords: Fireflies, bioluminescence, Lampyridae, Rhagophthalmidae, aposematic, light organs, Hong Kong.

Introduction

Fireflies are the best known animals displaying bioluminescence. The light emitting part of a firefly body is called lantern, luminescent organ, photic organ or light organ. Light organs of fireflies often appear as conspicuous white patches on preserved specimens. However, for some species, the light organs are not conspicuous or even not visible externally. In some cases, the light produced is very dim or only lasts for a short period of time during the development from larva to adult. As a result, they could sometimes be overlooked. In this study, long exposure photography was used to record the luminescence configuration of fireflies.

Materials and methods

As the light emitted by fireflies is very dim, special camera settings were required to clearly show the light. To increase exposure of the firefly luminescence to the camera sensor, long exposure time (from 1/8 sec. to 120 sec., depending on species) was used, with a tripod. In many cases, sensor sensitivity would be adjusted to a higher value (ISO 400 to ISO 3200), and/or large lens aperture would be selected. Although the glowing light organs are shown, the other parts of the body are not exposed to light when the firefly is in the dark. Consequently, in order to show the whole body and therefore the relative positions of the glowing light organs, two methods were used in this study: 1. As soon as the long exposure photo was taken, another photo with flash light was produced, so that the relative position of the light organs could be seen by comparing the two photos; 2. using fill-in light. This was done by either pointing a torch towards the objects nearby, allowing the reflected light to shine onto the firefly, or simply using fill-in flash light from the camera system. The intensity of fill-in light was controlled such that it would not overshadow the light emitted by the light organs. All photos were taken with either an Olympus E3 digital camera connected to a Zuiko Digital ED 50 mm f/2.0 Macro lens, or an Olympus E620 digital camera connected to the same lens, or a Canon 550D digital camera connected to a EFS 60 mm f/2.8 Macro USM lens or to a MP-E65 mm f/2.8 1-5X macro lens.

The study involved 10 species of fireflies belonging to eight genera, collected from 2006 to 2010 in Hong Kong , China, namely:

1. *Rhagophthalmus motschulskyi* and *Rhagophthalmus* sp. (Rhagophthalmidae). Two females of *Rhagophthalmus motschulskyi* were seen glowing in the wild and in captivity respectively, and long exposure photos were taken at the moment when they glowed. The identity of the female was inferred from another female with the same morphological features found in the same locality, which mated with an identified male of *R. motschulskyi.* A pair of unknown *Rhagophthalmus* sp. were found mating in the wild and were collected. The female was observed and a series of long exposure photos was taken during oviposition.

2. *Stenocladius* spp. (Lampyridae: Ototretadrilina-Ototretinae complex). More than 50 females were observed in about 20 night trips in three different well vegetated localities in Hong Kong, from November, 2009 to January, 2010, and from November 2010 to December, 2010. Long exposure photos were taken to show the luminescence configurations of eight different female individuals in the wild. Two females were collected for intensive observation and for taking long exposure photos in an indoor environment. A light emitting male of a *Stenocladius* sp. found on a spider web was collected and long exposure photos were taken during the short moment when it emitted light. A *Stenocladius* sp. larva was collected in the wild and reared; long exposure photos were taken when it glowed. Because of the very different markings of two types of larvae found (another one without long exposure photo taken), it could be inferred that there are two different species of *Stenocladius* in Hong Kong. Therefore, it is possible that the females and males mentioned in this study belong to different species. From their distinct external morphology, there is no doubt that they belong to this genus. Two events of attempted mating

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were observed in the wild, which gave support to the association between the male and the female.

3. *Lamprigera* sp. (Lampyridae: Lampyrinae)
A female larva of an unknown *Lamprigera* was collected in the wild and reared; it pupated but died before emergence of the adult. Long exposure photos were taken when light was emitted from the larva and from the pupa. Another female and a male of the same unknown *Lamprigera* were seen glowing in the wild and long exposure photos were taken. All the individuals mentioned above were found in a very restricted locality on Tai Mo Shan.

