NATURAL HISTORY OF FIJI'S ENDEMIC SWALLOWTAIL BUTTERFLY, *PAPILIO SCHMELTZI (HERRICH-SCHAEFFER)*

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Abstract - The wild population of *Papilio schmeltzi* (Herrich-Schaeffer) in the Fiji Islands is very small. Successful rearing methods should be established prior to any attempts to increase numbers of the natural population. Therefore, we studied the biology of this species. *Papilio schmeltzi* was reared on *Micromelum minutum*. Three generations were reared during the period from mid April 2008 to end of November 2008, and hence we estimate that in nature *P. schmeltzi* may have up to eight generations in a single year.

Key words: *Papilio schmeltzi, Micromelum minutum*, life cycle, larval host plant, developmental duration, morphological characters, captive breeding

INTRODUCTION

Most of the Asia-Pacific swallowtail butterflies (Lepidopera: Papilionidae) belonging to the genus *Papilio* are widely distributed in the tropics (*e.g.* Asia, Papua New Guinea, Australia, New Caledonia, Vanuatu, Solomon Islands, Fiji and Samoa). These tropical *Papilio* utilize a diverse array of habitats such as forest, mountains, grasslands and suburban gardens. Within this genus, eggs are mostly laid singly, and many species feed on the members of Rutaceae. Many species exploit native and cultivated *Citrus* species and some are considered pests (Parsons, 1999; Grund, 1999; Braby, 2000).

Papilio schmeltzi (Herrich-Schaeffer, 1869) is endemic to the Fiji Islands and, due to habitat loss and predators, is currently undergoing significant population decrease (Chandra et al., unpublished). All type material and Herrich-Schaeffer's records were destroyed during World War II (Robinson, 1975). Existing information on *P. schmeltzi* is derived mainly from studies by Mathew (1885), Robinson (1975) and Hancock (1983a; 1983b). Mathew (1885) had studied developmental stages of this butterfly but the descriptions are brief and only a pupa and fifth instar larva are illustrated. Similarly, Hancock's (1983a; 1983b) accounts of the mature larva are limited. Robinson (1975) and Hancock (1983a; 1983b) gave only short notes on morphology of adult *P. schmeltzi*.

A detailed study of the life history of *P. schmeltzi* is necessary in order to fully understand its population ecology and to employ effective conservation programs. Recent investigations of *P. schmeltzi* have gained information on seasonal development of larvae by field observations (Chandra et al., unpublished). However, this approach was problematic because eggs of *P. schmeltzi* were scarce in nature; larvae were found to occur in low numbers, and larvae that were encountered tended to already be in third or later instars.

The aim of the current study was to rear *P. schmeltzi* in captivity and to describe its life history, including information on inter-stage mortality, feeding behaviour and mating ecology. In addition to providing basic information on the ecology of this uncommon species, the potential for captive rearing of butterflies to provide specimens for augmentation of wild populations is discussed.

MATERIALS AND METHODS

P. schmeltzi was reared in a screened enclosure from mid April 2008 to end of November 2008. The enclosure was designed to provide conditions as close to its natural habitat as possible and was located in an open area at the University of the South Pacific, Suva. The enclosure measured 3.4 m X 7.1 m X 1.8 m, and was large enough to allow observations while standing inside the cage without causing significant disturbance to the butterflies. The enclosure was covered with two layers of mesh: silver aluminum 1-mm² mesh covered the sides to allow maximum sunlight to pass through, and black polythene mesh covered the top to provide shade and keep the inside of the cage cool. Polythene mesh on the roof had periodic gaps to allow sunlight. The floor of the cage was also covered with aluminum mesh to prevent predators. Temperatures throughout the duration of the study ranged from 25 °C – 32.9 °C, and averaged 28.2°C.

Flowering plants (nectar source for adults) were placed along one side of the enclosure and larval host plants on the other side in pots. Two native trees (*Ficus* sp. and an umbrella tree, *Brassaia actinophylla*) were provided for shelter, and four rutaceous plants (*Euodia hortensis*, *Murraya koenigii*, *Citrus reticulata*, and *Micromelum minutum*) were provided as potential host plants and to test oviposition preference. *Lantana camara* (pink flowers), *Ixora coccinea* (red flowers), *Stachytarpheta urticifolia* (purple flowers), *Pentas lanceolata* (white & purple flowers), and *Tagetes erecta* (yellow flowers) were used as enclosure nectar sources and to determine potential wild nectar plants.

