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Field studies on Fiji's endemic swallowtail butterfly, *Papilio schmeltzi*: Habitat, activity patterns, phenology and distribution

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Abstract

Fiji's swallowtail butterfly, Papilio schmeltzi, is a Rutaceae feeding, tropical Papilionid butterfly that is endemic to the Fiji islands and generally occurs in low density. Field observations on habitat and the seasonal activity patterns of P. schmeltzi were carried out in the Vatukarasa area in Korolevu, Sigatoka over the course of one year. P. schmeltzi adults were found throughout the year but with dry and wet seasonal variation in abundance. High abundance was recorded for all the P. schmeltzi stages during the dry season (May to September). Adults and larvae were the most abundant when compared to eggs and pupae, and showed the greatest variation with respect to distribution of life stages throughout the year. P. schmeltzi currently occurs at four localities on the mainland and ten localities in the outer islands, with high abundance in Sigatoka and Koro Island. Adults of the species mainly occupy isolated forest edge habitat and gardens near forested areas and display a strong affinity for running water. At least two larval host plants, Micromelum minutum and Citrus reticulata, were found to sustain populations of P. schmeltzi, in its natural environment.
Keywords: *Papilio schmeltzi, Phenology, Distribution, Natural habitat*

1. Introduction

One of the most important aspects of the population dynamics of insects is their phenology, which is the study of the seasonal timing of recurring biological events (Tauber *et al.* 1986; Shapiro *et al.* 2004). Seasonal patterns of biological events in the tropics differ from those in the temperate zone, for instance, temperature fluctuations are small, but seasonal fluctuations in precipitation (i.e. dry and wet seasons) are more pronounced (Tauber *et al.* 1986).

The phenology of swallowtail butterflies is well studied, mostly on continent swallowtails, such as, *P. machaon* (Dempster *et al.* 1976), *P. xuthus* (Watanabe 1979; Watanabe *et al.* 1984) and *P. polyxenes* (Sims 2007), and their evolutionary relationship with environmental variables (Owen *et al.* 1972; Shapiro 1975; Young 1982; Wolda 1987; Wolda 1988; Cardoso 2010; Altermatt 2012.). Butterflies in temperate regions enter into diapause mainly in the pupa stage, until the return of suitable environmental conditions such as humidity, temperature and food resources (Badawi 1981; Sims 1983; Watanabe *et al.* 1984; Watanabe and Nozato 1986; Yamanaka *et al.* 2004; Hiraga 2006; Sims 2007; Scriber *et al.* 2012; Yamanaka *et al.* 2013). Most tropical insect species, however, grow and reproduce all year round because their larval host plants are available throughout the year, even though most of them show distinct seasonal cycles in the level of their activities (Young 1982; Wolda 1983; Wolda and Denlinger 1984), as larval host plants are more abundant during specific seasons (Tauber *et al.* 1986).

Papilio schmeltzi is Fiji's largest butterfly and only Papilionidae. *P. schmeltzi* is of particularly great interest as it is endemic to Fiji Island archipelago. Robinson (1975) made a significant contribution to information on Macrolepidoptera of Fiji, however, his research on *P. schmeltzi* were restricted to distribution in the Fiji archipelago.

This is the first study over an extended period that investigated the changes in activity patterns and the seasonal influence of environmental factors such as rainfall, temperature and humidity on *P. schmeltzi*. The objectives of this study were: i) to identify the larval host plant, and nectar sources for adults of *P. schmeltzi*, ii) to investigate the effect of weather variables and predation on *P. schmeltzi* abundance and activity patterns and iii) to investigate the current abundance and distribution of *P. schmeltzi* in Fiji.

Preliminary results of this investigation were presented at a conference and reported as part of the proceedings (Chandra *et al.*, 2011). Detailed observations of this study are reported herein.

2. Study Area

The area for studying *P. schmeltzi* in its natural habitat was located in Vatukarasa area, Sigatoka, situated on the dry western side of the island of Viti Levu, Fiji. Rainfall in this area is less than 103mm per month during the cooler months in Sigatoka. In addition, Sigatoka has a mean monthly temperature that ranges between 26.5 °C in January and 22 °C in July, and sunshine hours that range from 7.5 hours a day in December to approximately 6.2 hours a day in June (Prasad 1980; Climate of Fiji 2007). Vatukarasa village is located along the Coral Coast and is 14.5

km away from Sigatoka town, and the study area was located 1.7 km inland from the main road. The area selected for observing *P. schmeltzi* was limited to 120 m long and 108 m wide are (12960m²) due to accessibility. The presence of steep slopes made it difficult to cover more area for the study site.

The soil was moist and swampy in some places, as a small creek ran through the study area. The land area to the south of the study area was used for subsistence farming (plantation of root crops) for the Vatukarasa village, and for grazing of horses and cattle. The vegetation in the study area was secondary forest community; however, it seemed to be frequently disturbed by man and livestock. Tall trees provided shade, allowing very little sunlight to pass through. Light intensity as measured by a Lux meter was 8.62 X 100K.

