# ECOLOGY, DISTRIBUTION AND BEHAVIOUR OF ROVE BEETLE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE) IN RELATION TO HUMAN SETTINGS

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# ECOLOGY, DISTRIBUTION AND BEHAVIOUR OF ROVE BEETLE, *Paederus fuscipes* CURTIS (COLEOPTERA: STAPHYLINIDAE) IN RELATION TO HUMAN SETTINGS

by

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## ABSTRAK

*Paederus fuscipes* Curtis telah mendapat perhatian yang luar biasa sejak kebelakangan ini kerana ia menyebabkan luka kulit yang teruk pada manusia di negara-negara tropika. Kajian ini memberi tumpuan kepada aspek biologi dan tingkah laku, interaksi dengan premis kediaman manusia dan pemencilan bakteria yang berkaitan dengan *P. fuscipes*. Dalam kajian interaksi pemangsa-mangsa, *P. fuscipes* menunjukkan tindak balas fungsi Jenis II untuk semua spesis mangsa. Pada kepadatan mangsa yang tinggi mereka lebih banyak cenderung pada *Recilia dorsalis* Motschulsky. Antara spesies mangsa, *R. dorsalis* dan *Nilaparvata lugens* Stål biasanya disukai oleh *P. fuscipes* berbanding *Nephotettix virescens* Distant kerana ciri-ciri badannya yang kecil dan lembut. Ini menunjukkan bahawa *P. fuscipes* adalah pemangsa yang cekap terhadap mangsa yang lebih kecil, dan amat berguna dalam mengawal perosak serangga semasa peringkat awal semaian padi. Walaupun bermanfaat dalam agro-ekosistem, *P. fuscipes* semakin terkenal sebagai perosak bandar di kawasan penduduk manusia. Kajian ini menunjukkan populasi *P. fuscipes* meningkat pada bulan-bulan yang lebih panas dan lembap terutamanya semasa luar musim padi. Ini secara tidak sengaja menyebabkan jumlah infestasi yang paling besar dalam premis kediaman manusia, terutamanya semasa peringkat penuaian padi. Aktiviti penerbangan *P. fuscipes* memuncak dari 2045 h, dengan suhu ambang antara 25-27 °C, dan kelembapan relatif 84-94% RH. Kebanyakan aktiviti penerbangan berlaku pada malam tanpa angin, tetapi *P. fuscipes* mampu terbang di keadaan yang

sedikit berangin. Kajian semasa menunjukkan bahawa pencahayaan terang yang dihasilkan dari premis perumahan merupakan faktor tarikan kepada penyebaran *P. fuscipes*. Selain itu, penduduk yang tinggal di tingkat atas pangsapuri bertingkat tinggi amat terdedah kepada serangan kumbang terutamanya semasa peringkat penanaman dan penuaian padi. Warna hijau dan biru yang dipancarkan oleh lampu buatan manusia didapati sangat menarik kepada kumbang *P. fuscipes*. Oleh itu, di hipotesiskan bahawa tarikan *P. fuscipes* terhadap lampu putih daripada premis kediaman manusia di sebabkan oleh warna hijau dan biru tersebut. Oleh itu, sumber cahaya yang mengeluarkan warna kuning atau merah gelombang cahaya disarankan untuk pencahayaan untuk mengelakkan serangan *P. fuscipes* dalam tetapan manusia.

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## ABSTRACT

*Paederus fuscipes* Curtis has garnered tremendous interest in recent years because it causes nasty skin lesion in humans in tropical countries. This study focuses on the biological and behavioural aspects, the interactions with human residential premises and the isolation of bacteria associated with *P. fuscipes*. In the study of predator-prey interaction, *P. fuscipes* showed a Type II functional response for all prey species. At the high prey density they consumed predominantly more on *Recilia dorsalis* Motschulsky. Among the prey species, *R. dorsalis* and *Nilaparvata lugens* Stål were commonly preferred by *P. fuscipes* as compared to *Nephotettix virescens* Distant due to their small and soft body characteristics. This revealed that *P. fuscipes* is an efficient predator of smaller prey, and is particularly useful in regulating insect pest during rice nursery stage. Even though being beneficial in the agro-ecosystem, *P. fuscipes* is gaining notoriety as urban pests in human-populated areas. The present study showed that *P. fuscipes* population increased in the warmer and humid months especially during the off rice season. This inadvertently caused greatest number of beetle infestation in human residential premises, especially during rice harvesting stage. *Paederus fuscipes* flight activity peaked from 2045 h onwards, with threshold temperatures between 25–27°C, and relative humidity of 84–94% RH. Most flight activity occurred under windless nights, however *P. fuscipes* is able to fly under slightly windy conditions. The current study showed that bright illuminance produced from housing premises served as attractant factor of *P. fuscipes* dispersion.

Besides, residents that live at the upper floor levels of high-rise apartment are more prone for beetle infestation especially during rice growing and harvesting stage. Green and blue hues emitted by artificial light were found particularly attractive to *P. fuscipes* beetles. Hence, it is hypothesized that *P. fuscipes* attraction towards white lightings produced from human settings is due to the green and blue hues. Consequently, warm light sources that emits yellow or red light wavelengths is recommended for lighting to avoid *P. fuscipes* infestations in human settings.