4. *Pyrocoelia* sp. (Lampyridae: Lampyrinae)
A female larva of an unknown *Pyrocoelia* sp. was collected in the wild and reared. It was observed intensively and a series of long exposure photos were taken in the course of its development from pre-pupa to adult. Another female and several males of the same *Pyrocoelia* sp. were seen glowing in the wild and long exposure photos were taken.

5. *Diaphanes citrinus* (Lampyridae: Lampyrinae)
A male adult was collected and series of long exposure photos were taken in an indoor environment. Another male adult was seen glowing in the wild and a series of long exposure photos were taken.

6. *Aquatica* cf. *ficta* (Lampyridae: Luciolinae)
A female pupa was obtained in February, 2011, by rearing larvae. A series of long exposure photos were taken in the course of its development into an adult.

7. *Luciola terminalis* (Lampyridae: Luciolinae)
A male adult was collected in the wild and kept in a transparent plastic vial. An AVI format (30 frames per second) video (duration: 1min. 24 sec.) was taken when it emitted light. The video was taken with an Olympus EPL1 digital camera connected to a Zuiko Digital ED 50 mm f/ 2.0 Macro lens. The video was played frame by frame to see the changes in the luminescence pattern.

8. *Pteroptyx* sp. (Lampyridae: Luciolinae)
A female pre-pupa of *Pteroptyx* sp. was obtained in October, 2010, by rearing larvae. A series of long exposure photos were taken when it glowed during larval development. A male adult was collected in the wild and kept in a transparent plastic vial. An AVI format (30 frames per second) video (duration: 45 sec.) was taken when it emitted light. The video was taken with the same camera and lens mentioned above. The video was played frame by frame to see the changes in the luminescence pattern.

The numbering of abdominal segments and ventrites refers to the true segments.
In some cases, light is emitted from the light organs located just beneath the ventrites, but in other cases, especially in immature stages, light is emitted from somewhere inside the abdominal segment or from a whole abdominal segment. They are termed differently in the results section.

Abbreviation: V= Abdominal ventrite

Results

1. *Rhagophthalmus motschulskyi* and *Rhagophthalmus* sp.
Two different luminescence configurations were observed on adult female specimens. The first one was a large light spot that appeared on V8 (Fig. 1.1, 1.2). The second one was during oviposition, a bright light spot appeared near the right posterolateral margin of mesothorax, metathorax, and 1st-9th abdominal segment (presumably there are corresponding light spots at the opposite side, but they are not shown in the photo records). An additional light spot appeared near the posterodorsal margin of each of the 11 segments mentioned above. The lateral light spots on each of the abdominal segments were glowing during observation, but the lateral light spots on the two thoracic segments as well as the dorsal light spots were sometimes not emitting light (Fig. 1.3-1.6). No well-defined light organs were seen in the preserved specimens.

2. *Stenocladius* spp.
The larva displays one pair of light spots was evident on the 7th and 8th abdominal segments (Fig. 2.1). Three different patterns of luminescence were observed on adult female specimens. The whole body, except the anterior part of pronotum and the head, glowed evenly (Fig. 2.2) and this was the most common pattern observed. Less frequently, the whole body, except the anterior part of the pronotum and the head, glowed evenly, and at the same time a pair of large, brighter light spots appeared on the 8th abdominal segment (Fig. 2.4). Finally, a pair of large light spots appeared on the 8th abdominal segment and at the same time the whole body glowed very weakly, there was also a pair of tiny light spots close to the left posterolateral margin of abdominal segment 2-4 (presumably, the same pairs could be seen on the right side of the body, but is not shown in the photos). It appeared that tiny light spots also appeared in the metathorax, but they were not definitely shown in the photos (Fig. 2.5). Adult males seldom emit light, and only two instances were observed amongst about 20 individuals in the wild; both were caught in spider webs. A pair of weak light spots appeared on V6 (Fig. 2.6). No well defined light organs are seen in the preserved specimens.