A wild gravid female was released in the butterfly cage. She successfully laid eggs on one of the host plants, and three successive generations were subsequently raised. The number of eggs laid was counted daily, and the preferred host plant was noted. Immature stages were monitored while on potted *M. minutum* to obtain estimates of survival. Durations of different developmental stages (egg, larval, and pupal stages) and longevity of adults were recorded.

All morphological observations reported here are based on adults and different stages obtained from the reared generations in the butterfly cage with additional information drawn from Mathew (1885), Van Son (1949), Hancock (1983b), Parsons (1999) and Braby (2000). Numbers of individuals of each
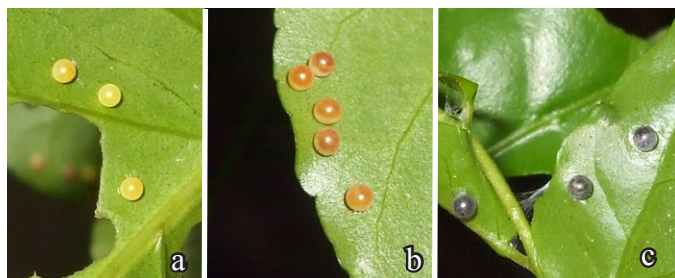
Fig. 1. Colour variation of *P. schmeltzi* eggs with age in the enclosure. Newly laid eggs (a), half way through egg stage (b) and eggs close to hatching (c).

stage on which morphological observations are based and the measurements are given in Table 1. We recorded variation in the colour and other morphological characteristics, duration of pupa stage and time of day the adult emerged. Fecundity of adults was estimated by counting eggs deposited in cage and oviposition rates were calculated by number of eggs laid daily for the first five days of oviposition. The number of larval instars was assessed as well as duration of individual instars, and the overall growth rate. Courtship and mating behaviour including mating frequency were observed. Longevity of adults and their interactions in a closed environment in cage were observed. Adult butterflies were observed in various behaviors such as feeding, coupling, chasing and oviposition. The camera used to take photos in the cage was a FujiFilm (FinePix A820) digital camera with 8.3 Mega Pixel recording and 4X Optical Zoom.

RESULTS AND DISCUSSION

Description of *P. schmeltzi* Stages:

The descriptions of all life stages are based only on the external features and limited measurements. Further studies are needed for full description and comparisons of taxonomic significance. However, the results provided will form a fundamental basis for further studies on the morphological studies on the endemic *P. schmeltzi* and on other unstudied Fiji butterflies.

Eggs (Fig. 1; a-c).   Held in place by a clear adhesive. Spherical with a flattened base, chorion texture smooth, 1 – 1.2 mm wide x 0.85 mm tall, smaller than those of *P. aegeus* (2.5mm), *P. albinus* (1.5mm) and *P. ambrax* (2mm) (Braby, 2000).

Larval development commences immediately after eggs being laid (Vane-Wright & Ackery, 1984). Newly laid eggs glossy light yellow, but after 1 – 2 days became heavily speckled brown one-third of the way on top of the egg and turned orange-brown, then black one day before hatching. Just before hatching, the shell became clear or colourless, young larva seen curled into a U-shape beneath chorion, head facing up.

Larvae (Fig. 2; a-f). *First Instar*: Newly hatched, small, 3mm – 7.4mm in length (**Table 1**), head shiny black, hirsute; dorsal surface white with dark brown transverse band on 1st, 2nd abdominal segments; all segments have pairs of white subdorsal spinose tubercles, longest on prothorax facing forward on tenth abdominal segment pointing backwards; lateral, ventral regions dark brown.

Second Instar: 7.8mm – 12.6mm in length, similar to first instar, metathorax, 1st, 2nd, 6th, 7th, 8th abdominal segments olive brown dorsally with white subdorsal spinose tubercles reduced, mesothoracic region notably humped; osmeterium long reddish pink.