3. Methodology

The seasonal history of *P. schmeltzi* was determined by fortnightly field observation in the Vatukarasa area from January until December 2008. Temperature (°C) and relative humidity (%) were recorded using a standard alcohol thermometer and a simple humidity meter. Rainfall (mm) measurements were provided by the Fiji Meteorological Service in Nadi for Tabua sands (this station was closest to Vatukarasa area). These parameters were measured because it is widely accepted that they can have a significant effect on the distribution of butterflies (Vane-Wright and Ackery 1984). The influence of weather variables on the phenology of this sub-population were also determined to account for differences in activity during the study period.

Visual observations were made at hourly intervals from 6 am to 6 pm. *P. schmeltzi's* natural habitat, larval host plants, and types of flowers that the adult *P. schmeltzi* preferred for nectar source were identified in the field. Dr. Dick Watling of Birdlife International had indicated (verbal communication) that he had seen an egg and a larva of *P. schmeltzi* on *M. minutum* at his Tamavua residence. The occurrence and abundance of adult males and females, eggs, larvae and pupae were monitored from January through December on foliage of *M. minutum* once every 14 days, to determine if *P. schmeltzi* was seasonal. However, tracking *P. schmeltzi* for a long distance was practically impossible, partly due to their high flight activity and the dense canopy vegetation in the study area. More importantly, the presence of potential predators was recorded, such as, insects, reptiles and birds. Further, observations of behavioural aspects such as intraspecific and interspecific interactions, flight pattern, elevation of flight, feeding, oviposition behaviour, sites of laying eggs and general preference for oviposition in sunny or shaded areas were also recorded. Little known aspects such as the behaviour of larval stages (if they are gregarious or solitary) and localities of the larvae (if they are found in shady or sunny areas) were also studied.

Although research was confined primarily to Vatukarasa, Sigatoka, some observations were made in other areas on Viti Levu (Colo- I- Suva, Tamavua, Korolevu, and The University of the South Pacific) and the outer islands of Fiji (Kadavu, Vanua Balavu and Taveuni). *P. schmeltzi* was studied on Taveuni, Kadavu and Vanua Balavu (outer islands) to determine distribution and abundance, and spent six days on each island during December 2007 to January 2008. At these different localities where adult *P. schmeltzi* were sighted, the description of its habitat and nectar sources was recorded, in addition to the presence of larvae and host plants. Fuji Film Fine Pix A820 (8.3 Mega Pixel and 4X Optical Zoom) camera was used to take photos in the field.

A study of the complete life history of *P. schmeltzi* was not possible in Vatukarasa because not all life stages (from egg to adult) were observed during the study period and low abundances of different stages were recorded. A paired t-test was performed to find out if the immature stages of *P. schmeltzi* preferred the host plant in the shaded area or the sun exposed area.

4. Results and Discussion

4.1 Natural Habitat

In Vatukarasa, the main habitat for *P. schmeltzi* was isolated forested area. *P. schmeltzi* were found flying along the edge and in the gaps of the forests with nectar plants (*Stachytarpheta urticifolia*) and with larval host plants (*Micromelum minutum*). *P. schmeltzi* were found in slightly shady areas near streams or running water. The Vatukarasa forest consisted of a secondary plant community, dominated by a mature overstory of tall trees such as *Alibizia lebbeck, Alphitonia franguloides* and *Terminalia catappa*. Adult *P. schmeltzi* were found in disturbed secondary plant communities dominated by tall trees. *P. schmeltzi* were found at high elevations (5 to 11 meters) above sea-level and away from coastal waters. All stages of *P. schmeltzi* were present at the Vatukarasa study site but differed in abundance during different months of the year.

4.2 Larval Host Plant Relationship to Immature Stages

The larval host plant for *P. schmeltzi* at Vatukarasa was *Micromelum minutum* (Rutaceae). *M. minutum*) were scattered throughout the gaps in the forest, around the edges, and in the thickets of the forest. The average height of the plants that were selected by *P. schmeltzi* as their hosts was 0.64 metres.

P. schmeltzi females oviposited on *M. minutum* (Chandra *et al.*, 2011) which was shorter than its surrounding vegetation. No evidence was found to

suggest that, at the Vatukarasa field site, eggs were ever laid on plants other than *M. minutum*. Although, *M. minutum* grew both in open areas in the forest gaps and along the forest margin, female *P. schmeltzi* confined their oviposition to shaded plants. The immature stages of *P. schmeltzi* were found on the larval host plants in shady areas of the forest, rather than on the larval host plants exposed to the sun.