3. *Lamprigera* sp.
The larva displayed one pair of “C”-shaped light spots on V8 (Fig. 3.1), which were also shown by the female pupa and adult. The male adult showed one pair of light spots on V8 (Fig. 3.4).

4. *Pyrocoelia* sp.
The larva displayed one pair of large light spots on the eighth abdominal segment (Fig. 4.1) which was the same

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for the female prepupa and pupa (Fig. 4.2, 4.3). On the last day before emergence, an additional pair of small light spots appeared on V6 (Fig. 4.4). In the adult female, an additional pair of larger spots appeared on V7 on the second day after emergence. All three spots glowed simultaneously (Fig. 4.5). The light spots at the eighth abdominal segment gradually dimmed and finally disappeared on the fourth day after emergence (Fig. 4.6). In the adult male there was an obround light spot on V6 and V7 (Fig. 4.7). When the intensity of light given out was low, it appeared as 2 spots at both end of the obround light organs (Fig. 4.8).

5. *Diaphanes citrinus*
The male adult emitted light on V6 and V7, sometimes in an obround shape (Fig. 5.1), but when the intensity of light emitted was low, it appeared as 2 spots at both end of the obround light organs (Fig. 5.2).

6. *Aquatica* cf. *ficta*
Glowing larvae under water were occasionally seen, but no long exposure photo was successfully taken to show this. Clearly defined light organs could be seen as a pair of spots on the eighth abdominal segment (Fig. 6.1) On a five days old pupa a pair of light spots appeared on the eighth abdominal segment and a pair on V6 (Fig. 6.2). When the same pupa was 8-day old (two days before emergence), the light spots on V6 became obround shaped (Fig. 6.3). When the intensity of light emitted was low, the two extremes of the stripe were brighter (Fig. 6.4). The light spots on the eighth abdominal segment diminished as the pupa became more mature. On the first day after emergence of an adult female, the same obround light spots appeared on V6. When the intensity of light emitted was low, it appeared as two-spotted form (Fig. 6.5). On the third day after emergence, the light spots on the eight abdominal segment became very small (Fig. 6.6) and disappeared on the fifth day after emergence (Fig. 6.7). The light source on V6 appeared as two spots when it was not glowing fully (Fig. 6.8). No flashing (only intermittent glow) was observed until the twelfth day after emergence.

7. *Luciola terminalis*
The male adult emitted light from V7. It was continuous and steady throughout the recording period and was more or less even across the whole surface of V7 except on the terminal portion. The light emitted from V6 was flashing and bipartite throughout the recording period (Fig. 7.1). The light organs on V6 and V7 are well defined white patches covering nearly the whole surface of V6 and V7 (Fig. 7.2).

8. *Pteroptyx* sp.
Larvae were occasionally seen glowing either in captivity or in the wild, but no long exposure photo was successfully taken to show the glowing pattern. Two light organs could be seen on the eighth abdominal segment, although they were not very well defined (Fig. 8.1). The prepupa displayed two light spots on the eighth abdominal segment, which coincided with the light organs of the larva (Fig. 8.2). A two days old female pupa displayed a pair of light spots on V8 (Fig. 8.3). The last day before emergence (10-day old pupa), an obround light organ was clearly visible on V6 (Fig. 8.4). As soon as the pupa turned into an adult, light was emitted as two spots on V8 and evenly from the light organ on V6 (Fig. 8.5). No flashing was observed. In the male adult, a flashing light appeared either on V6 as a pair of spots with none on V7 (Fig. 8.6), or from both V6 and V7 as a bipartite structure (Fig. 8.7). Only when the light organs were glowing fully, did they appear as rectangular structures (Fig. 8.8). The light organs beneath V6 and V7 were well defined white patches covering nearly the whole surface of these ventrites (Fig. 8.9), leaving only the median posterior projection of V7.