Third Instar: 12.8mm – 20.6mm in length, similar to second instar, spinose tubercles not conspicuous, resembled short, fleshy, wart-like tubercles of brown colour on all segments except for prothorax, 3rd, 4th, 9th, 10th abdominal segments where it retained its white colouration; saddle mark rather V-shaped dorsally on 3rd, 4th abdominal segments extending laterally on to

2nd abdominal segment; an obscure brown stripe running along central dorsal abdominal segments.

Fourth Instar: 21mm – 29.2mm in length, similar to third instar. Glistening dark brown with creamy white prothorax (extending laterally to mesothorax), 10 abdominal segments; all prolegs, ventrolateral abdominal area above is white.

Fifth Instar: 29.7mm – 49.5mm in length, osmeterium is long and red; tubercles present on all thoracic segments, abdominal segments 1, 5 to 9**;** thorax slightly humped; all prolegs, ventrolateral abdominal regions are white. Larvae exhibited colour dimorphism: green or striped. Green larvae dorsally uniform golden green or green with yellow-green lateral patches, transverse white to dark brown thoracic band with white ventrolateral line. Abdominal segments have white or brown ventrolateral band extending obliquely backwards dorsally over each of abdominal segments 4 and 6, margined with white above and below, that on segment 4 extending dorsally backwards to segment 5. For striped larvae, body colour variable, green or orange brown with many white, yellow-white, yellow-green, yellow lateral streaks, transverse dark brown to black thoracic band. Abdominal segments with black or brown ventrolateral band extending obliquely backwards dorsally over each of abdominal segments 4 and 6, margined with white above and below; that on segment 4 extending dorsally backwards to segment 5. V-shaped saddle mark dorsally on 3rd and 4th abdominal segments, extending laterally on to 2nd abdominal segment, distinctive; a structured, pale, small, v-shaped mark mid-dorsally on all abdominal segments; tubercles on abdominal segments 5 and 6 are prominent black.

First four larval instars closely resemble fresh bird droppings as is typical of *Papilio* species, apparently to hide from potential predators, turning green in later instars (Henning et al., 1997; Parsons, 1999; Braby, 2000; Suwarno et al., 2007). *P. schmeltzi* early larval instars are closely related to *P. godeffroyi* (Mathew, 1885), *P. aegeus* (Braby, 2000) and *P. fuscus* (Parsons, 1999), as all are dark-coloured with anterior, middle, posterior parts having broad transverse white bands on dorsal surface. *P. schmeltzi* and *P. godeffroyi* larvae have a prominent white V-shaped mark in middle of larvae but in *P. schmeltzi* white V-shaped mark becomes bigger through growing instars unlike in *P. godeffroyi* (Mathew, 1885). *P. schmeltzi* larvae are distinguished from that of *P. fuscus* by presence of fleshy, subdorsal-branched tubercles. In contrast, *P. aegeus* bears much longer subdorsal tubercles than in *P. schmeltzi*, *P. amynthor* and *P. godeffroyi* (Hancock, 1983b).

Last instar larvae feeding on *M. minutum* have two different colour patterns (tiger stripe type and flat green type), camouflaging with leaf backgrounds. This color characteristic corresponds to those larval colors of *P. aegeus* which often use *Citrus* plants as larval host. The tiger-stripe type has variation in colour, but the V-shaped white colouration in middle is distinctive. Preliminary work done by Clarke et al. (1963) on larval colour patterns of *P. demodocus* feeding on *Citrus* (Rutaceae) and Apiaceae in South Africa shows that the final instars of *Citrus*-feeding larvae have different larval colour pattern when feeding on Apiaceae rather than Rutaceae. Their results showed no evidence that different

Table 1. Measurements of different life stages of *P. schmeltzi* reared in caged enclosure.