P. schmeltzi oviposits on *M. minutum* and consequently on those of various heights. Over 60% of *P. schmeltzi* larvae (n=187) were found at heights between 0.6 m and 1.4 m. The leaves from the plants higher than 1.6 m (tall trees) were tough and thick while those from shorter (younger) plants were tender and thin. The higher probability of oviposition on shorter larval host plants in this population is similar to the results obtained by Watanabe (1979) for *P. xuthus*, likely due to the thin and soft leaves which maybe more suitable for the first instar larvae to utilize (Watanabe 1979; Watanabe *et al.* 1984). The majority of the immature stages of *P. schmeltzi* were observed singly on host plants. Rarely two or more immature stages occupied the same leaf. *Citrus reticulata* of the Rutaecae family co-exist with *M. minutum* in the study area but no larvae were seen on this plant.

4.3 Activity of P. schmeltzi in the Vatukarasa Area

4.3.1 General Flight Pattern

P. schmeltzi flight was slow and powerful but became swift and restless when alarmed. The flight height for *P. schmeltzi* was about 0.6 m to 5 m off the ground. These butterflies flew near the upper parts of taller trees. However, their oviposition and feeding sites were close to the ground. They did not fly into dense areas and frequently used watercourses as flyways. *P. schmeltzi* butterflies appeared to be strictly diurnal and started flying around 6 am. As the darkness came, they moved from the open area into the interior of the forest and became less active.

Males and females of *P. schmeltzi* flew out of the forest into the open area mainly in the mornings and evenings. Flight activity showed two distinctive peaks that were seen for marginal forest from 8.30 am to 10.30 am in the morning and 3.30 pm to 5 pm in the evening.

P. schmeltzi adults become more active and more abundant at the forest edge during periods of low to moderate temperature (26 °C - 28 °C) (**Figure 1**). This is reported by May (1979) that diurnal insect species are most active early morning or evening, usually in the hot season. During midday, *P. schmeltzi* normally flew inside the forest and seldom flew out of it as this microhabitat provided more tolerable temperatures. **A**ctivity level of *P. schmeltzi* was lowest when the temperature was high (29 °C – 34 °C) during the day and the butterflies shifted inside the forest and the activity inside the forest increased (**Figure 1 and 2**).

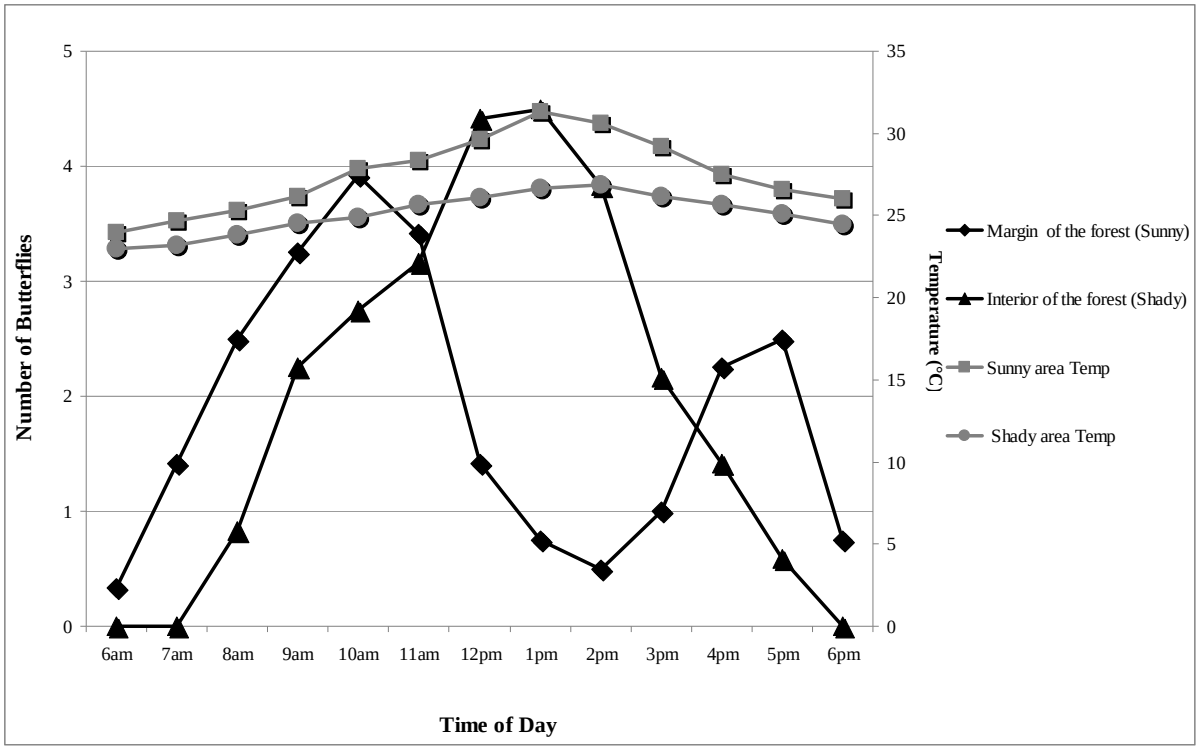

Figure 1. Flight activity patterns (average) of *P. schmeltzi* in shaded (gaps) and sunny areas (margin) for 12 months.