Discussion

From the results, it is shown that long exposure photography with a single macro lens reflex camera can be a useful tool to record the luminescence configuration of fireflies, which does not always coincide with the configuration of light organs of the same firefly. In this study, light organs of *Rhagophthalmus* and *Stenocladius* are even not visible in both dry specimens and specimens preserved in alcohol.

All members of the Lampyridae observed in this study and in both sexes, are capable of displaying bipartite light spots from their obround or rectangular light organs (*Pyrocoelia*, *Diaphanes, Pteroptyx*); in the genus *Lamprigera*, the light organ is already bipartite. Therefore, the obround or rectangular light organ may be regarded as a combination of two enlarged spot light organs in an abdominal segment, rather than being two distinct structures. All larvae and larviform females involved in this study had two spotted light. This two spotted configuration could be explained by their proximity to the two spiracles of each abdominal segment, which supply oxygen necessary for the bioluminescence's chemical reaction; or the result of uneven innervation. In males the enlargement of the two spotted light organs merging into an obround light organ may well be the result of competition for females by displaying larger light patch(s). It is interesting to note that in *Lamprigera*, both the adult male and female retain the two spotted pattern on V8 of their larval stage, but *Pyrocoelia* and *Diaphanes*, while members of the same family, change their light organs to V6 and V7. Close examination of the specimens showed that in order to make room for the genitalia, there was no fat deposited in segment eight of *Pyrocoelia* and *Diaphanes* (both sexes). Although segment eight of *Lamprigera* is not substantially larger, a considerable amount of fat is deposited in this segment and the preceeding one which showed no light. In *Pyrocoelia*, *Aquatica* and *Pteroptyx*, adult females developed their light organs when their larval light organs on V8 were still intact and functioning. Therefore the light

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organs of the adults of these three species are not directly derived from their larval stage.

Luminescence configuration of *Stenocladius* is exceptional in that it is not localised as spots. Buck (1948) suggested that photogenic cells were typically grouped together in one or more compact localised masses with specific tracheal and nervous supplies; and regarded the light emitted in *Phengodes*, which is produced by loose independent giant cells, apparently without tracheae, as exceptional. The light produced by *Stenocladius* is more evenly distributed and the light producing mechanism may possibly be even more loosely organised than that of *Phengodes*. Chen (2003) reported that the prepupa (sex not mentioned) and the male pupa of *Stenocladius bicoloripes* in Taiwan produced diffused light and the larvae of *Stenocladius* do not have such diffused luminescence. Adult females of *Stenocladius* gain the ability of producing spot light as larvae, as is in many other fireflies, therefore what would be the reason for having additional diffused luminescence? Males have well developed antennae used in sexual interaction, therefore communication between the two sexes may not solely rely on light signals and chemical signaling may also play an important role. In view of their soft body surface and low mobility, aposematic display may be an explanation to added luminescence. Many fireflies were found to be able to produce unpalatable or toxic substances (Blum and Sannasi, 1974; Eisner *et al*., 1978; Fu *et al*., 2009) and it has been proposed and tested that luminescence is an aposematic display in firefly larvae (Buschman, 1988; De Cock, 2000; Fu *et al*., 2009, Sivinski, 1981). For the wingless and less mobile adult females of *Pyrocoelia, Diaphanes* and *Lamprigera*, their comparatively very bright light organs may also play an important role of aposematic display.

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Figures

Fig. 1.1. *Rhagophthalmus motschulskyi* adult female— Large light spot on V8.

Fig. 1.2. *Rhagophthalmus motschulskyi* adult female— Large light spot.