Stage (n)	Mean Length (mm)	Range (mm)
Egg (80)	1.0 ± 0.0	1.0 - 1.2
First Instar Larva(80)	5.6 ± 0.4	3.0 -7.4
Second Instar Larva (80)	10.1 ± 0.2	7.8 - 12.6
Third Instar larva (80)	16.3 ± 0.2	12.8 - 20.6
Fourth Instar Larva (80)	25.0 ± 0.3	21.0 - 29.2
Fifth Instar Larva (80)	38.1 ± 0.7	29.7 - 49.5
Pupa (30)	34.0 ± 0.4	29.8 - 37.3
Adult Female (17)	101.4 ± 1.0	94.0 – 106.0
Adult Male (30)	93.2 ± 1.1	84.0 - 104.0

Fig. 2. Dorsal view of the first instar (a), second instar (b), third instar (c) and fourth instar (d) larvae of *P. schmeltzi* on the *M. minutum* leaf in the enclosure; Lateral view of the flat green fifth instar (e) and the tiger-striped fifth instar (f) larvae of *P. schmeltzi* in the enclosure.

food plants caused diverse larval patterns, but that instead the colours were determined by a single pair of genes that determines distinct larval colour patterns.

Pupa (Fig.3; a-d). 34mm – 39mm in length (**Table 1**). Curved, roughly textured, has two short angular projections on head, a small pair of tubercles on dorsal side of head, a less prominent dorsal projection on thorax, with two pairs of angular lateral projections on thorax. Abdomen has two small pairs of ridged, subdorsal, conical projections or tubercles. Middle of pupa strongly convex ventrally, moderately concave dorsally, narrowed where suspending silken girdle supports it. Occurs in green and brown forms. Green to dull blue green matches colour of *M. minutum* leaves. The ventral side of pupae presents wing cases and abdomen marked with silver grey white stripes, with bright yellow green dorsal markings on abdomen, forming a conspicuous triangular mark; also, there is a short grey white stripe dorsally on both sides, starting from anal end to middle of abdomen. Brown pupae are dark orange-brown with dark brown projections, the ventral side being light brown with silver grey white streaks, and a thick, central white grey line on the dorsal side of abdomen, running from the anal end to middle of abdomen .

Mathew (1885) reported *P. schmeltzi* and *P. godeffroyi* pupae to be 30mm - 35mm in length. *P. godeffroyi* pupae have similar colouration, and are strongly curved and body narrowed at centre, but they attach to the midrib of a leaf and those of *P. schmeltzi* attach to the stem or twig of host plant.

Adult (Fig. 5). *Upper side* – The female is dark brown-black, and the male is velvety black; *fore-wing* with narrow subapical band of white spots united with a postdiscal band, but much reduced or absent in males, with small white spots along outer margin. *Hind-wing* with a broad white postmedian area, deeply curved along outer edge, followed by submarginal series of blue crescentic spots, below this an irregular series of orange crescentic subtornal and subterminal spots, with thin white lines along outer margin, termen with a prominent lobed shaped tail at end of vein M_3.

Under side – The female is dark brown-black, the male being velvety black; *fore-wing* with a broad subapical band of white spots united with postdiscal band, evenly curved, much narrower in males with small white spots along outer margin. *Hind-wing:* postmedian white area found on the upperside of the hind wing is greatly reduced to a thin series of spots but still evenly curved; the submarginal series of blue and orange crescentic spots are distinct (well-developed below, reduced above), with thin white lines along outer margin.

Most white, blue and orange markings on the wings on both sides become reduced with age; scales come off by brushing vegetation during flight, with the white areas becoming creamy to light yellow hue.

Sexes quite similar; females generally larger than males, often having larger abdomens for carrying eggs, subapical band on forewing is much more distinctive in females. Large wing span, male: 84 – 104 mm, female: 94 – 106 mm. Length similar to that of *P. aegeus* (Male: 102 mm; Females: 108 mm) and *P. fuscus* (Male: 85 mm; Females: 91mm) from Australia (Braby 2000). Sexes similar also in *P. amynthor* (Hancock, 1983b) and *P. godeffroyi* (Semper, 1866). Hancock (1983b) considered *P. schmeltzi* and *P. godeffroyi* adult morphological features as analogous. Forewings have subapical pale band united with postdiscal band; however, in *P. schmeltzi,* it is much reduced and evenly curved, and in *P. godeffroyi,* it is angled apically. Orange markings on underside of *P. schmeltzi* wings are much extensive than on *P. godeffroyi* butterfly.

