DIET EFFECT, LIFE TABLE, PHYSIOLOGICAL TOLERANCES, DISPERSAL ACTIVITY AND TOXICOLOGICAL STUDIES OF THE ROVE BEETLE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE)

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DIET EFFECT, LIFE TABLE, PHYSIOLOGICAL TOLERANCES, DISPERSAL ACTIVITY AND TOXICOLOGICAL STUDIES OF THE ROVE BEETLE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE)

BY

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LIST OF ABBREVIATIONS

DW	Desa Wawasan
SP	Sri Pinang
AJ	Ampang Jajar
EY	Egg yolk
CK	Cockroach
DF	Dog food
L1	First larval instar
L2	Second larval instar
DDT	Dichlorodiphynyltrichloroethane
APOP	Adult pre-oviposition period
CP	Cuticular permeability
RH	Relative humidity
TBW	Total body water
SC	Suspension concentrate
MC	Microencapsulated
EC	Emulsifiable concentrate
AI	Active ingredient
KT	Knockdown time

KESAN PEMAKANAN, JADUAL HIDUP, KERINTANGAN FISIOLOGI, AKTIVITI SEBARAN DAN KAJIAN TOKSIKOLOGI KUMBANG ROVE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE)

ABSTRAK

Aspek biologi dan ekologi *Paederus fuscipes* Curtis terutamanya: (1) kesan pemakanan terhadap kecergasan dan perkembangan pembiakan; (2) keupayaan pertumbuhan populasi; (3) kerintangan terhadap kekeringan dan suhu; dan (4) kesan faktor cuaca dan gangguan secara mekanikal terhadap sebaran kumbang dewasa, ditumpukan dalam kajian ini dengan tujuan mendalami pengetahuan bagaimana faktor diatas mempengaruhi infestasi tempat tinggal manusia, dan (5) kajian toksikologi, dijalankan untuk membantu pihak berkuasa merancang program kawalan yang lebih baik.

Jangka hayat selama 42 hingga 43 hari dan penghasilan bilangan telur yang banyak (121 telur bagi seekor betina) ditunjukkan oleh kumbang dewasa yang diberi makanan tinggi protein. Ini menunjukkan sumber protein diperlukan untuk kecergasan dan pembiakan *P. fuscipes* yang optimum. Sebaliknya kumbang dewasa yang diberi makanan tinggi karbohidrat mempunyai jangka hayat yang lebih panjang (dari 64 hingga 74 hari) tetapi kadar pembiakannya berkurangan. Pengambilan makanan tinggi lipid yang mencukupi dilaporkan memanfaatkan pembiakan kumbang, tetapi pengambilan yang berlebihan akan memudaratkan kedua-dua kemandirian dan pembiakan *P. fuscipes*.

Keadaan yang sesuai untuk pembiakan secara besar-besaran, tempoh masa perkembangan bagi peringkat tak matang *P. fuscipes* berjulat antara 17 hingga 19 hari. Dewasa hidup lebih kurang dari 42 hingga 58 hari tanpa mengira jantina, dan

kumbang betina bertelur sebanyak lebih kurang 121 hingga 147 biji sepanjang hayatnya. Dengan purata masa generasi dari 43 hingga 49 hari dan kadar pembiakan bersih dari 40 hingga 45 progeni, populasi meningkat pada kadar 0.07 hingga 0.08 sehari.

Spesies ini berjaya berkembang ke peringkat dewasa pada keempat-empat suhu yang dikaji, 15, 23.5, 28, dan 35˚C, dengan masa perkembangan bagi setiap peringkat pra dewasa menurun selaras dengan peningkatan suhu. Kedua-dua peringkat telur dan larva pertama memerlukan lebih kurang 80 darjah-hari atas pada ambang 10 °C untuk berkembang ke peringkat seterusnya. Dengan kadar mandirian yang tinggi, jangka hayat yang panjang (dari 53 hingga 58 hari), dan kesuburan yang tinggi (127 telur), spesies ini mencapai kadar intrinsik peningkatan yang tertinggi (0.08 sehari) dan purata masa generasi yang terpendek (49 hari) pada suhu 28 °C. Dewasa dan pupa adalah rintang terhadap kekeringan, mencatatkan nilai keterlapan kutikel dari 10 hingga 17 µg cm^{-2} h^{-1} $mmHg^{-1}$ tetapi larva adalah rentan terhadap keadaan kering dengan nilai keterlapan kutikel dari 68 hingga 70 µg cm^{-2} h^{-1} $mmHg^{-1}$.

Aktiviti sebaran *P. fuscipes* menunjukkan dua puncak iaitu, dari bulan Februari hingga bulan April dan dari bulan Ogos hingga bulan Oktober. Pada keseluruhannya, tiada korelasi statistik yang signifikan antara parameter cuaca dan aktiviti sebaran. Namun, aktiviti sebaran dicetuskan terutamanya oleh aktiviti manusia di sawah padi yang bertanggungjawab untuk lebih daripada 60% kevariabelan pada aktiviti sebaran.

Turutan bagi kelajuan kesan membunuh adalah seperti berikut: deltamethrin > imidacloprid > fipronil > fenitrothion. Walaupun deltamethrin menunjukkan tindakan terpantas terhadap *P. fuscipes,* kadar pulih spesies ini selepas

48 jam rawatan adalah sederhana (≈ 25%) bagi jenis permukaan jubin sehingga tinggi (≈ 80%) bagi jenis permukaan papan lapis. Sebaliknya, kematian yang tinggi (hampir 100%) dicatatkan pada *P. fuscipes* 48 jam selepas didedahkan pada jubin yang dirawat imidacloprid. Peratusan rendah sehingga tiada kematian dicatatkan dalam rawatan fenitrothion. Di sebaliknya, fipronil menunjukkan respon toksik terlewat terhadap *P. fuscipes*, dan lebih daripada 80% kematian dicatatkan pada jubin dan papan lapis yang dirawat fipronil.