# CHAPTER ONE

## GENERAL INTRODUCTION

Rove beetles from the family Staphylinidae are the second largest family of beetles after the Ichneumonidae (Hymenoptera), with an estimated 55,440 described species (Grebennikov and Newton 2009). In general, these beetles are identified by their slender elongated form and short elytra, making considerable portion of the abdomen visible (Lott and Anderson 2011). Within these rove beetle members, only the *Paederus* genus that could trigger the bullous contact dermatitis described as erythematous lesions due to the vesicating fluid, paederin in their body that causes burns on human skin whenever they are crushed (You et al. 2003). Paederin is a vesicant toxic amide produced by the endosymbiont bacteria (*Pseudomonas* spp.) which are largely found in the hemolymph of the adult female beetles (Kellner 2002, Piel 2002). Hence, *Paederus* are world-wisely recognized as the agent of human dermatitis as this beetle has remarkably caused serious health threat to the public health (Nasir et al. 2015).

Outbreak cases were reported throughout the continents of the world within tropical and subtropical regions of Asia including Indonesia (Vorderman 1901), Japan (Armstrong and Winfield 1968, Armstrong and Winfield 1969), China (Sheng and Sheng 1995, Wang et al. 2004, Huang et al. 2009), Egypt (Morsy et al. 1996, Assaf et al. 2010, Awad et al. 2013), Iran (Zargari et al. 2003, Nikbakhtzadeh and Tirgari 2008), Iraq (Al-Dhalimi 2008), India (Gnanaraj et al. 2007, Malvankar et al. 2011), Sri Lanka (Kamaladasa et al. 1997, Senanayake et al. 2011), Pakistan (Dursteler and Nyquist 2004), Korea (Kim et al. 1989, Kim et al. 1995, You et al. 2003, Kim et al. 2007), Africa such as in Nigeria (George and Hart 1990, Okiwelu et al. 1996), Sudan (Iserson and Walton 2012), Sierra Leone (Qadir et al. 2006), Tanzania (Fox 1993, Poole 1998), Republic of the Congo (Vasudevan and Joshi 2010), Americas such as in the Amazon river (Mammino 2011), Venezuela (Kerdal Vegas and Goihman Yahr 1966, Rivas et al. 2001, Cressey et al. 2013), Brazil (Lima et al. 2015), Arizona (Claborn et al. 1999), Peru (Alva-Da´valos et al. 2002), Europe such as in Italy (Gelmetti and Grimalt 1993, Veraldi et al. 2013), Turkey (Sendur et al. 1999, Uslular et al. 2002), Bosnia (Croft et al. 1996) and Australia (Todd et al. 1996, Banney et al. 2000, Peters and Davies 2012) except for Antarctica as no *Paederus* species was discovered in this extremely cold weather condition (Frank and Kanamitsu 1987).

Dermatitis plague in Malaysia was first noted during the year 1919 (Raju 2002). Ever since, *Paederus fuscipes* Curtis beetle is increasingly common in Malaysia and infestation in human settings has gained public attention within the country such as in Penang (Ahmad et al. 2010, Bong et al. 2013), Kelantan (Mokhtar et al. 1993), Terengganu (Rahmah and Norjaiza 2008) and Selangor (Heo et al. 2013). *Paederus fuscipes* is a notorious predator of various insect pest species in the rice ecosystem in addition to their medical important function (Frank and Kanamitsu 1987). When it is seen epidemically, one of the factors that might influence *P. fuscipes* infestation in human settings is their role as bio-control agents in the rice fields (Manley 1977). The increasing *Paederus* population in the rice field inadvertently caused the increment of paederus dermatitis reported cases especially for those living nearby the rice field areas (Gnanaraj et al. 2007). Furthermore, rice cultivation phases are known in resulting beetle invasion to human residential premises. According to Bong et al. (2013a), massive dispersal of *Paederus* beetle was due to human activities during the harvesting stage. Although human disruption was known to trigger beetle invasion into human settings, environmental factors might also play a role on their peak dispersal time. Neoh and Lee (2009) also stated that under ideal climatic condition, the onset dispersal flights of most insects are stimulated. Moreover, as these beetles are nocturnal by nature, the movement of *P. fuscipes* out of the rice field into human settings is due to their attraction towards artificial light sources from the residential premises (Lima et al. 2015). Although certain types of light sources are known to attract most adults of *P. fuscipes* from their breeding grounds into human residential premises, the spectral sensitivity and colour preferences of this beetle is yet to be known. Interestingly, *Paederus* infestation is not only limited to land houses, but as well as in high-rise apartment buildings. Studies have shown that numerous dermatitis cases were also observed in residents living in high-rise apartments (Raju 2002, Huang et al. 2009).

It is crucial to determine the attracting factors for *P. fuscipes* dispersal and to understand the dispersal pattern of these beetles flying towards human residential areas. Therefore, this study was proposed because less research has been done on this species to understand their dispersal pattern and behaviour, which consequently leads them to dispersed to human settings instead of being in their normal habitats such as in the rice field. This research is important because *P. fuscipes* beetle is a significant insect species worldwide (Frank and Kanamitsu 1987, Bong et al. 2015). The study of *P. fuscipes* interactions among organisms and their environment will give us a better understanding of factors that trigger *Paederus* beetle invasion to human settings. By doing further research that includes behaviour and biology features of this beetle, a successful control on *P. fuscipes* population movement could be conducted. Therefore, preventive measures against *Paederus* infestation can be taken to curb paederus dermatitis outbreak cases in the future.

In this study, a thorough understanding of the *P. fuscipes* biological aspects, behaviour, their interactions with the rice ecosystem and bacterial community associated with the rove beetles were evaluated. As such, this dissertation encompasses four specific objectives and the overall goals of this dissertation were

1) To determine the feeding behaviours of *P. fuscipes* on three types of prey species under various experimental trials.
2) To examine *P. fuscipes* abundance, distribution, and dispersal time using UV light traps with regard to the cultivation phases of the rice cycle and environmental parameters.
3) To evaluate the underlying factors for *P. fuscipes* attraction towards human settings based on the influence of light illuminations and height of each floor level of residential buildings.
4) To investigate the spectral wavelength properties (blue to infrared spectra) that is most sensitive for *P. fuscipes* vision.