Life History and Behaviour of *P. schmeltzi*: *M. minutum* was the host plant used by this butterfly for egg laying and development, in captivity.

Eggs. Incubation period of first batch of 267 eggs varied from 5 to 6 days, average of 5 days. Most tropical *Papilio* species reportedly hatch within 5 days after oviposition, as seen in *P. ambrax* (3 days), *P. albinus* (4 days), *P. aegeus* (5 days) (Parsons, 1999) and *P. polytes* (3 days) (Suwarno et al., 2007).

Larvae. Larval stage lasted from 18 – 32 days in cage. First instar: 2 – 6 days; second instar: 3 – 7 days; third instar: 4 – 7 days; fourth instar: 3 – 6 days, and fifth instar: 4 – 12 days before it moulted.

At time of hatching, the larva chewed an opening through the egg shell and emerged head first, rested for about 2 minutes, then ate the egg shell, and after that, crawled to the upper surface and moved to the tip of the young leaf. The larva spun a pad of silk in the center of the leaf for support and then started feeding on the edge of the leaf. First to third instar larvae are found at the leaf tips, while fourth and fifth instar larvae are found on the middle of the leaves.

All larval instars feed and rest openly on upper surface of the foliage. Larvae are solitary, and feed independently in all instars on larval host plants, avoiding exposure to direct sunlight. Larvae of *P. aegeus*, *P. ambrax* (Braby, 2000), and *P. demoleus* (Badawi, 1981) also feed openly on foliage. All instars

start to eat leaves from the edge, ending at the midrib; midrib and portions of leaf that have eggs are not consumed. Fourth and final instars inflict the most injury to host plants as they vigorously consume foliage. In the cage, later larval instars often ran out of food on one larval host plant and moved to another to complete their development.

Leaves that were completely eaten were then clipped by larvae at the petioles and dropped from the plant. Vane-Wright & Ackery (1984) suggested that this is done to reduce predation from birds that locate prey by searching for damaged leaves. Larvae of *P. schmeltzi* feed on their moulted skins and only head capsules remain after each moult; this behaviour is also recorded for *P. demoleus* (Badawi, 1981).

One *M. minutum* plant had ten larvae on it. This apparently was due to a large density of larvae and shortage of larval host plants in cage. On one of the infested *M. minutum* plants with larvae, it was observed that when a fifth instar larva encountered a first instar larva, it ate the latter. Larval cannibalism has been observed in many species of butterflies. To avoid this, female butterflies usually lay no more than one egg on each plant in their natural environment, as they can detect already-laid eggs (Vane-Wright & Ackery, 1984).

All instars got irritated when touched or disturbed. They shrunk in size when touched and reared their head and thorax towards the annoying object to dissuade the antagonist before moving. When disturbed, a larva would protrude its forked, bright red osmeterium, lifting its anterior part of body and swinging it from right to left, releasing a pungent odour resembling that of rotten *Citrus* fruits (**Fig. 4**). An osmeterium is present in all instars but the colouration is not so vivid in younger instars. This behaviour to ward off predators has been observed in other tropical *Papilio* species (Parsons, 1999; Braby, 2000).

Pupation. Before entering the prepupal stage, larvae stopped producing normal droppings at the end of the fifth instar and discharged a green-black substance on the floor of cage. Larvae purge the gut of semi-digested larval host plant and metabolic wastes in this manner (Vane-Wright & Ackery, 1984). During this stage, larvae stopped feeding, settled on a secluded site, and became attached to the posterior to the stem by a strong cremaster to a silken pad, with head held upwards or upright by support of a frail, black, central silken girdle thrown around both the thorax and the stem that held them in place. Pupation usually occurred on undersides of leaves on the stem of the larval host plant. The prepupal stage in our study lasted for 1 to 2 days, and the pupa stage was 15 to 20 days long.

P. schmeltzi showed no tendency to wander from the larval host plant for pupation. However, a few left larval host plants to pupate on stems of other plants, or on the sides of potted plants, stonewall and the mesh of the cage due to the scarcity of larval host plants in cage. Papilionini pupae are often dimorphic and usually match well the substrate for pupation, being either green or brown (i.e., resembling a new leaf bud or dead twig) to blend with their environment to avoid predators (Hancock, 1983b; Braby, 2000). All larvae that had wandered off from their larval host plants became brown pupae except for the ones on stems of other plants that turned green. *P. schmeltzi* produced a high frequency of green pupae (53 green and 7 brown in first generation) on slender stems in cage.