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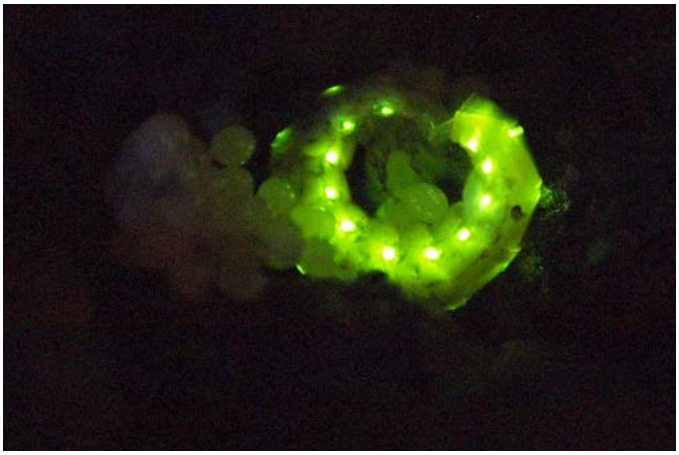

Fig. 1.3. *Rhagophthalmus* sp. adult female— luminescence during oviposition.

Fig. 2.1. *Stenocladius* sp. larva — light spots on seventh and eighth abdominal segments.

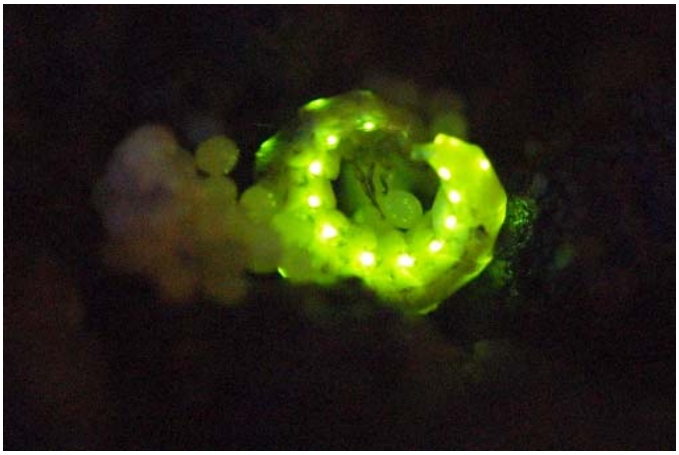

Fig. 1.4. *Rhagophthalmus* sp. adult female— luminescence during oviposition

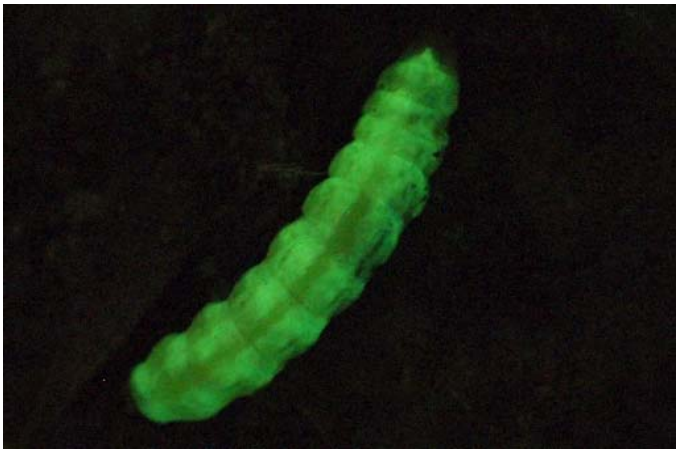

Fig. 2.2. *Stenocladius* sp. adult female — diffused glow from the whole body.

Fig. 1.5. *Rhagophthalmus* sp. adult female — luminescence during oviposition

Fig. 2.3. *Stenocladius* sp. adult female — whole body under flash light.

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Fig. 2.4. *Stenocladius* sp. adult female — diffused glow from the whole body with two spotted light on the eighth abdominal segment.

Fig. 3.1. *Lamprigera* sp. larva — one pair of “C”-shaped light spots onV8.