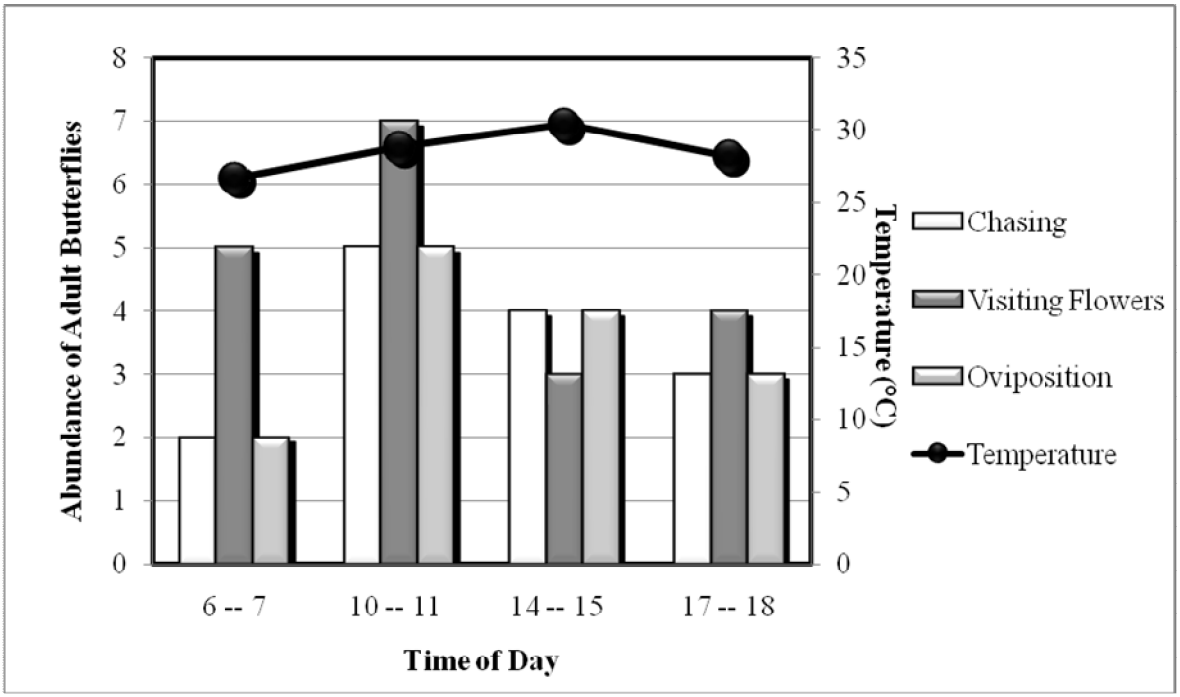

Figure 2. *P. schmeltzi* activity in a year. Males pursing females for copulation (white), *P. schmeltzi* feeding on flowers (dark gey) and females laying eggs on larval host plants (light grey).

4.3.2 Visiting flowers/Foraging

Butterflies utilize many plant species as nectar sources, but the main sources are usually restricted to several plant species according to the nectar preference of butterflies and the relative abundance of the nectar sources (Wiklund *et al.* 1979). The availability of nectar plays an important role in habitat selection (Watanabe *et al*. 1988). Both sexes of *P. schmeltzi* butterflies were seen feeding on the nectar of *Stachytarpheta urticifolia* (Blue rat's tail), which were abundant and the only nectar plant in the study area. *S. urticifolia* plants grew sporadically in forest gaps and periphery throughout the study area. Furthermore, *S. urticifolia* flowered all year around and constitutes an extremely important nectar source in the Vatukarasa area to adult *P. schmeltzi* butterflies. This low-growing shrub is related to *Lantana* species and has been introduced to Fiji from tropical South America (Smith 1953).

P. schmeltzi visited its nectar plants more frequently at the edge of the forest than those inside the forest gaps. Visit to nectar plants by *P. schmeltzi* was usually restricted to the inside of the forest during midday, where solar radiation was less intense (**Figure 1**). Adults fed mainly in the mornings and evenings, two peakswere found in the frequency of visiting flowers of *S. urticifolia*. The morning peak (8 am - 10 am), however, was greater compared to the evening peak (5 pm - 6 pm) (**Figure 2**).

4.3.3 Chasing

Chasing activity was concentrated around midday and as more frequently observed in the gaps of the forest, rather than in open marginal areas of the forest. Chasing behaviour was mostly observed in the mornings and evenings. In *P. schmeltzi*, chasing behaviour attained a peak during 10 am to 11 am, when oviposition and feeding by the females are high (**Figure 2**), and thus males had more chances of courting a female.