DIET EFFECT, LIFE TABLE, PHYSIOLOGICAL TOLERANCES, DISPERSAL ACTIVITY AND TOXICOLOGICAL STUDIES OF THE ROVE BEETLE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE)

ABSTRACT

Biological and ecological aspects of *Paederus fuscipes* Curtis namely: (1) effects of diet on the fitness and reproduction development; (2) population growth capacity; (3) desiccation and temperature tolerance; and (4) impact of climatic factors and mechanical disturbances on the adult dispersal, were focused in this study to provide insight into how the above mentioned factors influence the insect infestation into human dominated areas, and (5) toxicological studies were carried out to aid the authorities in planning for a better control programme.

The longevity of 42 to 43 days and substantial numbers of egg laid (121 eggs per female) were recorded in protein-rich diet fed adults. This showed that protein source is a necessity to *P. fuscipes* for optimal fitness and reproduction. This study also showed that carbohydrate-rich diet fed adults had extended life span (64 to 74 days) but the reproductive rate decreased. An adequate intake of lipid diet was reported beneficial to reproduction, but too much in the diet was detrimental to both survival and reproduction in adult *P. fuscipes*.

Under ideal condition for massive breeding, the total development time of the immature stages of *P. fuscipes* ranged from 17 to 19 days. The adults lived for approximately 42 to 58 days with no discrepancies between genders, and the females laid an average of 121 to 147 eggs in her lifetime. With a mean generation time of 43 to 49 days and net reproduction rates of 40 to 45 offsprings, the population increased at a rate of 0.07 to 0.08 per day.

This species successfully developed to adulthood at the four temperatures tested, 15, 23.5, 28, and 35˚C, with development time of each pre-adult stage significantly decreased with increasing temperatures. Both egg and first larval instar required approximately at least 80 degrees-day above a threshold of approximately 10 °C to develop to the subsequent stage. With high survival rate, longer life span (53 to 58 days), and high fecundity (127 eggs), this species achieved the highest intrinsic rate of increase (0.08 per day) and shortest mean generation time (49 day) at 28 °C. The adults and pupae are tolerant to desiccation, registering a cuticular permeability value ranging from 10 to 17 µg cm^{-2} h^{-1} $mmHg^{-1}$, but the larvae are susceptible to dry condition with a cuticular permeability value 68 to 70 µg cm^{-2} h^{-1} $mmHg^{-1}$).

The dispersal activity of *P. fuscipes* showed two peaks, i.e., from February to April and August to October. Overall, there was no statistically significant correlation between climatic parameters and dispersal activities. However, the dispersal activity was primarily triggered by human activites in rice field that accounted for more than 60% of the variability of the dispersal activity.

The relative order of the speed of the killing effects was as follows: deltamethrin > imidacloprid > fipronil > fenitrothion. Although deltamethrin showed the fastest action against *P. fuscipes,* the recovery rate of this species at 48 hours post-treatment was moderate (≈ 25%) on tile surface to high (≈ 80%) on plywood surface. In contrast, high mortality (almost 100%) was recorded on imidacloprid-exposed *P. fuscipes* on tile surface at 48 hours post treatment. A low percentage to no mortality was recorded in the treatment of fenitrothion. On the other hand, fipronil showed delayed toxic response against *P. fuscipes* and more than 80% mortality was recorded on fipronil-treated tile and plywood.

CHAPTER ONE

GENERAL INTRODUCTION

In 1891, personnel at the Anjet-Kidoel lighthouse in Java, Indonesia were found suffering from dermatitis when came into contact with ant-like beetle that was later identified as *Paederus* (Vorderman 1901). Since then, the medical importance of *Paederus* spp. has caught the public attention especially when the beetle infested human settings. In fact, *Paederus* are beneficial to agriculture owing to their predation on insect pests. However, they are attracted to incandescent and fluorescent lights in residential areas. Inadvertently, humans come into contact with these insects which can cause dermatitis linearis when the beetles are crushed on the skin (Frank and Kanamitsu 1987). Outbreak cases were reported throughout the world (Plate 1.1) from the tropics to temperate countries like Malaysia (Mokhtar et al. 1993, Rahmah and Norjaiza. 2008), India (Isaacs 1933, Strickland and Roy 1939, Somerset 1961, Verma and Agarwal 2006, Gnanaraj et al. 2007), Vietnam and Laos (Genevray et al. 1934), Thailand (Papasarathorn et al. 1961, Wongsathuaythong et al. 1977), Sri lanka (Kamaladasa et al. 1997), China (Jin 1990, Huang et al. 2009), Japan (Armstrong and Winfield 1969), Australia (Todd et al. 1996, Banney et al. 2000), Europe (Borroni et al. 1991, Gelmetti and Grimalt 1993, Croft et al. 1996, Sendur et al. 1999), Korea (Kim et al. 1995), Taiwan (Miyamoto 1934, Wang et al. 1969, Wang 1971), Iran (Zargari et al. 2003, Nikbakhtzadeh and Tirgari 2008), to name a few. In Malaysia, outbreak cases are increasingly high especially in residential areas adjacent to rice fields (data provided by Seberang Perai Municipal Council, Penang).

There are several factors that might play a role in influencing the infestations. First, high rate of population increase (Sakai et al. 2001). Under ideal conditions for

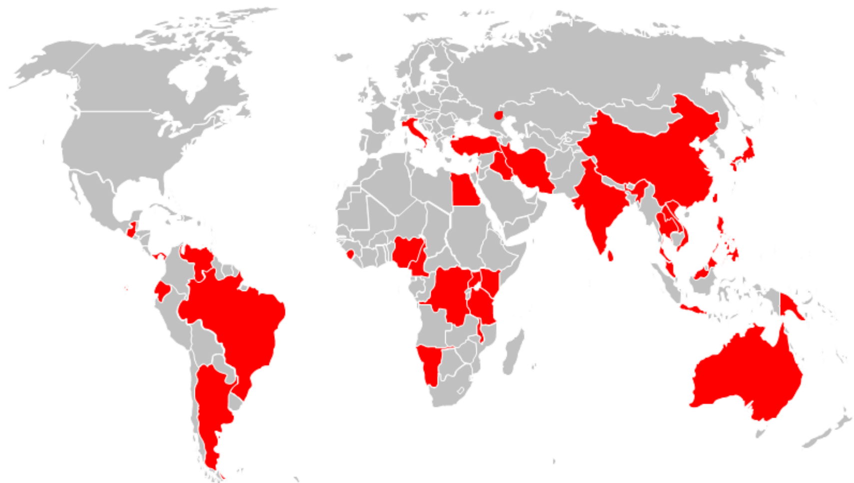

Plate 1.1 Worldwide distribution of *Paederus* species (in red mark).