Towards the end of the study, it is hypothesized that *P. fuscipes* will show significant preferences towards different prey species and density of prey. Besides, rice cultivation phases and environmental parameters might have significant influence on the abundance, distribution and dispersal time of *P. fuscipes* towards human settings. In addition, light illuminations and height of each floor level of residential buildings will affect *P. fuscipes* dispersal flight pattern towards human settings. It is also postulated that spectral wavelength properties and intensity of light emitted by artificial light sources trigger *P. fuscipes* flight behaviour.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Diversity of *Paederus*

According to Grebennikov and Newton (2009), more than 50, 000 staphylinid beetles are distributed globally. Among them, with at least 650 described species of small 'rove beetles' of the genus *Paederus* is found (Willers 2003).

Throughout the tropical as well as the temperate regions, northern and southern of the equator, the genus *Paederus* are found dispersed almost everywhere (Frank 1988). However, according to Frank and Kanamitsu (1987) there is no species of *Paederus* found in Antarctica. Capinera (2008) stated that all genera of the subtribe Paederina, which consisting of *Paederus*, *Paederidus,* and *Megalopaederus* can cause paederus dermatitis which is also known as dermatitis linearis. Different species of rove beetles are known to cause paederus dermatitis in several parts of the world. *Paederus brasilensis* Erichson, also called 'El podo', and Venezuelan species, *Paederus columbinus* Laporte (Singh and Ali 2007) were reported to cause dermatitis in South America. Nairobi fly or Kenya fly such as *Paederus eximius* Reiche and *Paederus sabaeus* Erichson are two common beetle species which are the causal organism for keratoconjuctivitis in East Africa (Williams 1993). However, Mbonile (2011) stated that the conjunctivitis caused by *Paederus* beetles is rare throughout the world.

In contrast with other *Paederus* spp., the major paederus dermatitis agent in Malaysia is the rove beetle *Paederus fuscipes*. It is distributed to all parts of the country in marshes and rice fields (Manley 1977).

Wetland or moist environmental conditions such marshes, riverine and crop fields are habitats that are well adapted by the *Paederus* spp. Manley (1977) stated that among the species living under moist conditions, some have adapted their life cycles according to seasonal variations. There is only single annual breeding season in the temperate-zone species. Conversely, in the tropics the breeding season of the *Paederus* is closely associated with the amount of rainfall that normally provides the ideal condition for this beetle to thrive (Ghoneim 2013).

## 2.2 General description of *Paederus fuscipes* Curtis

### 2.2.1 Scientific classification

The species *Paederus fuscipes* is from a genus of small beetles known as *Paederus* of the family Staphylinidae in the order Coleoptera. This coleopteran beetle comes under the class Insecta of the Arthropoda phylum of the kingdom Animalia. The rove beetle is also commonly known as the 'Beetle Tomcat' as *P. fuscipes* has a similar shape that looks like an American fighter aircraft, called TOMCAT. In Malaysia, it is locally known as ‘semut semai’, ‘semut kayap’ or ‘charlie’ (Raju 2002).

### 2.2.2 Morphology

Similar to other beetles in the order Coleoptera, rove beetles have hardened forewings that cover the flight wings. Among the species of the rove beetles, there are considerable variations amongst them. Size range is from 1 to 35 mm with the most is in the 2–8 mm ranges. Besides, they normally have an elongated body form with some being ovoid in shape. Being made up of a slender body form with short elytra which are wider than their pronotum and by having sclerotized abdominal segment is the main characteristic of a *Paederus* beetle. The elytron is barely longer than the combined width of its elytra with a substantial portion of their abdomen is exposed.

*Paederus* beetles have black, blue and red body markings and sometimes even whole body is black in colour. Compared with other rove beetles, the *P. fuscipes* species have brighter colour with blue or green metallic coloured elytra and many consisted with black and striking orange or red colouration on the abdomen. By having these aposematic colours on their body showed a warning sign to repel possible predators (Mullen et al. 2009).

Generally, an adult *P. fuscipes* is approximately 1 mm in width and 7-8 mm in length, which consists of the head, thorax, elytra and the abdomen (Plate 2.1). The abdominal segments I to IV are usually bright orange or red in colour, whereas the abdominal segments V and VI is black in colour. Their appendages are of bicolourous colour with partly orange and black. For instance, their 11 segmented flilliform antennae are mostly black while the first four basal segments are orange in colour. The fore legs, middle legs and hind legs are mostly orange but darkening can be seen around the femur which is more obvious on the basal part of the femur particularly on the hind legs.