Eclosion and Adult stage. Pupae became long, their segments stretched and colour changed one day prior to emergence, and the adult inside the transparent casing was plainly visible. This colour change was due to pigment appearing in adult butterfly scales (Vane-Wright & Ackery, 1984). Adult emergence was observed in early morning soon after sunrise. Only two adults were observed to have emerged after 9 a.m.

The pupa case split open in front of its head and the butterfly emerged with its upper body coming out first, then its legs to grasp on to something, and then the lower body. When it first emerged, the body was swollen and wings were wet and crumpled. Adult butterflies hung upside down and it took about 55 minutes to 1 hour & 55 minutes to expand their wings.

Under caged conditions, the female lived from 15 to 41 days, averaging 24 days; the male lived from 12 to 28 days, averaging 18 days. The sex ratio of emerged adults was 3:2 (33 males, 20 females).

Temperature. In cage, flight began shortly after sunrise and their activities were largely restricted to feeding, chasing, mating and oviposition. They rested in the middle of day (12pm – 3pm), probably due to high temperatures at that time and then became active again from 4pm until 6pm. However, activity was higher in the morning than in the evening (**Fig. 6**). During night hours, adults rested on top of leaves of tall plants or hung on wired mesh, with their wings open widely, shaded by framework of the cage and staying motionless.

Foraging. Feeding during the day had significant peaks in morning and afternoon (**Fig. 6**). Whilst feeding, butterflies did not settle on flowers but grasped a flower with their legs, hovering with wings vibrating.

Fig. 3. Dorsal (a) and lateral (b) view of the green pupae and dorsal (c) and lateral (d) view of the brown pupae of *P. schmeltzi* on the *M. minutum* plant in the enclosure.

Copulation. Breeding studies of *P. machaon bairdii* (Thompson, 2003; Tkacheva et al., 2005) suggested that swallowtails do not readily pair by themselves in captivity, so hand-pairing and force-feeding is advised. However, no hand-pairing or force-feeding was needed in this study as the cage size used was adequate and the cage design was suitable for butterflies to engage in normal activities as close to those in natural habitat as possible.

No patrolling and perching mate-location behaviour was seen in the males of *P. schmeltzi*, nor was any aggressive behaviour. They perched separately on a plant or hung onto the mesh of the cage.

This study in captivity allowed observations on mating that could not be recorded in the wild. Males of *P. schmeltzi* initiated courtship as is generally seen in other butterflies (Vane-Wright & Ackery, 1984; Suzuki et al., 1985). Males hovered below a female and came up for her response. Already-mated females rejected males by rapidly flying upwards or settled down on a leaf with wings open and becoming passive.

The male extended his claspers, approached towards a receptive female from one side with his abdomen curved, and grasped her abdomen. Mating took place while butterflies were resting on a plant or when in flight, but after abdomens came into contact, they settled on PVC mesh or on a plant. When in copulation, the pair faced in opposite directions with wings wide open and hung downward or settled on a leaf with female above and male below (**Fig. 5**). However, when the pair was disturbed, the female flew off dragging the male to another location, while the male held on with its claspers with wings closed.

Males intercepted some females as soon as they came out of their chrysalids, apparently being sexually receptive even on the day they emerged. Such mating pairs began to copulate after 8.00 a.m. on the day of female emergence. The copulation frequency was high during the morning and became irregular later in the day (**Fig. 6**). Thirteen pairs were observed in copulation, and each pair remained in copulation about 1 hour 28 minutes to 18 hours 30 minutes. Butterfly copulations are often prolonged, possibly due to females mating with older males, which produce smaller spermatophores (Vane-Wright & Ackery, 1984).

Females were observed to mate only once in their lifetime. However, males were observed mating twice in their lifetime. Male butterflies flew off immediately after copulation and there was no post-mating behaviour observed.