massive breeding, insect population might attain a spectacular size that could facilitate infestation if the population is not suppressed. Life table is one approach to estimate the population growth rate of an insect (Chi 1990, Sakai et al. 2001). This is important especially when studying pest population ecology because knowledge generated from the life table is crucial when planning for possible control programmes (Metcalf and Luckmann 1982). Although it may not reflect the insect actual population dynamic in natural conditions, it provides information about the optimal development and reproduction capability. Second, high tolerance of insect towards abiotic stresses as this reflects the insect's ability to adapt to new environments (Lodge 1993). This phenotypic plasticity characteristic also determines the insect geographical distribution. Third, suitability of abiotic factors especially climatic factors in influencing insect dispersal. Numerous studies reported the pronounced role of these factors on insect dispersal (Isard et al. 1999, Elliot et al. 2000, Neoh and Lee 2009). In *Paederus* spp., flight is typically scheduled during humid and rainy days to minimize the risk of desiccation during flight (Frank and Kanamitsu 1987). Last but not least, habitat disturbances that pose a serious threat to the insect, and trigger insect dispersal that results in infestation of human settings (Holway 1998). However such information is rarely reported in *Paederus* spp. Thus, it is important to understand their population biology and ecology to identify the underlying factors that trigger their dispersal to residential areas.

In this study, the biological aspects and management of *Paederus fuscipes* Curtis were evaluated with the following specific objectives:

1. To examine the fitness and reproductive development of *P. fuscipes* under different diet regimes.
2. To determine the population capacity of *P. fuscipes* using life table analysis.

3. To identify *P. fuscipes* tolerance to dessication, the relationship of every life stage with water to determine cuticular permeability, and their survival under different temperatures.
4. To identify the impacts of environmental factors and rice field activities on dispersal of adult *P. fuscipes* into human settlements.
5. Insecticide residual testing against adult *P. fuscipes.*

CHAPTER TWO

LITERATURE REVIEW

2.1 *Paederus* in general

Of 50, 000 staphylinids species distributed worldwide (Grebennikov and Newton 2009), only the genus *Paederus* of the paederine staphylinid subtribe Paederina (Coleoptera: Staphylinidae) is notoriously known to cause dermatitis linearis on human skin. *Paederus* constitutes one of the largest groups in the subtribe Paederina, with at least 650 described species distributed worldwide (Willers 2003). Originally, the subtribe Paederina consisted of 14 genera (*Paederidus* Mulsant and Rey, 1878, *Allopaederus* Fagel, 1958, *Madecapaederus* Fagel, 1958, *Pachypaederus* Fagel, 1958, *Oreopaederus* Fagel, 1958, *Ctenopaederus* Fagel, 1958, *Eupaederus* Scheerpeltz, 1957, *Diplopaederus* Scheerpeltz, 1957, *Oncopaederus* Scheerpeltz, 1957, *Megalopaederus* Scheerpeltz, 1957, *Lobopaederus* Scheerpeltz, 1957, *Parameropaederus* Scheerpeltz, 1957, and *Uncopaederus* Korge, 1969), which has been further organized into 11 subgenera, namely *Anomalopaederus* Scheerpeltz, 1966, *Eopaederus* Scheerpeltz, 1957, *Gnathopaederus* Chapin, 1927, *Harpopaederus* Scheerpeltz, 1957, *Heteropaederus* Scheerpeltz, 1957, *Nepalopaederus* Scheerpletz, 1976, *Oedopaederus* Scheerpeltz, 1957, *Oreinopaederus* Scheerpeltz, 1957, *Paederus s. str.*, Poederomorphus Gautier des Cottes, 1862, *Dioncopaederus* Scheerpeltz, 1957, and *Pseudopaederus* Bernhauer, 1915 (Li and Zhou 2009).

Paederus is holometabolous comprising of four life stages: egg, larva, pupa and adult. Adult *Paederus* vary from 3 to 25 mm in length depending on the species. The beetles are slender with short elytra and sclerotized abdominal segments. They are identifiable by the orange and dark coloration, with the head and abdominal apex black in colour; and the elytra metallic blue or green in colour. Some species are entirely orange. The eggs are yellowish white and spherical, measuring 0.5 to 1.0 mm in diameter. The larvae are campodeiform with sclerotized head and large, sickle-shaped mandibles that resemble those of the adults. The pupae are exarate and unsclerotized (Frank and Kanamitsu 1987).

The development time of immature stages vary from a few days to a few weeks depending on the species. The females oviposit eggs singly on moist substrates. The egg incubation time ranges from 3 to 19 days (Isaacs 1934, Ramírez 1966, Verma et al. 1969, Manley 1977, Tawfik and Abouzeid 1977). Unlike other staphylinids, *Paederus* have two larval instars (Papasarathorn et al. 1961, Manley 1977, Frank and Kanamitsu 1987). The development time of the first larval instar (L1) ranges from two to four days, and 5 to 22 days for the second larval instar (L2) (Kurosa 1958, Ramírez 1966, Tawfik and Abouzeid 1977), while the development time of the pupal stage ranges from 3 to 14 days (Isaacs 1934, Ahmed 1957, Kurosa 1958, Ramírez 1966). Both the eggs and larvae are highly susceptible to desiccation (Frank and Kanamitsu 1987). The incubation period of immature stages increased with decreasing temperatures (Frank and Kanamitsu 1987).