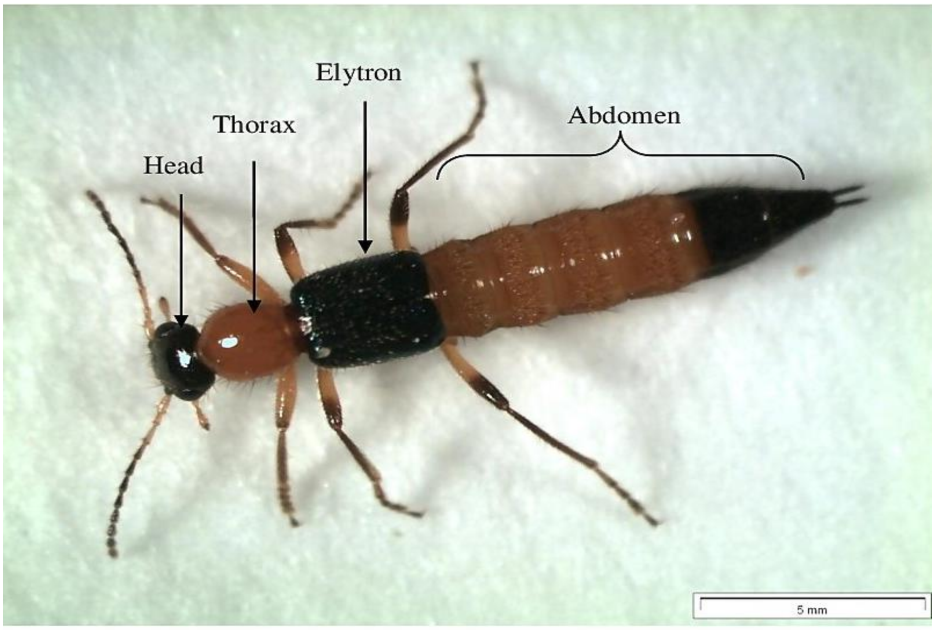



**Plate 2.1** Adult of *P. fuscipes.*

The sternum is the ventral portion of an arthropod thorax or abdomen and is further divided into subunits called sternites (Lawrence and Slipinski 2013). Sternites of the arthropod are modified on the terminal abdominal segments ($6^{th}$ segment) so as to form part of the functional genitalia that are normally reduced in size and development. Adult male and female of a *P. fuscipes* beetle is differentiated by identifying on the sixth sternite of the ventral posterior part of the abdomen. For example, there is a narrow median excision or a small grove on the sixth abdominal sternite of the male adult (Plate 2.2). However, on the female adult, the surface of the sixth abdominal sternite is smooth without the grove (Plate 2.3).