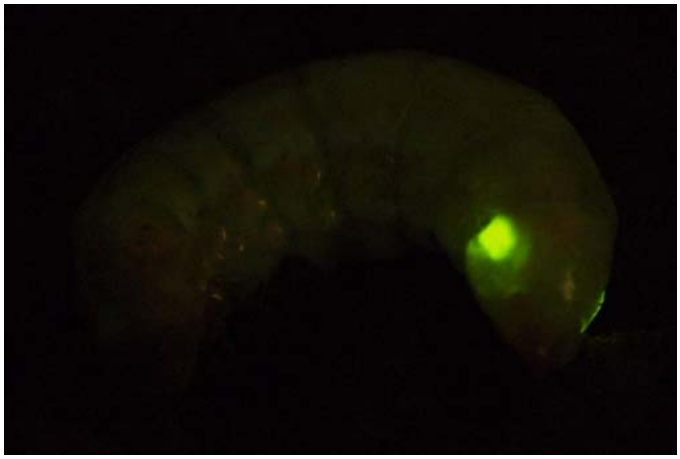

Fig. 2.5. *Stenocladius* sp. adult female — light spots on the eighth abdominal segments, whole body glows weakly with tiny light spots on the second to fourth abdominal segments.

Fig. 3.2. *Lamprigera* sp. female pupa — one pair of “C”-shaped light spots onV8.

Fig. 2.6. *Stenocladius* sp. adult male — light spots on V6.

Fig. 3.3. *Lamprigera* sp. adult female — 1 pair of “C”-shaped light spots on V8.

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Fig. 3.4. *Lamprigera* sp. adult male — 1 pair of light spots on V8.

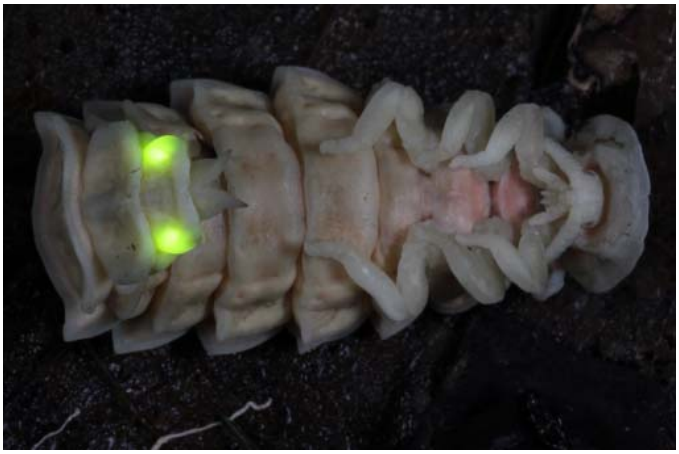

Fig. 4.3. *Pyrocoelia* sp. Female pupa — one pair of large light spots on the 8th abdominal segment (dorsal view).

Fig. 4.1. *Pyrocoelia* sp. larva — one pair of large light spots on the 8th abdominal segment.

Fig. 4.4. *Pyrocoelia* sp. female pupa (last day before emergence) — one pair of light spots on the 6th & 8th abdominal segments.

Fig. 4.2. *Pyrocoelia* sp. prepupa — one pair of large light spots on the 8th abdominal segment.

Fig. 4.5. *Pyrocoelia* sp. adult female (2-day old) — one pair of light spots on the 6th, 7th & 8th abdominal segments.

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Fig. 4.6. *Pyrocoelia* sp. adult female (4-day old) the light spots one the 8th abdominal segment have disappeared.

Fig. 5.1. *Diaphanes citrinus* adult male — obround light organ in full glow on V6 & V7.

Fig. 4.7. *Pyrocoelia* sp. adult male — obround light organ in full glow on V6 & V7.

Fig. 5.2. *Diaphanes citrinus* adult male — 2-spotted light from the obround light organ on V6 & V7.