Oviposition and Fecundity. To oviposit, the female landed on a leaf of larval host plant, keeping her balance by actively fluttering her wings. Holding on to leaves with her tarsal claws (Wiklund, 1974), she curved her abdomen up and deposited an egg at the edge of the underside of a *M. minutum* leaf.

Single eggs were laid on the underside (97%) of young foliage of larval host plants near leaf edges. Eggs thus laid are hidden from predators (Parsons, 1999; Braby, 2000; Henning et al., 1997). Less than 1% of eggs were laid on stems and petioles. *P. aegeus* reportedly also occasionally lays eggs on stems (Braby, 2000).

The ecological significance of laying eggs on tender foliage by female swallowtails is that older leaves may soon drop to the ground where eggs can easily start to rot (Vane-Wright & Ackery, 1984). In addition, young leaves are high in nitrogen and water that makes them nutritionally sufficient (Scriber & Slansky, 1981). In field, females were seen to deposit one egg per leaf (Chandra et al., unpublished); however, in the cage situation, several eggs were seen laid per leaf. This could be due to the limited number of *M. minutum* plants in the cage and confined restriction in movements of the butterflies. Females preferred to lay their eggs on small plants less than 2 meters high. Oviposition began shortly after sunrise and had two peaks between 11am – 12pm, and 2pm – 3pm (**Fig. 6**).

Fecundity and fertility are important parameters in the interpretation of population dynamics of *P. schmeltzi* butterflies; however, there has been no study of these parameters under natural conditions because of the butterfly's

Fig. 4. Defensive posture of fifth instar larvae of *P. schmeltzi* in the enclosure.

high flight activity and low population density. Fertility per day of *P. schmeltzi* in captivity was higher than that under natural conditions as revealed by field data. The number of eggs laid on individual larval host plants ranged from 4 to 36.

It was observed in the cage that young females flew straight to their larval host plants and quickly oviposited, whilst apparently older and more tattered females spent far longer selecting sites for laying their eggs. Females produced relatively few eggs during first few days of adult life, but oviposition rate quickly rose to a peak and then sharply declined after a few days. Highest fecundity observed was 267 eggs for one female (first generation), and number of eggs deposited in a day decreased with female age.

Generations and Mortality. *P. schmeltzi* is multivoltine, and three generations were reared from April until November 2008 in captivity. Time taken from egg to adult was 38 – 66 days and temperature ranged from 24 °C to 32.9 °C. Larval stage was completed in about 18 to 32 days (24.7 °C – 32.9 °C). Based on this study it is estimated that 6 to 8 generations of the butterfly may occur annually. *P. xuthus* and *P. machaon* have more than 4 annual generations (Watanabe & Nozato, 1986), *P. helenus*, *P. bianor* and *P. protenor* have 2 discrete generations in a year at Shikoku Island (Watanabe et al., 1984). *P. demoleus* was estimated to have about 8 generations a year in Riyadh region in Saudi Arabia by Badawi (1981) who reared 5 generations of this species. *P. xuthus*, *P. machaon P. helenus*, *P. bianor* and *P. protenor* have fewer generations in a year when compared to *P. demoleus*, possibly because of climate and temperature differences.

P. schmeltzi are encountered at low densities and a population is maintained at a very low level in its natural habitat, unlike *P. aegeus* (Braby, 2000) and *P. demoleus* (Badawi, 1981) which are pests on *Citrus*.

Mortality rate from egg to adult was generally high for all three generations; however, mortality rate increased through each generation (**Table 2**). This could be due to changes in seasons as first and second generations were reared in the dry season and the third generation was reared in the wet season.

More importantly, the restricted environment and relatively smaller space apparently could not sustain several successive generations of *P. schmeltzi* and subsequently each generation gave fewer offspring. In general, egg survival was high in all 3 generations. The highest mortality rate occurred in the third generation. Most deaths were in the pupal stage.

The minimum area of tropical forest required for a successful self-sustaining *P. schmeltzi* population is not known. Similarly, the optimum densities of primary and secondary larval food plants are not known. Therefore, appropriate conservation plans cannot be established. Fortunately, *P. schmeltzi* butterflies can live and do well in captivity, as shown in this study. This makes it possible for preservation of this butterfly species through captive propagation and release of the reared adults and pupae (near the stage of eclosion) to areas that contain larval host plants that will support larvae in natural environments, in order to increase wild population size. However, in natural environment new habitats need to be created, existing habitats need to be managed for butterflies, and habitats need to be linked by a network of natural corridors. Furthermore, technical knowledge gained from research will be a useful tool for studying the status of several other endangered, endemic and native butterflies.