Paederus is well adapted to habitats associated with moist environments like freshwater lakes, marshes, riverine floodplains, riverbanks, crop fields, to name a few (Frank and Kanamitsu 1987, Li and Zhou 2008). Similar to other staphylinids, this genus is a polyphagous predator (Frank and Kanamitsu 1987). Species such as *P. alfierii* Koch, *P. ilsae* Bernhaurt, *P. melampus* Erichson, *P. fuscipes*, *P. alternans* Walker, *P. cruenticollis* Germar, *P. columbinus* Laporte that are found to inhabit crop fields, are beneficial to agricultural systems as they are predators to agricultural pests (Fróes 1934, Genevray et al. 1934, Dallas 1935, Anon 1942, Pujatti 1947, Papasarathorn et al. 1961, Ibrahim 1962, Fain 1966, Verma et al. 1969, Awadallah and Khalil 1979, Shukla et al. 1983, Zhu 1984, Frank and Kanamitsu 1987). However, contact with these species causes serious health impact in humans, resulting in dermatitis linearis (Frank and Kanamitsu 1987). Few cases of dermatitis linearis involving farmers during crop cultivations were reported (Dallas 1935, Tálamo 1946). However, beetle infestations in human settlements are of increasing concern among the public (Gordon 1925, Lewis 1958, Papasarathorn et al. 1961, Magalháes 1964, Wang et al. 1969, Wongsathuaythong et al. 1977, Mhalu and Mandara 1981, Méndez and Iglesias 1982, Jin 1990, Mokhtar et al. 1993, Zargari et al. 2003, Nikbakhtzadeh and Tirgari 2008, Rahmah and Norjaiza. 2008, Huang et al. 2009).

2.2 *Paederus* as beneficial insect to the agriculture system

Generalist arthropod predators play important roles as natural enemies of agricultural pests. The family Staphylinidae is among the coleopteran that constitutes a major and ecologically important group of arthropod predators in arable land (Dennis et al. 1990, Winder 1990, Andersen 1992). The assemblages of these generalist predators effectively suppress both the indigenous and exotic phytophagous pests in crop fields (Symondson et al. 2002, Thorbek and Bilde 2004).

Adults and larvae *Paederus* are polyphagous predators of arthropod insects (Kurosa 1958, Frank and Kanamitsu 1987). In Henan, China, it was estimated that average numbers of *P. fuscipes* present in soybean plantation was approximately five adults per plant (Zhu 1984). In Bangkhon, Thailand, approximately 69,000 and 110,000 *P. fuscipes* per hectare resided in sweet potato and maize (*Zea*) fields, respectively (Papasarathorn et al. 1961). In Egypt, the population of *P. alfierii* in cotton fields were as high as 288,000 per hectare in Shebin el Kom (Ibrahim 1962), and 34,500 per hectare in Nile delta (Bishara 1934). The high population densities of these species are beneficial to the agriculture systems. For example, adult *P. alfierii* was reported to consume approximately 10 to 20 immature stages of cotton leafworm, *Spodoptera littoralis* Boisduval, per day (Kamal 1951). In Indonesia, high populations of the indigenous *P. fuscipes* was reported to play comparatively similar role as coccinellid in suppressing the exotic population of soybean aphid *Aphis glycines* Matsumura in soybean crops aged 40 days (van de Berg et al. 1997).

Paederus fuscipes are commonly found to inhabit rice fields of most countries of Asia (Kuwayama 1932, Pujatti 1947, Kurosa 1958, Manley 1977, Shukla et al. 1983, Frank and Kanamitsu 1987). Nonetheless, *P. melampus* and *P. alternans* are the predominant species in Southern India and Vietnam, respectively (Genevray et al. 1934, Pujatti 1947). These species act as important biological control agents of many crop pests in rice fields such as the rice borer, *Schoenobius incertellus* Walker (Shiraki 1937), rice leaf beetle, *Lema oryzae* Kuwayama (Kuwayama 1932, 1935), green rice leafhopper, *Nephotettix cincticeps* Uhler (Kang and Kiritani 1978), brown planthopper, *Nilaparvata lugens* (Stål) (Lim et al. 1978a, Lim et al. 1978b, Ooi et al. 1978), whitebacked planthopper, *Sogatella furcifera* (Horvath) (Shukla et al. 1983), and rice leaf folder, *Cnaphalocrocis medinalis* (Guenée) (Yuen 1982). Apart from rice fields, *P. fuscipes* are also found to prey upon pests in bean, cotton, maize and tobacco fields in China (Zhu 1984).

In Egypt, adults *P. alfierii* prey upon legume aphid, *Aphis laburni* Kaltenback, black cutworm, *Agrotis ipsilon* Hufnagel, and cotton leafworm, *S. littoralis* in clover fields; cotton thrips, *Thrips tabaci* Lindeman, springtail, *Lepidocyrtus incertus*

Handschin, cotton aphid, *Aphis gossypii* Glover, spiny bollworm, *Earias insulana* Boisduval, and pink bollworm, *Pectinophora gossypii* Saunders in cotton fields; and maize aphid, *Rhopalosiphum maidis* Fitch, corn borers such as *Sesamia cretica* Lederer and *Chilo Agamemnon* Bleszynski in maize fields (Tawfik et al. 1976). *Paederus spp.* are also found to feed on insect pests in other crop fields such as vegetable plantations, banana plantations, potato plantations and sugarcane plantations (Silva 1912, Fróes 1934, Dallas 1935, Baliña 1939, Anon 1942, Fain 1966, Frank and Kanamitsu 1987).

2.3 Medical importance of *Paederus*

Adult *Paederus* are attracted to incandescent and fluorescent lights (Baba 1943, Scott 1950). Thus, adult flights are restricted to night and congregated around the fluorescent lights in human dominated areas. Inadvertently, human comes into contact with this beetle. This beetle neither bite nor sting. However, accidental brushing against or crushing the beetle provokes the release of its toxic haemolymph called paederin, the potent vesicant that causes dermatitis linearis on human skin (Frank and Kanamitsu 1987).