4.3.4 Oviposition

Oviposition was observed from April to September but no oviposition was seen from October until December, even though females were observed in flight. Females of *P. schmeltzi* laid eggs singly on the young leaves of *M. minutum* and usually on the lower surface in shaded areas. *P. schmeltzi* oviposited only inside the forest and oviposition activity was high from 10 am to 3 pm (**Figure 2**).

Forty-five eggs were recorded from *M. minutum* plants in the field and 87% were found on the lower leaf surface (the remainder were laid on the upper surface of the leaves)

4.4 Phenology of P. schmeltzi in the Vatukarasa Area

Flights of adult *P. schmeltzi* were observed from January to December 2008 but were more common in the months of April to October. The adult numbers of the Vatukarasa population were generally lower for the whole year and fluctuated from month to month. There was a general decline in abundance recorded throughout the year. The abundance of larvae in the study area fluctuated throughout the year but peaked in June and July, then decreased from August to December 2008. In contrast, the abundance of pupae peaked in May and July 2008 (**Figure 3**).

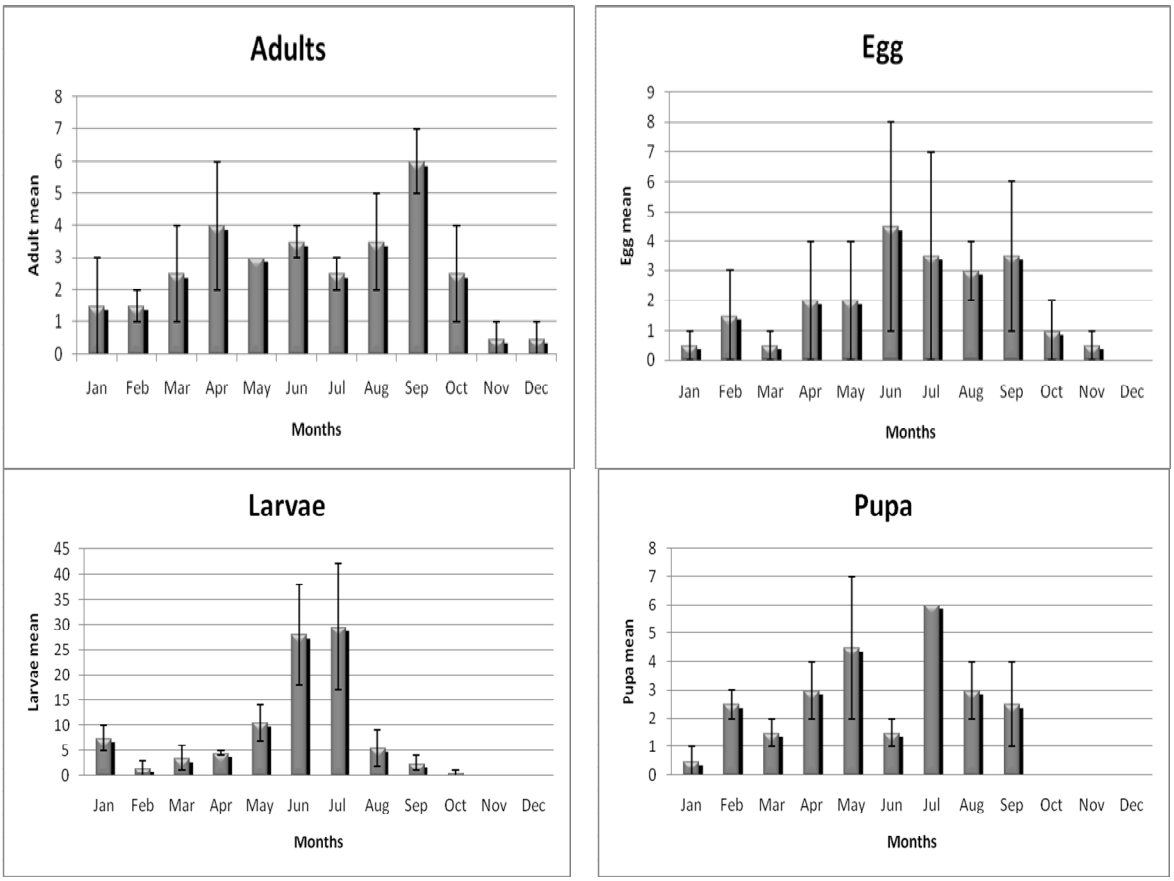

Figure 3. Seasonal abundance of *P. schmeltzi* stages (adults, eggs, larvae and pupae) based on observations in the field for one year.