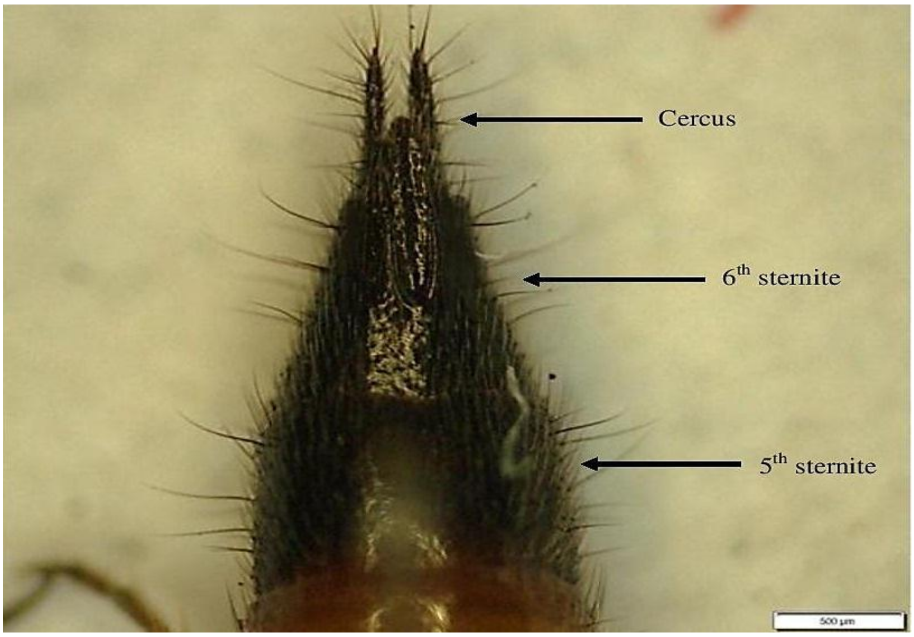



**Plate 2.2** The sixth sternite on the abdomen of the adult male *P. fuscipes*.

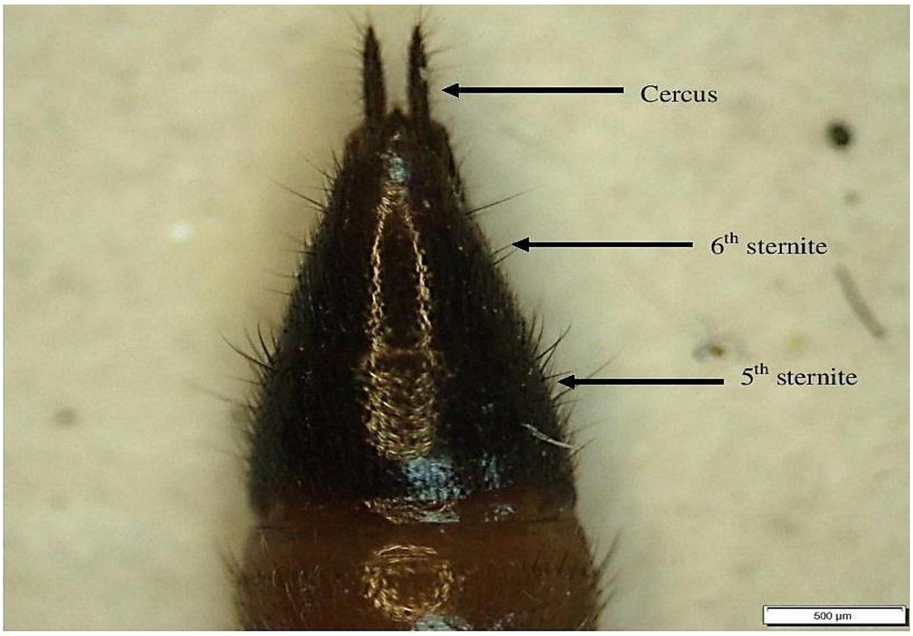



**Plate 2.3** The sixth sternite on the abdomen of the adult female *P. fuscipes*.

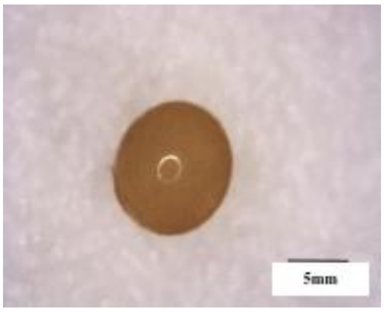
### 2.2.3 Life cycle

According to Manley (1977), *P. fuscipes* undergoes a complete metamorphosis (holometabolous) life cycle in approximately two to three weeks which includes the egg, larva (two instars), pupa and adult stages. As reported by Bong et al. (2012), about four to six days for the eggs to hatch and before reaching adulthood, they undergo three immature stages which are the 1$^{st}$ larva instar, L1 (three to five days development time), 2$^{nd}$ larva instar, L2 (five to seven days development time) and pupa (three to four days development time). The egg is about 0.5-1.0 mm in diameter, spherical in shape and yellowish white or creamy in colour. Once the egg hatches, the L1 larva measuring 2.0 mm is whitish in colour and translucent. After few hours, the L1 stage becomes slightly darker in colour. The L2 larva is campodeiform in shape and about 5.0-6.0 mm in length. At this stage, the larva has well developed legs, a head and have distinguishable thorax and usually with ten abdominal segments. Normally both L1 and L2 stages have darkened heads, chewing mouthparts with noticeable spiracles along the sides of its body. The pupal stage is about 4 mm in length bare, off-white to yellowish-tan in colour at maturity (Plate 2.4). The pupa is generally immobile.

Although each stage of the development time between every individual varies. The incubation period of most eggs increased with decreasing temperatures (Frank and Kanamitsu 1987). In contrast, the development time and adult longevity are shortened in hotter temperature with an increased in reproductive rate (Bong et al. 2012). Furthermore, the adult has a longer life span of up two to three months in cool areas.

Nasir and Akram (2012) reported that *P. fuscipes* females preferred damp porous soils rich in decaying organic matter to lay their eggs compared with dry sandy and clay soils as their eggs need moist condition to live.

According to Bong et al. (2013b), larvae were highly susceptible to dry condition due to the high cuticular permeability (CP) and high percentage total body content (%TBC). In contrast, the pupa and adult stage of the *P. fuscipes* beetles have lower CP that enables them to tolerate in xeric environment (Danks 2000, Hull-Sanders et al. 2003). As a result, they can only inhabit hygric areas as this trait curbs divergence of *P. fuscipes* into different ecological zone as their larvae are too fragile and need humid environment to survive (Ghoneim 2013). Thus, in the rice field, *P. fuscipes* larvae are normally found on tillers of the rice plants, in soil cracks and crevices as this area is moist and cool which are appropriate for the larvae development.




i) Egg stage


ii) First larval instar


iii) Second larval instar


iv) Pupa

**Plate 2.4** Immature stages of the *P*. *fuscipes* consisted of the egg stage, first and second larval instars and the pupal stage.

## 2.3 Food and predatory behaviour

*Paederus* is a predator in nature (Triplehorn and Johnson 2005). Many rove beetle species are predators of other living creatures and invertebrates, also feeds on animals matter and decaying vegetables. On the whole, their food intake includes just about anything apart from the living tissues of the higher plants. *Paederus fuscipes* is a polyphagous predator during the adults and larval stages (Frank and Kanamitsu 1987, Manley 1977).

In general, staphylinid beetles are saprophagous feeders (or scavengers). However, other subfamilies such as Steninae, Paederinae including Staphylininae had evolved from saprophagy to carnivorous feeding behaviour, making most of the Staphylinidae, tens of thousand species facultative predators (Frank and Thomas 2002).

Depending on its hunger conditions, both the adult and larva of the *P. fuscipes* show some searching behaviour before confronting its prey (Manley 1977). If the hunger motivation is high, once the prey is offered, *P. fuscipes* will directly attack its prey. Both predatory adults and larvae capture their prey using their mandibles as well as their mouthparts. For instance, like most staphylinid beetles, during attacking, *P. fuscipes* will seize its prey by abruptly moving its mandibles in a stabbing motion then grabbing them by its mouthparts and hold it with the first and second pairs of legs before start feeding (Aloszynski and Olszanowski 2013).

Based on a study by Manley (1977), *P. fuscipes* is an aggressive predator on the green leafhoppers, particularly on the nymphal stage in the rice fields of West Malaysia. However, its diet also includes other insects like the planthoppers, leaf rollers, thrips and many other soft body pests in the rice fields (Nasir et al. 2012, Padmavathi et al. 2008).

### 2.3.1 Functional response of prey-predator relationship

Jeschke et al. (2002) stated that functional response is one of the key characteristics of a predator-prey system. It requires the estimation of two basic principles; the process of searching (searching rate or attack coefficient) of a predator, and the time taken to fight, subdue, and consume a prey (also known as the handling time) (Holling 1959). According to Murdoch and Oaten (1975), the functional response helps to determine the efficacy of a predator in regulating its prey populations using predator-prey interaction model. Predator-prey interaction model is the relationship between the availability of prey number and the number of prey killed by a predator (Holling 1959).

Holling (1959) classified the functional response of predators into three main categories; Type I is a linear response with zero intercept where rate of prey capture is proportional to prey density which levels off to a plateau when it reaches the maximum attack rate (i.e. filter feeders), Type II functional response is a negatively accelerated response where the rate of prey capture increases with the prey density at a decreasing rate towards a maximum value (i.e. commonly shown by predators dealing with a single prey species). Conversely, Type III is a sigmoidal (S-shaped) response where the rate of prey capture at first increases with prey density at a positively accelerated rate, but finally approached a negatively accelerated from at high prey densities under the influence of handling time or satiation (i.e. shown by predators that learns while foraging or prey that has refuge in the predation arena).