Clinically, dermatitis linearis is a necrotic blister that is characterized by linear vesiculobullous lesions on erythematous bases (Plate 2.1) and pruritus (Frank and Kanamitsu 1987, Nicholls et al. 1990, Zargari et al. 2003). This clinical appearance is sometimes confused with liquid burns, herpes simplex, herpes zoster, periorbital cellulitis, and acute allergic contact dermatitis (Kamaladasa et al. 1997).

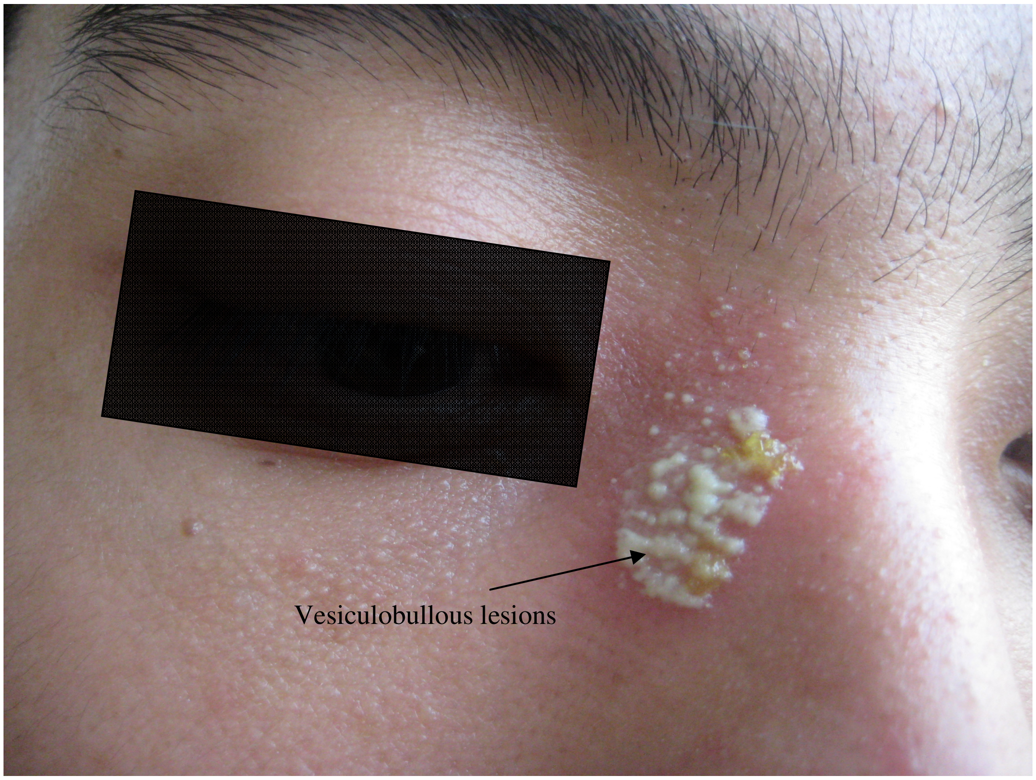

Plate 2.1 Dermatitis linearis with vesiculobullous lesions.

It is a self-healing dermatitis that occurs within 24 to 48 h after contact, and takes more than one week to heal (George and Hart 1990, Vegas et al. 1996). Complications such as post-inflammatory hyper-pigmentation, secondary infections, and extensive exfoliating and ulcerating dermatitis might occur if proper care is neglected (Frank and Kanamitsu 1987, Todd et al. 1996, Zargari et al. 2003). The lesions occur predominantly on exposed skin especially face and neck (Sendur et al. 1999). However, ocular reaction due to secondary transfer of the vesicant from the skin by fingers is common (Frank and Kanamitsu 1987, Zargari et al. 2003).

Paederus dermatitis was first reported at Anjet-Kidoel lighthouse in Java, Indonesia in 1891 (Vorderman 1901). Since then, the epidemics resulted from adult flight to human dominated areas have been receiving increasing attention. The outbreaks are geographically widespread, though such incidents mostly occurred in the tropics (Frank and Kanamitsu 1987). For example, *Paederus* dermatitis is common in Iran which is predominantly caused by *P. fuscipes* in the northern part (Zargari et al. 2003), while *P. ilsae* and *P. iliensis* Coiffait are the major dermatitis causing agents in southern Iran (Nikbakhtzadeh and Sadeghiani 1999, Nikbakhtzadeh and Tirgari 2008). In India, *P. fuscipes*, *P. irritans* Chapin, *P. sabaeus* Erichson, and *P. himalayicus* Bernhauer are the culprits for the dermatitis suffered by soldiers deployed near the agricultural land in Madhya Pradesh and Punjab (Verma and Agarwal 2006). In central coastal Queensland of Australia, *P. cruenticollis* and *P. australis* Guérin-Méneville were the reason for the 250 outbreak cases reported in late 1998 (Banney et al. 2000). These incidences are reported to occur during warmer months. In Malaysia, *P. fuscipes* are reported as the dermatitis causing agents for the outbreak cases in Kelantan (Mokhtar et al. 1993), Terengganu (Rahmah and Norjaiza. 2008), and Penang (Table 2.1).

Table 2.1 Cases of adult *P. fuscipes* infestation from 2004 to 2010 in mainland Penang.

Year	Number of cases												Total
	Jan	Feb	Mac	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2004	0	0	4	0	0	0	0	1	42	0	0	0	47
2005	0	0	0	0	0	0	0	17	38	16	0	1	72
2006	0	6	1	1	0	0	2	3	3	1	0	0	17
2007	0	1	4	2	0	0	1	2	6	1	1	0	18
2008	0	0	1	1	0	0	2	4	10	1	0	2	21
2009	0	0	6	5	0	0	0	3	12	0	1	0	27
2010	0	3	2	1	2	0	0	19	NA	NA	NA	NA	31
total	0	10	18	10	2	0	5	49	115	19	2	3	233

Provided by Seberang Perai Municipal Council, Penang, Malaysia

NA, not available

2.4 *Paederus fuscipes* Curtis

Paederus fuscipes is among the six species that are categorized in the subgenus *Heteropaederus* Scheerpeltz, 1957 (Frank 1988). Compared to other *Paederus* spp., *P. fuscipes* is widely distributed, extending its distribution from central Asia to west to the British Isles, east to Japan, and southeast to Australia (Frank and Kanamitsu 1987). In Malaysia, the species predominantly inhabits rice fields (Manley 1977).