This observation is supported by works done on *P. godeffroyi* in all parts of Western Samoa and Tutuila by Hopkins (1927), on *P. aegeus* at Cairns, Queensland and on *P. fuscus* at North Eastern Queensland (Braby 2000), which might suggest that tropical *Papilio* butterflies breed year round. Climatic variations during seasons, insufficient or reduced food resources (Vane-Wright and Ackery 1984) and high temperatures (Parsons 1999; Braby 2000) may explain lower abundance of different stages of *P. schmeltzi* during wet season. Butterflies have been shown to synchronize their fluctuating abundances with the phenology of their larval host trees (Tauber *et al.* 1986).

Seasonal differences in the abundance of the butterfly composition during the two seasons of 2008 were observed with the dry season having a relatively high diversity of 18 eggs, 78 larvae, 18 pupae and 22 adults (May to October). During the wet season 6 eggs, 17 larvae, 8 pupae and 13 adults were counted (November to April), suggesting that abundance, growth and activity of *P. schmeltzi* is affected by the dry and wet seasons in a year. Larvae and adult stages showed an increase in abundance from the wet to dry season. In general, pupa and egg showed similar patterns, but differences between seasons were less pronounced compared to that for larvae and adults. Even though the overall pattern in the abundance for each life stage of *P. schmeltzi* was different between months, the abundance generally declined dramatically from October to December 2008, a period during which temperature on the sampling days was high (30-34°C).

Average annual precipitation in the Vatukarasa study area varied from 0 to 48 mm. Average dry season (May to October) temperatures varied from 23˚C to 26˚C, and average wet season (November to April) temperatures varied from 29˚C to 33˚C. The lowest number of adult butterflies and immature stages observed, coincided with the high temperatures over the twelve months. Immature stages were most abundant during the dry season (May to September).

There was variation in the air temperature and rainfall between sampling months. The negative relationship between air temperature and butterfly abundance at the study site indicates that air temperature plays an important role when surveying butterflies (May 1979; Badawi 1981; Blau and Feeny 1983; Parsons 1999; Braby 2000). Air temperatures may account for seasonal differences in *P. schmeltzi* butterflies foraging and breeding activity.

The observed seasonal fluctuation of abundance with *P. schmeltzi* being more abundant in the dry season conforms to the observations of Mathew (1885), who reported that the abundance of *P. schmeltzi* fluctuated during certain seasons and was

most common in May, June and August from 1882 – 1884 at Suva and Levuka. Some insects are known to synchronize their life histories with the dry season in order to maximize utilization of resources such as nectar and pollen (Frankie 1975). The decline in abundance from September could be due to the onset of the wet - hot season when other butterfly species are less active (Vane-Wright and Ackery 1984). Also, the deforestation of the study area in September 2008 (the forest along the gravel main road was cleared due for maintenance of the power line posts) may have been an added factor affecting the observed decline in population in this study. Additionally, this increased sunlight penetration in areas that are shaded were now exposed to the sunlight. In October, the creek that ran through the study area dried up, and the area had an increase in the number of patches of sunlight where most of the *M. minutum* plants were wilted. By November, only few *M. minutum* plants were left in the study area and most of them were now exposed to the sunlight, which could be an important contributing factor to the further decline in abundance of *P. schmeltzi* stages, apart from seasonal changes. At the end of December 2009, Mr. Takashi Inoue visited the study area and found that most of the habitat of *P. schmeltzi* in the Vatukarasa area was destroyed by hurricanes and there were hardly any swallowtails to be seen. Many *M. minutum* seedlings are established in the sunny areas.

P. schmeltzi females were more easily captured than males, because they often flew slowly and only a few metres above the ground, likely seeking suitable plants for oviposition. However, the number of females was lower than that of males during the study period. The proportion of males to females caught at a ratio of 3:2which is similar to that reported by Hopkins (1927) for *P. godeffroyi* in Samoa, suggesting females being scarcer than the males.

4.5 Predation on *P. schmeltzi* in Vatukarasa Area

Butterfly populations are attacked at all stages in their life cycle by a wide range of predators, but chiefly by arthropods and vertebrates (Parsons 1999). At Vatukarasa, no cases of bird attacks on the adult butterflies were observed but a beak mark on the wings of one adult was observed. Birds (unidentified species) were present on the upper canopy and hardly came down to the understory of the forest. In addition, a female was observed with its wings damaged, this could have been due to its wings being caught on branches and twigs while flying inside the forest, as no beak marks were present on its wings. Mathew (1885) also reported that *P. schmeltzi* damaged their wings by frequently flying through thick forest undergrowth, where they soon lose their tails and get their wings torn.

Twenty four days of direct observation, only the larval stages were observed being preyed on by a hemipteran bug (stinkbug or shield bug) throughout the study (**Figure 4**).

Larval remains with traces of sticky black fluid were observed, a virus or disease rather than predation could have caused the death as seen in other *Papilio* species (Parsons 1999). No information is available regarding diseases of the *P. schmeltzi* butterfly.

4.6 Current Distribution of *P. schmeltzi* in Fiji Islands

Chandra *et al.* (2011) briefly reported the distribution of this butterfly in Fiji. More details and further information based on this investigation are reported here.