## 2.4 Rice field crop and association with *Paederus*

An annual grass in the family Gramineae, known as rice is categorized to the genus Oryza that consist of twenty-two wild rice species distributed throughout the tropical, sub-tropical, and temperate regions, but only two of the rice species are cultivated: *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) (Seck et al. 2012). The seeds of monocot plants *Oryza sativa* or *Oryza glaberrima* are the staple food for more than half or as much as 60% of the human population (Zeigler and Barclay 2008), and is the main food crop in warm and humid environment such as in the tropical region of Asia including Africa (Seck et al. 2012). In Peninsular Malaysia, the largest granary with 98 860 ha is at Muda in Kedah while the smallest granary area with only 1300 ha is at Seberang Perai in Penang (Karim et al. 2004).

In mainland Penang, rice is mostly cultivated in two seasons per year. The main season which is normally from September to February and the off season which is from March to September (Bong et al. 2013a). Depends on the variability and the environmental condition, a rice plant normally takes three to six months to reach maturity. In a tropical environment, a 120 days rice type takes about 60, 30, 30 days for the vegetative, reproductive and the ripening stages respectively (Vergara 1991).

To ensure successful production of rice crop, the rice cultivation system in mainland Penang practices four main cultivation activities consisting of ploughing, seeding, growing, and harvesting stage. In general, the rice growth consists of three stages, namely the (1) vegetative phase which is from germination to tillering during the early vegetative phase, and tillering to panicle initiation during the late vegetative phase, (2) reproductive phase which is from panicle initiation to flowering, and finally the (3) flowering phase which is from flowering to maturing (Vergara 1991; Rasit et al. 2016). Plate 2.5 shows the component of a mature rice plant.

Improper management of rice cultivation leads to pest infestation. Over 100 insect species are rice pests with about 20 species have major significance that can cause economic damage such as the stem borers, gall midge and vectors like leafhoppers and planthoppers which cause direct damage and transmit various diseases to rice plant (Pathak and Khan 1994). Certain pest species may infest the entire parts of the rice crop throughout the growing stages of rice and some can even transmit plant viral diseases in addition to direct damages. Rice crop consists of ten phases during its growing stage: (l) seeds germination to emergence, (2) young seedling, (3) tillering, (4) stem elongation, (5) panicle initiation, (6) panicle development, (7) flowering, (8) milk grain, (9) dough grain, and (l0) mature grain stage (Salmah et al. 1998). Plate 2.6 shows the development stages of the rice plant.

During these growth stages, stem borers are generally known to infest from the seeding stage to maturity stage of the rice plants. Stem borers from Pyralidae, Noctuidae and Diopsidae families are considered the most serious pests of rice worldwide (Pathak and Khan 1994). Besides, rice thrips, black bugs, rice hispa and mealybugs are other insect pests that attack throughout the early and late vegetative phase of the rice crop (Behera et al. 2013).

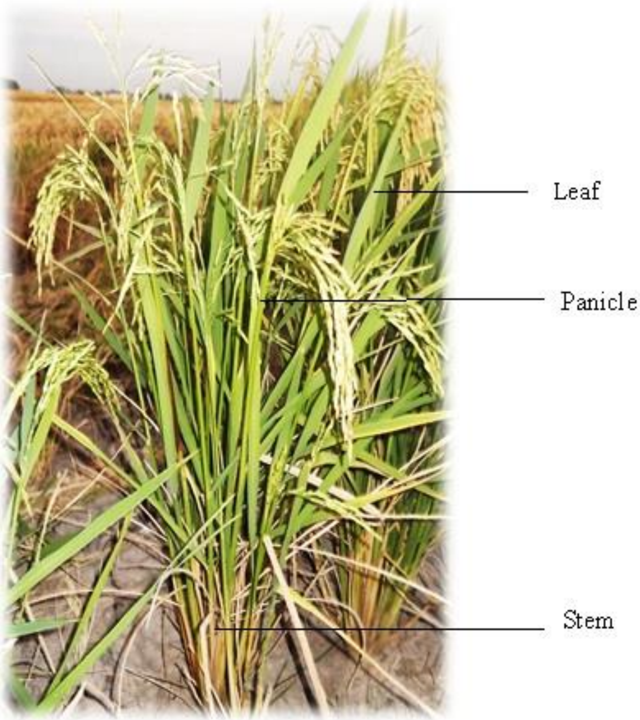



**Plate 2.5** Components of a mature rice plant are illustrated above. A matured rice plant consists of the stem, leaves and flower panicles.