2.4.1 Identifying characters

Adult *P. fuscipes* is six to seven mm in length (Plate 2.2). The head, pronotum and abdominal segments I to IV are orange in colour, while the elytra is metallic blue, and the abdominal segments V and VI are black in colour. The appendages are partly orange and black. For example, the antennae are black with the basal two to four segments colored orange. The mandibles and maxillary palps are orange, with the apical half of penultimate segment of the maxillary palps colored black. The front legs are predominantly orange with darkening around the knees. The darkening is especially apparent at the base of the femur of the hind legs. The adult can be distinguished by its particularly elongated elytra which are wider than the pronotum, and the six abdominal segments (Isaacs 1934, Lott and Anderson 2011). The sixth sternite (Plate 2.3) of the male possesses narrow median excision, while the corresponding sternite of the female is complete (Isaacs 1934).

Plate 2.2 Adult *P. fuscipes*.

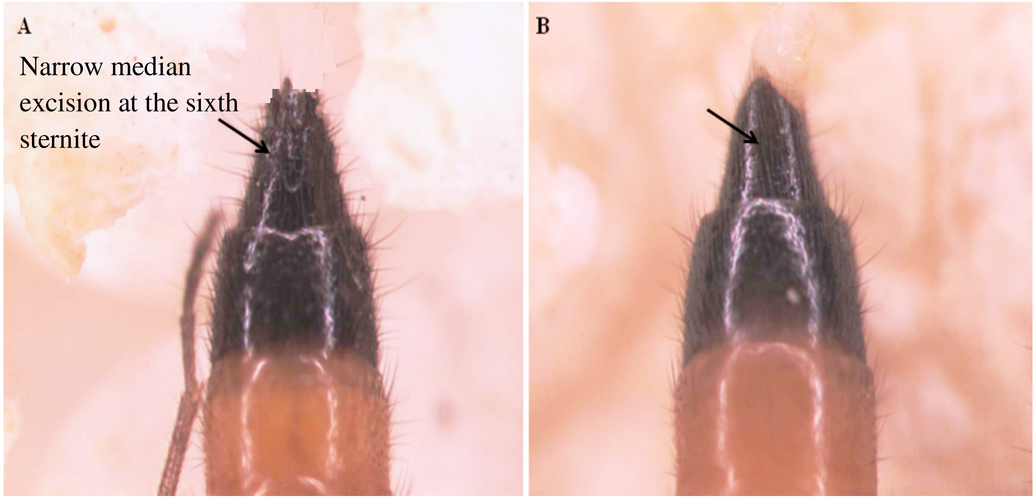

Plate 2.3 Ventral view of the posterior extremity of *P. fuscipes* abdomen (sixth sternite). A) adult male, and B) adult female.

The egg (Plate 2.4A) is yellowish white to light brown in color. It is spherical with approximately 0.7 mm in diameter. The L1 (Plate 2.4B) is approximately 2.0 mm in length. The larva consisted of ten abdominal segments with a pair of chitinous single-jointed cerci at the ninth segment. The tenth segment is short and appears between the cerci. There are few setae on the body of the larva. The L2 (Plate 2.4C) is darkening in color. The head is yellow and the thoracic tergites are brownish black. The cerci appear as straight, two-jointed at the ninth segment. The pupa (Plate 2.4D) is white to creamy yellow in color. It is approximately 4.0 mm in length. The head is bent downwards and held close to the thorax. It is exarate and unsclerotized (Isaacs 1934).

2.4.2 Life cycle

The beetle *P. fuscipes* undergoes approximately two to three weeks of complete metamorphosis (holometabolous) from egg to adult (Isaacs 1934, Manley 1977). In order to ensure fecundity and fertility succession, the adult undergoes repeated copulations throughout its lifetime. Each copulation lasts for approximately 20 minutes (Isaacs 1934).

The mated female lays approximately six eggs per day, singly on a moist substrate. The egg takes approximately two to four days to hatch into the larval stage. Under ideal condition with abundance of food, the larva undergoes one moulting process and takes approximately one to two weeks before pupation. The pupa incubates for approximately three to four days before emerging as adult (Isaacs 1934, Manley 1977). The adult has a long life span of approximately two to three months (Manley 1977).