Fig. 4.8. *Pyrocoelia* sp. adult male — 2-spotted light from the obround light organ on V6 & V7.

Fig. 6.1. *Aquatica* cf. *ficta* larva — light organ on the 8th abdominal segment.

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Fig. 6.2. *Aquatica* cf. *ficta* pupa (5-day old) — a pair of light spots on V6 and V8.

Fig. 6.5. *Aquatica* cf. *ficta* adult female (1-day old) — a pair of light spots on V6 and V8.

Fig. 6.3. *Aquatica* cf. *ficta* pupa (8-day old) — a pair of light spots at V8, obround shaped light on V6.

Fig. 6.6. *Aquatica* cf. *ficta* adult female (3-day old) — light spots on V8 diminished.

Fig. 6.4. *Aquatica* cf. *ficta* pupa (8-day old) — a pair of light spots on V8 and V6.

Fig. 6.7. *Aquatica* cf. *ficta* adult female (5-day old) — light spots on V8 have disappeared.

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Fig. 6.8. *Aquatica* cf. *ficta* adult female (3-day old) — 2-spotted light on V6.

Fig. 8.1. *Pteroptyx* sp. larva — a pair of light spots on the 8th abdominal segment.

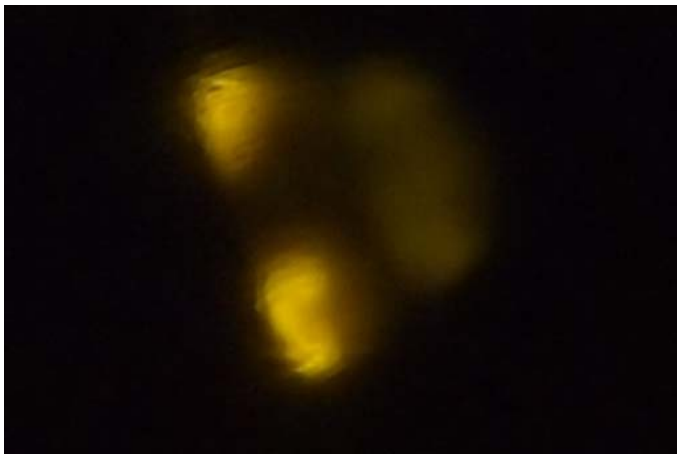

Fig. 7.1. *Luciola terminalis* adult male — partial light from V7 and 2-spotted light from V6.

Fig. 8.2. *Pteroptyx* sp. prepupa — a pair of light spots onthe 8th abdominal segment.

Fig. 7.2. *Luciola terminalis* adult male — light organs on V6 and V7 occupying the whole ventrite surface.

Fig. 8.3. *Pteroptyx* sp. Pupa (2-day old) — a pair of light spots on the 8th abdominal segment.

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Fig. 8.4. *Pteroptyx* sp. Pupa (10-day old, last day before emergence) — a pair of light spots on the 8th abdominal segment & obround light organ on V6.

Fig. 8.5. *Pteroptyx* sp. adult female (1-day old) trapped in pupal case — 2-spotted light from V8 and obround shaped light from V6.

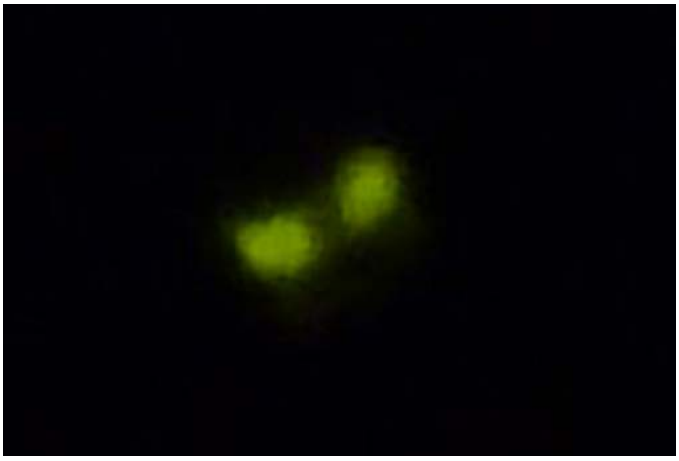

Fig. 8.6. *Pteroptyx* sp. adult male — 2-spotted light from V6.