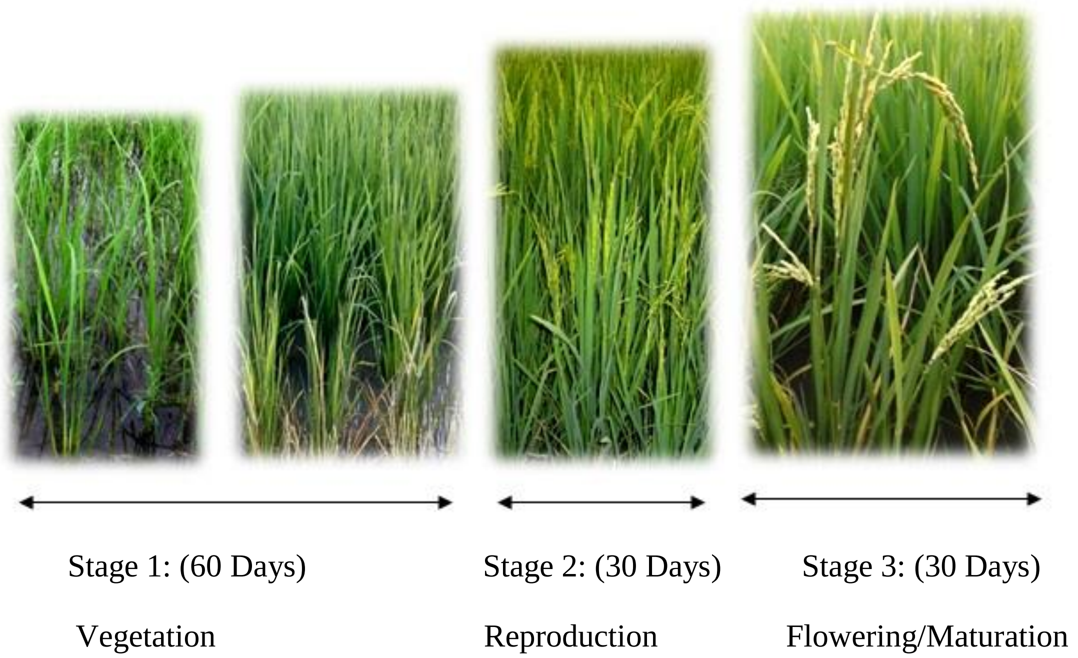



**Plate 2.6** Developmental stages of rice plants.

The leafhoppers and planthoppers are significant rice pests during the reproductive phase of the rice crop, instigating noncontagious disease known as ‘hopperburn’ and eventually caused significant yield losses (Backus et al. 2005). These pests such as green leafhoppers, brown planthoppers and zigzag leafhoppers are to blame for transmitting the virus of mycoplasma-like organism that causes severe diseases (Mathur and Chaturvedi 1980).

Ripening or flowering phase of the rice growing stage is mainly divided up into milky, dough, yellow-ripe and maturity stages (Rasit et al. 2016). During this stage, rice pests such as both nymphs and adults of pentatomid or stink bugs feed on the developing grains of rice specifically during the milk and dough stage that caused partly or completely unfilled grains (Pathak and Khan 1994).

Rice pest infestation eventually attracts predatory insect into rice field areas due to available food source. Staphylinid beetles particularly *P. fuscipes* is significant in controlling insect pests of rice crop in the tropics (Ghoneim 2013). They usually migrate to the young rice plants shortly after rice seeding and remain among the rice crop throughout the developmental stages of the rice plants (Manley 1977). *Paederus fuscipes* species is well distributed in Malaysia, and is a predator of most crop pests in the rice field (Frank and Kanamitsu 1987). However, Bong et al. (2013a) stated that *P. fuscipes* infestation at residential premises, mostly occurred once their habitat is severely disturbed and destroyed when field was being ploughed and during harvesting when rice stalks were cut and straws were burnt.

### 2.5 Rice pests as food source for *Paederus*

An ideal host for many insect species is the rice plant as every bit of the plant's part such as the stem, leaves even the roots are susceptible to the rice pests in between the seeding stage until the harvesting stage of the rice grains (Ane and Hussain 2016). They include the stem, leaf and grain suckers along with root feeders. Several species of insect pests that attack the rice crop during the reproduction stage are of the Cicadellidae and Delphacidae families such as the green leafhoppers, zigzag leafhoppers and the brown planthoppers which are also major pest species in the Malaysian rice ecosystem (Rashid et al. 1998). These insect pests are responsible for the huge economic losses to rice yields among major rice producing countries throughout the world (Ane and Hussain 2016). All of these pest species are the food source for *P. fuscipes* (Manley 1977, Meng et al. 2016).

#### 2.5.1 Green leafhopper (*Nephotettix virescens* Distant)

Among the Cicadellidae family, one of the important rice field pests is the leafhopper. These minute insects consist of various species which feed on rice plant by sucking the plant sap as well as from other grasses, shrubs or tress as they are plant feeders. Some leafhopper species are vectors of plant viruses and phytoplasmas (Stiller 2009).

One of the most important leafhopper damaging rice crops in the rice field of South and Southeast Asia is the green leafhopper, *N. virescens* (Plate 2.7). According to Hibino et al. (1979), *N. virescens* is the vector for rice tungro disease caused by rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV). *Nephotettix virescens* is infected by the virus on feeding from a susceptible rice plant for at least 30 minutes (Rivera and Ou 1965), and the viruses are spread instantly after acquisition to other rice crops during a short feeding period (Azzam and Chancellor 2002).


**Plate 2.7** Green leafhopper, *Nephotettix virescens* Distant.

Other names given to tungro including ‘penyakit merah’ in Malaysia, leaf yellowing in India, and yellow-orange leaf virus in Thailand (Ou and Rivera 1969, Ling 1972). *Nephotettix virescens* is predominantly found in low altitude rice fields. Conducive weather such as high temperature, low rainfall, and abundant sunshine has shown an increase of the *Nephotettix* spp. The population of *N. virescens* is mainly numerous during the tillering and panicle initiation stages of the reproduction phase of the rice crop (Pathak and Khan 1994). Moreover, seedling and reproduction stages are susceptible as well. They migrate to the field soon after seedlings have emerged.

Generally, the adults *N. virescens* leafhoppers are pale green in colour with black markings on their head and wings. Furthermore, they also have two black spots at the centre of their fore wings. Male adults are about 4.3-4.5 mm, whereas the females are about 5.5 mm in length. They are active during daytime as well as night time. Both the nymphs and adults of *N. virescens* feed by sucking the sap from the leaves and stems with their sucking mouth parts which cause the leaves to become yellowish in colour which then turn to brown and finally dry up (Singh and Singh 2014).