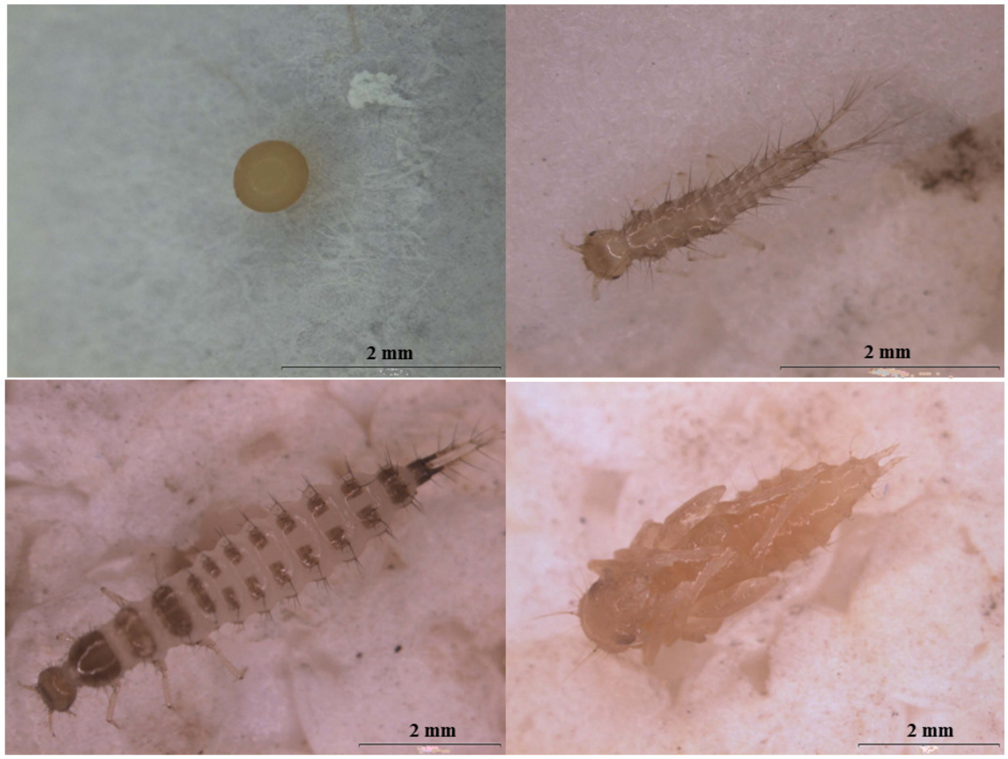

Plate 2.4 Immature stages of *P. fuscipes*: A) egg, B) first larval instar, C) second larval instar, and D) Pupa.

2.4.3 Life table

Previous studies on the biology and ecology of *Paederus* spp were mainly on the life cycle, but no studies have been reported on the population growth parameters. Life table is a fundamental study on insect population ecology that gives the most complete description on biological development, reproduction, and population demographic parameters to estimate the insect population growth capacity (Chi 1990). Insect life table is often carried out under control laboratory condition, so, it may not reflect the actual insect population dynamics in natural conditions because insect can be subjected to other environmental harshness, both biotic and abiotic. However, it gives information about the optimal biological potential for development and reproduction. Traditional age-specific life table focused only on the female population and ignored the variable developmental stage of each individual (Lewis 1942, Leslie 1945, Birch 1948, Southwood 1978). Developmental rate of the different stages of each individual is different (Istock 1981), so it is crucial to consider these differences when studying life table because omission of these data could lead to an inaccurate estimation of the dynamics of population growth (Chi and Yang 2003). So, Chi (1988) developed an age-stage, two-sex life table theory to resolve these problems.

2.4.4 Habitats

Similar to other *Paederus* spp., *P. fuscipes* inhabits damp habitats. It is commonly found in riverbanks, marshes, and irrigated crop fields (Frank and Kanamitsu 1987). In India (Isaacs 1933), this species is found to reside along river banks, a few inches above the edge of the river and stagnant water channels like drains, pools, and lakes. The adults are commonly found crawling on the damp porous soil under the vegetation, and hiding in the crack and crevices.

In Malaysia (Manley 1977), this species is commonly found in the rice fields. In irrigated fields, adults reside among the tillers during warmer days, but actively climb down the foliage during cloudy and rainy days. The larvae are also found foraging among the tillers of rice plants. During the rice growing season, the adults are found foraging food and shelter in the damp porous soil among plant roots. At night, they fly actively between rice plants.

In some parts of Europe, this beetle can be found in wet mires, salt-marsh and sandy riverbanks (Lott and Anderson 2011). Although *P. melanurus* is found to be the predominant species in Northern Italy, a few species of *P. fuscipes* inhabit the edges of lakes (Focarile 1964).

2.4.5 Food

Both the adults and larvae of *P. fuscipes* are aggressive polyphagous predators (Isaacs 1934, Kurosa 1958, Manley 1977, Frank and Kanamitsu 1987). Not only do the adults prey on any insects that are small like soil nematodes, flies larvae, moths, phytophagous insects such as leafhoppers, and etc. (Isaacs 1934, Kurosa 1958, Manley 1977), they also feed on algae, decaying vegetables, and animal matters (Isaacs 1934). Apart from that, the adults reportedly feed on carabids beetles that served as natural enemies for the larvae and pupae of *P. fuscipes* (Kurosa 1958). The larvae feed on tadpoles, fly larvae and decaying matters (Isaacs 1934).

2.4.6 Natural enemies

Although *P. fuscipes* are predators of agriculture pests, the immature stages are usually vulnerable to several invertebrate predators. For example, the larvae are preyed upon by carabid beetles and spiders from the genus *Lycosa* (Kurosa 1958), and some arthropods such as soil mites and carabid larvae are reported to preyed upon larvae and pupae of *P. fuscipes* (Isaacs 1934). The parasitoids exploit nutrient from the hosts (Askew 1971) and cause drastic changes in the host's behaviour and physiology, like feeding, movement, development routine activity, etc. (Trabalon et al. 2000, Brodeur and Boivin 2004, Sze et al. 2008). Though immature stages are the sedentary stage that are targets for parasitism (Stireman et al. 2006).several studies have documented that adult *Paederus* were infected by fungus (e.g. *Laboulbenia cristata* Thaxter), mites and, nematodes (Ito 1934, Ishikawa 1952, Kurosa 1958, Frank 1982). Vertebrate predators like frogs, toads, lizards, and birds are reported to prey upon the *Paederus*. However, the effect of the toxin caused on these predators in the same way as mammals is still unclear (Frank and Kanamitsu 1987).

2.4.7 Distribution and abundance

In temperate countries, the fluctuating climatic factors are usually the cause for the fluctuation in population density of *P. fuscipes* in its habitat. In Northern India and central Japan (Nawa 1925, Isaacs 1934), this species is inactive and undergoes diapause during winter. Copulation begins as soon as winter is over when weather turns warm. Under ideal environmental conditions as well as high food availability, the rapid breeding renders an increase in the insect population density which reaches its peak in the late spring or early summer until fall. On the other hand, the breeding season in Southern Japan is extended (Yamamoto 1935), while this species not present in cold and mountainous areas like Northern Japan (Kurosa 1958). This clearly shows the capability of the temperate-zone species to overwinter during winter and massively breed in the warmer months to maintain the population (Frank and Kanamitsu 1987).