CONCLUSION

The experimental study in captivity was designed and undertaken to investigate many aspects of *P. schmeltzi* biology, ecology and behaviour that could not be recorded for various reasons in field observations. Numerous observations made during this study in captivity on Fiji's endemic swallowtail butterfly yielded a considerable amount of new information about *P. schmeltzi*. This study focused on all stages of *P. schmeltzi* life cycle. One of the highlights of this investigation is that it has established a protocol for successfully rearing *P. schmeltzi* in captivity. The protocol can be applicable to other butterflies, too. This study has revealed several hitherto unknown or little-known aspects of its behaviour and life history that could not be studied in the natural habitat. Successful rearing providing generations of viable offspring has very important implications in designing conservation strategies for this endemic butterfly in Fiji. Findings will form the basis of several other areas of future research on this iconic species.

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Table 2. Survival (%) of different developmental stages of *Papilio schmeltzi* in captivity.

Generation	Number of Females	Total Eggs Laid	1st Instar Larvae	2nd Instar Larvae	3rd Instar Larvae	4th Instar Larvae	5th Instar Larvae	Prepupa	Pupa	Adults
1	1	267	73.8	56.9	44.6	34.5	27.7	24.0	21.7	19.9
2	12	388	75.0	53.1	34.3	20.9	15.3	8.8	7.2	5.4
3	5	294	75.5	60.2	48.3	36.7	27.6	19.4	10.9	6.1
Average	6	316.3	74.8	56.7	42.4	30.7	23.5	17.4	13.3	10.5

Fig. 5. Copulation of *P. schmeltzi*.
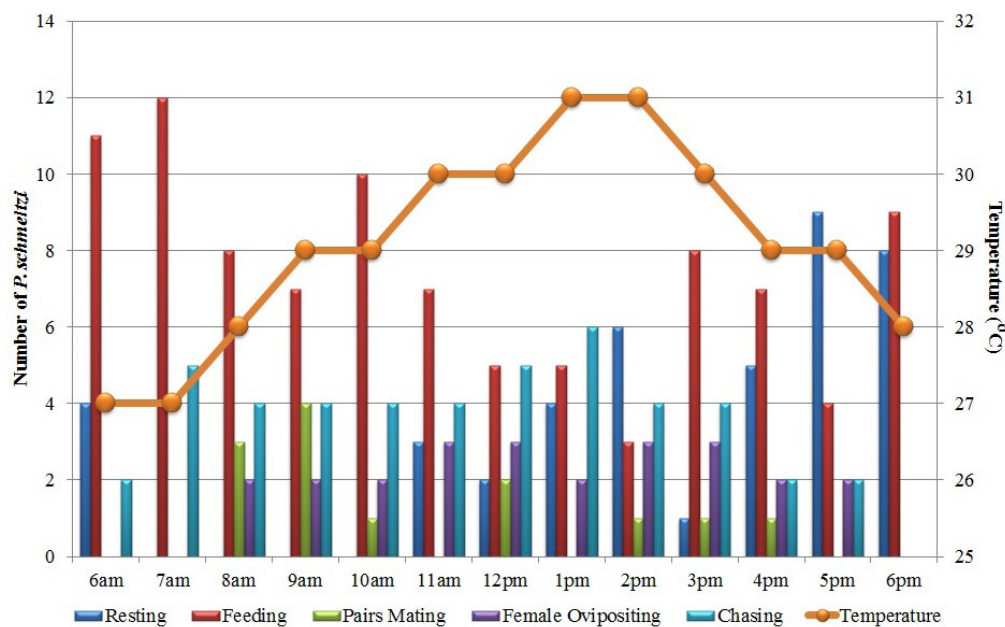
Fig. 6. Average daily activities of seventeen *P. schmeltzi* butterflies at different hours in a day in relation to temperature in the enclosure.

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