4.6.1 Viti Levu

Colo – I – Suva Park, Suva: Fieldwork was done at fortnightly intervals from August 2007 until November 2007 but only two swallowtail butterflies were seen throughout the survey. The flight route of the butterflies was along the vehicle track of the park with steep slopes on each side of the track. In addition, the forest was very dense which made it difficult to follow the butterflies. Furthermore, disturbance by human activity might have reduced the numbers of *P. schmeltzi.* In the park no *Citrus* or *M. minutum* plants were seen and no host plant could be located in that area. However, *Melicope cucullata* and *Zanthoxylum pinnatum* of the Rutaceae Family were present in the forest park but no sign of immature stages were observed on them. It was observed that males of *P. schmeltzi* were mostly chased away by *Euploea boisduvalii boisduvalii* butterflies when they came to feed on the flowering plants (*S. urticifolia*) at the margin of the forest.

Korolevu, Sigatoka: In Sigatoka, four to six *P. schmeltzi* butterflies were found in Korolevu and Korolevu–I–Colo; the area was mostly hilly with steep slopes. *P. schmeltzi* was observed coming to *Lantana camara* and *S. urticifolia* flowers for feeding near the edge of the forest.

Kula Eco Park, Sigatoka: Two *P. schmeltzi* butterflies were seen flying high up in the trees (4 – 5 metres) in the Kula Eco Park on 23rd March 2008. The butterflies only came low to the ground to feed on the flowers of *S. urticifolia* and *Pentas lanceolata* (white and purple flowers). The two butterflies returned to the same area at intervals of 10 to 15 minutes. Only three *M. minutum* seedlings were seen in the whole park, but other Rutaceae plants such as *Citrus reticulata*, *Citrus limon*, *Euodia species*, *Murraya koenigii* and *Murray paniculata* were present. At 11 am, a female was seen laying an egg on the underside of the young soft leaf of a tall *C. reticulata* (mandarin) tree. This tree was located in a shaded area with a nearby stream.

Malevu village, Sigatoka: The *P. schmeltzi* butterflies were seen on the 22nd November 2007 along a vehicle track leading up a steep, hilly slope with forest on both sides of the road, away from the coast. There were abundant *S. urticifolia, L. camara*

Figure 4. A hemipteran bug sucking out the fluid from the dead fourth instar larva at Vatukarasa study site.

and *M. minutum* plants along the path and more *M. minutum* plants were seen inside the forest. Three males and two females of *P. schmeltzi* were observed feeding on the flowers of *S. urticifolia* (blue rat's tail) and *L. camara*. One of the male butterflies had damaged wings. The female butterfly was observed to lay her eggs on the *M. minutum* leaves in dark, shaded areas of the forest. Only one 2nd-instar larva was seen on the *M. minutum* plant.

Natawatawage Village and Qalaqara Creek, Sigatoka: *P. schmeltzi* butterflies were seen flying in September 2008, near the Natawatawage village and along Qalaqara creek. *M. minutum* plants were abundant in and around this village and creek, however no immature stages of *P. schmeltzi* was observed. *M. minutum* leaves were used by the villagers as medicine for soothing sore throats.

4.6.2 Taveuni

Two *P. schmeltzi* were seen flying near a *C. reticulata* tree in a flower garden in the morning. There were many different types of flowering plants and *Citrus sinensis* (sweet orange), *Citrus limon* (moli karokaro), *Citrus mitis* (kumquat) and *Euodia hortensis* (uci) of the Rutaceae family in the garden. Opposite the garden was a forested area mainly composed of tall trees, in Sukulu (Tanoa place), Taveuni.

4.6.3 Vanua Balavu (Lau)

One or two individuals of *P. schmeltzi* were sighted near Daliconi Village, Namalata Village and Biotaci Village. All three villages were surrounded by forest and the major nectar source on this island for *P. schmeltzi* was *S. urticifolia* flowers.

Daliconi Village: One male *P. schmeltzi* was seen flying high up in the trees along a foot track leading to the forest, and it` only came down to feed on the *S. urticifolia* flowers in a shaded area. Abundant *S. urticifolia* and *Citrus* plants were seen but no *M. minutum* was sighted in this area.

Namalata Village: Two *P. schmeltzi* were seen flying near the edge of the forest, on top of a small hill, away from the coast. Tall trees and a limestone cliff provided shade to the area. Plenty of *S. urticifolia* and *Citrus* plants were seen but no *M. minutum* was found in this area.

Biotaci Village: One *P. schmeltzi* was seen flying around the village and visiting the red *Hibiscus schizopetalus* (coral hibiscus) flowers near the houses. The forested area was around the village and along the coast.

4.6.4 Kadavu

Along the main road from Vunisea to Solodamu village, twelve *P. schmeltzi* were sighted near the edge of the forested areas and were seen feeding mostly on *L. camara* and *S. urticifolia* flowers. All the butterflies sighted were at the edge of forest, on steep slopes and near streams or creeks.