In the non-seasonal tropics, the breeding season of this species appears to be rainfall dependent. (Papasarathorn et al. 1961, Frank and Kanamitsu 1987). Sufficient amount of rain aids in rapid breeding, but heavy rain results in population suppression. The flooded habitat due to heavy rain drowns the immature stages, thus renders unsuitable the breeding site for *P. fuscipes* and chases the adults away from its habitat. In Malaysia with the mean annual rainfall of approximately 2,670 mm distributed evenly throughout the year (data from Malaysian Meteorological Department), the population density in rice fields is not climatic dependent. However, the abundance of *P. fuscipes* is associated with agricultural landscape and vegetation density. The species is abundant during the rice growing season, but decreases drastically during harvesting (Manley 1977). Not only do the cultivation activities disrupt the breeding habitats of the species by disturbing the vegetation structure (Topping and Sunderland 1994, Halley et al. 1996, Thomas and Jepson 1997, Kromp 1999, Lee et al. 2001, Thorbek and Bilde 2004), the decreased in prey availability (Wallin and Ekbom 1994) due to intensive crop cultivations posed a serious threat to these insects in the field. Thus, adults migrate to adjacent less disturbed habitat like rice field margins or riverbanks.

2.5 Adult dispersal

Arthropod predators are predominantly day-flyers, presumably due to easy food access during the daytime (Lewis and Taylor 1964). However, adult flight of *P.*

fuscipes is periodic which occurs only after dusk (Hanna and Hamad 1975). Presumably, the outdoor incandescent light plays the main factor affecting the nocturnal flight of this insect, thus initiating insect dispersal to resident areas (Baba 1943, Scott 1950).

The flight seasons of this species vary with locations. In temperate regions, flight events occur during warmer months (Frank and Kanamitsu 1987). In Japan, the flights are scheduled from April to October and peaked during the summer (Nishihara 1939, Soeda 1950). In Italy, however, the high population production during the summer renders massive flight in the autumn (Baccaredda 1935, Castelli 1935). In contrast, the adult flight in the tropics is postulated to occur throughout the year with some sporadic small flights occurring beyond the peak season, as evident from the complaint cases of adult infestation-prone residential areas (Table 2.1). However, there is an almost complete lack of experimental evidence concerning the flight activity of *P. fuscipes* in the tropics.

Undoubtedly, both abiotic, the exogenous factors, and biotic, the endogenous factors, are reported to influence insect flight or dispersal (Tuda and Shima 2002). Apart from that, other environmental aspects such as habitat disturbances should also be factored in.

2.5.1 Abiotic factors

The initiation and synchronization of insect flight activity is associated with climatic factors (Williams 1961, Taylor 1963, Johnson 1969, Abrol 1991, Peng et al. 1992, Isard et al. 1999, Elliot et al. 2000, Edde et al. 2006), especially temperature and rainfall. Temperature influences the flight amplitude by influencing insect physiological activity (Corbet 1999, Kaspari et al. 2001). This is clearly showed from the substantial flights of adult *P. fuscipes* that occurred during the warmer months in temperate regions (Frank and Kanamitsu 1987).

Rainfall and moisture conditions favor flights of most of the small insects as high humidity prevents them from desiccation during flight (Baccaredda 1935, Pickel 1940, Kaspari 1993). In adult *Paederus*, the exposed soft sclerotized thorax during flight is reported to pose a risk of desiccation. Thus, adult flight was typically restricted to rainfall periods within the warmer months (Kurosa 1977, Frank and Kanamitsu 1987). The fact is in agreement with observations on the high incidences of dermatitis linearsis caused by flying *Paederus* during the rainy season in Africa (Roberts 1942, Service 1963), Europe (Castelli 1934, Baccaredda 1935), Asia (Pujatti 1947, De Leon 1952, Armstrong and Winfield 1969), and Australia (McKeown 1951, Joyce 1952). However, heavy rainfall may be detrimental to the flight activity as well as foraging activity of *Paederus* (Isaacs 1934, Papasarathorn et al. 1961).

Wind can be an important factor in insect dispersal (Byers 2000, Williams et al. 2007). However, up to date, no study on the effect of wind on the dispersal of *Paederus* spp. has been reported.

2.5.2 Biotic factors

Biotic factor such as density of both prey or predator in nature is rarely evaluated (Comins et al. 1992, Travis and French 2000, French and Travis 2001), but their influence on the dispersal of arthropod predators should not be ruled out (Tuda and Shima 2002).

Adult *P. fuscipes* are among the most polyphagous predators of crop pests. Prey-predator system in the crop fields is impeded due to intensive crop management activities that disrupt the habitat of phytophagous arthropods (Topping and Sunderland 1994, Halley et al. 1996, Thomas and Jepson 1997, Kromp 1999, Lee et al. 2001, Thorbek and Bilde 2004). Due to the lack of food prey, *P. fuscipes* will disperse to adjacent less disturbed habitat for refuge and food.

2.6 Physical and chemical control of *Paederus* infestation

Physical control constitutes methods without using any chemicals, but minimizing the quantity of the pests in the infestation-prone residential areas. These include traditional physical methods such as voiding the pests crawling to houses by using window and door screens, and mosquito netting (Méndez and Iglesias 1982). The reduction in the number and intensity of lights used at night is another approach to reduce the number of the pests infesting human settings (Mhalu and Mandara 1981).

Chemical control such as insecticide application in the natural habitats of *Paederus* was reported to reduce the population density of *Paederus* (Isaacs 1933, Hafez 1960, Papasarathorn et al. 1961, Lim et al. 1978b). However, this approach conflicts with agricultural interests as *Paederus* served as biological control agents of agricultural pests. Moreover, the method may also expel the insects and exaggerate the insect dispersion to human settings. Thus, chemical control in infested human settings is the only remedy to the problem. Thermal fogging and direct chemical spraying using Pesguard FG 161 (d-tetramethrin 4.4% w/w and cyphenothrin 13.2% w/w) were deployed by the public health and municipal authorities in Malaysia to treat *P. fuscipes* infestation in human settings, but in most cases it provided only partial or temporary suppression. The insect invasion generally resurged in the days following spraying.