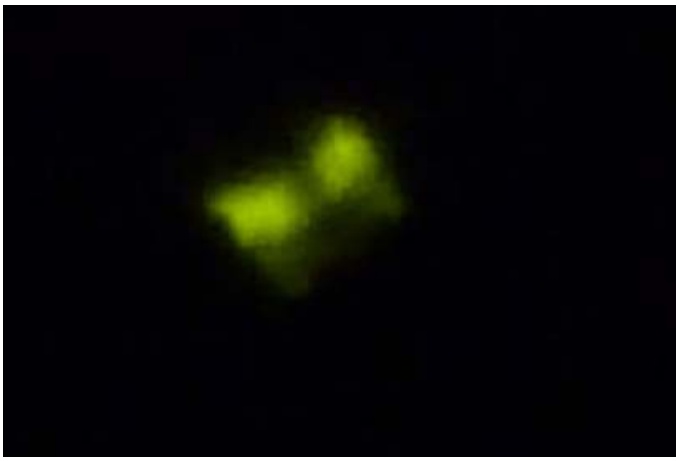

Fig. 8.7. *Pteroptyx* sp. adult male — 2-spotted light from V6 and 2-spotted light from V7.

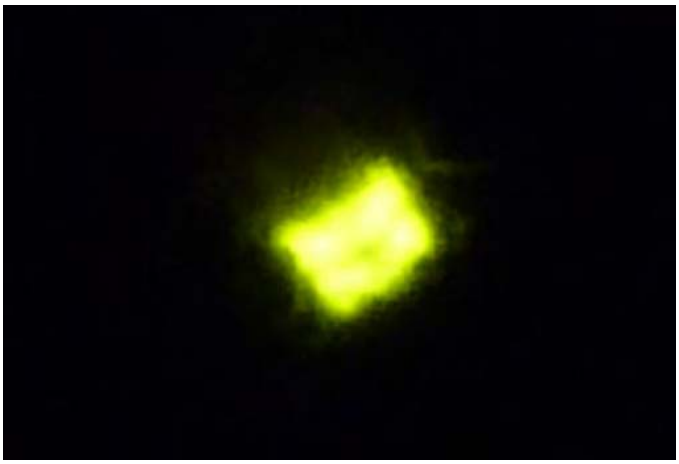

Fig. 8.8. *Pteroptyx* sp. adult male — Light from V6 and V7 in full glow.

Fig. 8.9. *Pteroptyx* sp. adult male — Light organs on V6 and V7.

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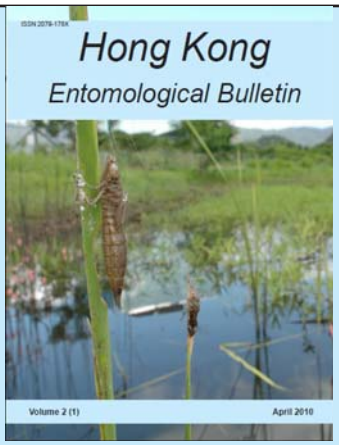
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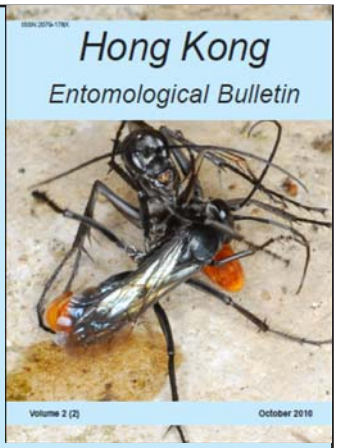
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