### 2.5.2 Brown planthopper (*Nilaparvata lugens* Stål)

Planthoppers from the Delphacidae family is an essential rice pest in numerous Asian countries (Kiritani 1979). Planthoppers for instance the brown planthopper, *Ni. lugens* is considered as a minor pest previously. However, its population had increased tremendously to the level of a key pest, threatening the rice production in several tropical countries mainly in South, Southeast and East Asia (Dyck and Thomas 1979). Unlike *N. virescens*, *Ni. lugens* is an epidemic type of pest (Kiritani 1979). It population may intensified in numbers until the whole rice crop is completely shattered, causing severe yield losses (Dyck and Thomas 1979).

Brown planthoppers are brownish, small in size 3.5-4.5 mm and is a sucking insect pest (Plate 2.8). Physically, adults show density-dependent wing dimorphism with macropterous and brachypterous forms (Hasegawa 1955). The brown planthoppers attack all plant growth stages immediately after germination until the reproductive stage of the rice crop. According to Sogawa (1980) they are known as a typical vascular feeder as they mainly feed on the phloem sap of the rice plant. Brown planthoppers cause economic damage to rice crop by direct feeding (Sogawa and Cheng 1979) where both nymphs and the adults insert their sucking mouthparts into the plant tissues to excrete plant sap from the phloem cells which consequently results in ‘hopper burn’ that can cause 100% crop loss (Bae and Pathak 1970). ‘Hopper burn’ happens when heavy infestations of brown planthoppers create brown patches of dried plants. As a vector, *Ni. lugens* transmits two types of viruses, the rice ragged stunt virus (Ling et al. 1978) and the rice grassy stunt virus to the rice crops (Rivera et al. 1966).


**Plate 2.8** Brown planthopper, *Nilaparvata lugens* Stål.

### 2.5.3 Zigzag leafhopper (*Recilia dorsalis* Motschulsky)

Another important rice pest from the Cicadellidae family is the zigzag leafhopper of the *R. dorsalis* (Plate 2.9). Zigzag leafhopper is white with dark brown markings (Singh and Singh 2014), and adult measures about 3.2-3.4 mm in males and 3.8 mm in females. It is given the name zigzag due to the light brown 'W' shaped bands which gave a zigzag pattern on the forewings of the adults (Barrion and Litsinger 1994). According to Pathak (1969), in South and Southeast Asia such as Malaysia, Bangladesh, Pakistan, Japan including Taiwan, the occurrence of zigzag leafhopper is considered common.


**Plate 2.9** Zigzag leafhopper, *Recilia dorsalis* Motschulsky.

Due to its low population, it is not so much known for the damage in sucking the leaf sap and leaf sheath of the rice plant. However, in a large population, zig-zag leafhoppers are important as vectors of rice dwarf, tungro and yellow-orange leaf viruses (Mathur and Chaturvedi 1980).

## 2.6 Behaviour

*Paederus* adults are active during the day, like most of the staphylinid adults, beetles actively searching for food sources in the rice field (Manley 1977). However, at night, artificial light sources are known to trigger *Paederus* dispersal flights (Davidson et al. 2009). Inadvertently, light sources brought beetle into contact with human beings, especially to people standing directly underneath or next to the artificial light sources outdoor (Ghoneim 2013).

## 2.7 Insect vision

Insect visual systems are remarkably sophisticated and are of extraordinary speed in processing retinal images in spite of their small eyes, tiny brain size and comparatively few neurons (Egelhaaf and Kern 2002). The adult stage have compound eyes which enable them to identify and respond to conspecifics, differentiate and evade predators, locate food sources in addition to capture prey, and depend on visual landmarks along with celestial cues for orientation and navigation (Srinivasan 1999, Warrant and Dacke 2011), besides having the capacity to distinguished colours.

Insects are sensitive to broad spectrum of lights ranging from the UV to red light among the visible spectrum (Menzel et al. 1986, Peitsch et al. 1992) (Figure 2.1). However, to the eyes of most invertebrates, the UV sensitive species are typically sensitive to the wavelengths of 300–700 nm (Briscoe and Chittka 2001), as compared to human visual spectrum, which is only within the range of 400–700 nm (Tovee 1995). Henceforth, insects are able to detect ultraviolet (UV), and other spectrum colours using their photoreceptor cells (Osorio and Vorobyev 2005). However, these cells within their eyes contain different rhodopsins or visual pigments that react differently towards light of specific wavelengths (Poiani et al. 2015). Hence, the photoreceptor spectral range varies between insect species; dichromacy in Blattoptera, trichromacy in Diptera, Hymenoptera, Hemiptera and Orthoptera to tetrachromacy in Lepidoptera and Odonata (Menzel and Backhaus 1991, Koshitaka et al. 2008).

Colour sensitivity in the UV spectrum plays an important role for both winged invertebrates and terrestrial insects (Honkavaara et al. 2002, Osorio and Vorobyev 2005), in their daily behavioural activity such as in intraspecific communication, foraging, and for circadian rhythms (Tovee 1995). This adaptive behaviour is crucial for insect to stay alive.

Previous studies have shown that insects are especially responsive to the shorter wavelength and higher frequency of the visible spectrum, particularly the UV light region. Barghini and Souza de Medeiros (2012) stated that UV radiation is used by night flying insects such as *Paederus* beetle for navigation. Hence, black light was found to be particularly attractive to most *Paederus* individuals (Lima et al. 2015), due to the emission of ultraviolet rays that is visible to most insects.

According to Menzel and Blakers (1976) insects normally have spectral sensitivity peaking in the UV, blue, and green regions of the light spectrum. A study conducted by Weiss et al. (1941) showed that approximately 60% of experimented beetles reacted positively towards the shorter wavelength from the 365 to 528 nm