Solodamu Village: Four *P. schmeltzi* butterflies were seen flying inside the sheltered mangrove swamp, high in the top canopy, near the village. One male *P. schmeltzi* was seen flying at the edge of the Solodamu Bird Forest Reserve - National Trust. At the Solodamu village, there were lots of *S. urticifolia* and *L. camara* plants. No *M. minutum* plants were observed but *Citrus* trees were abundant. On one occasion, a female approached the *C. reticulata* tree but did not touch the leaves and fluttered away inside the mangrove swamp after few seconds. The butterflies mostly flew around the edges of the forest, near hilltops.

4.6.5 Beqa Island and Koro Island

One *P. schmeltzi* was sighted on Beqa Island, in Lalati Village feeding on *Ixora coccinea* flowers by Prof. Randolph Thaman of the University of the South Pacific (verbal communication). Bird Life International (2007) undertook an inventory on the biodiversity of Koro Island and reported that *P. schmeltzi* is present on that island, near coastal forest but no indication of its abundance was given. However, observations by Tokasaya Cakacaka (a field assistant for this study - verbal communication) on June 17, 2009 along the coastal area of Nacamaki from 8 am to 12 pm showed that more than 40 *P. schmeltzi* butterflies were spotted flying along the

coastal area and also in the open grassland. In addition, *P. schmeltzi* was seen feeding on the *S. urticifolia* flowers and many *C. reticulata* plants were present in that area, which could likely be its larval host plant on that island.

On the outer islands (Kadavu, Vanua Balavu and Taveuni), where *P. schmeltzi* butterflies were sighted, there was an abundance of *Citrus* species but no *M. minutum* plants were observed. It was also observed that *P. schmeltzi* butterflies were always found in vicinity of streams or rivers. This probably provided a suitable surrounding environment, as waterways are cool, damp and shady. Also there were fewer obstacles in their flight path as there is sparse vegetation. *P. schmeltzi* inhabits disturbed tropical rainforest areas. It flies high in the rainforest canopy, landing for only a few seconds on each flower. It is also a frequent visitor of flowers in gardens.

To summarise, *P. schmeltzi* were not common, but are found throughout the year in many localities, from coastal forest to hill top forest, in all parts of Fiji. *P. schmeltzi* is most common on the outskirts of medium to thick forest where it mostly frequents the flowers of *S. urticifolia*. However, *P. schmeltzi* has been sighted in less developed places like small villages and big flower gardens.

These findings suggest that *P. schmeltzi* currently occurs at least four localities on the mainland and ten localities on the outer islands. To assess thoroughly the distribution of this species, further studies need to be conducted. The populations of adult *P. schmeltzi* butterflies were estimated at two to four individuals on average in all studied localities, with highest number sighted in Koro Island. *P. schmeltzi* is found in forest areas and shows a preference for habitat near streams and riverbeds. The sightings of *P. schmeltzi* on the outer islands of Fiji in the presence of *Citrus* trees, but no *M. minutum* plants, suggests that the butterfly's larval host plant could be *Citrus* species in absence of *M. minutum.* The areas colonized (Koro–I–Colo, Beqa, Taveuni and Kadavu) are in close proximity to the areas where *P. schmeltzi* is already established and have suitable forested areas, suitable larval host plant and nectar sources. Robinson (1975) states that *P. schmeltzi* is abundant on the Western side of Viti Levu and very common on Vanua Balavu in the Lau group. However, our results show that now only a few individuals are seen on the western side of Viti Levu and it is not so common on Vanua Balavu. The reason is not clear but habitat destruction and predators could be possible factors that have reduced the population size of *P. schmeltzi* in most localities. On the other hand, the reason for the high number of adult *P. schmeltzi* on Koro Island is not known but it could be due to favourable habitat, lack of predators or human disturbance.

At present, *P. schmeltzi* is not classified as an endangered species by the IUCN (Collins and Morris 1985). However, this study shows that they are vulnerable, because even though they are widely distributed in Fiji Islands, they have a restricted range and low numbers. The greatest threat to *P. schmeltzi* butterflies is probably the destruction of their habitat. This is associated with increasing urbanization, agriculture and deforestation. With continuing habitat loss, the outlook for this endemic species is far from bright as many populations will be inevitably pushed to near or actual extinction. The forest at the Vatukarasa study site was cleared to maintain the power lines in September 2008 and all the life stages of *P. schmetlzii* declined at an alarming rate in this area, as their habitat was changed and their larval host plants and nectar sources were destroyed. This study suggests that there could be less than eight flying adults at a particular time in the Vatukarasa study site. Any further decline may push many populations below minimal viable limits (Lehnert 2008). Therefore, it is imperative that *P. schmeltzi* be studied in detail for better management strategies to prevent a genetic bottleneck and a decrease in population size of this endemic species.

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