

Multifarious Roles of Feeding Behaviours in Rove Beetle, *Paederus fuscipes* (Peranan Multifarius dalam Tingkah Laku Pemakanan Kumbang Rove, *Paederus fuscipes*)

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ABSTRACT

The rice green leafhopper *Nephotettix virescens* Distant (Hemiptera: Cicadellidae), zigzag leafhopper *Recilia dorsalis* Motschulsky (Hemiptera: Cicadellidae), and brown planthopper *Nilaparvata lugens* Stål (Hemiptera: Delphacidae) are the most economically important insect pests infesting rice crop. *Paederus fuscipes* Curtis has been reported as the natural predator for these rice pest species in Southeast Asia. Under laboratory conditions, we evaluated the prey preference of this generalist predator when it encountered the three main agricultural pests of rice plant. *P. fuscipes* typically displayed a Type II functional response for all prey species. However, at high prey densities they consumed predominantly *R. dorsalis* with highest attack rate on dead *R. dorsalis* prey. Conversely, significantly highest time was needed to handle live *R. dorsalis*. When various density of preys was tested simultaneously, the predator showed greater preferences towards *R. dorsalis* and *Ni. lugens*. We observed the behavioral response of *P. fuscipes* predator on its prey items. Highest number of searching and capturing attempt was most frequently displayed on live *Ni. lugens* prey species. Whereas, *P. fuscipes* spent more feeding time in consuming dead prey compared to the alive ones. Overall, *P. fuscipes* showed successful control of small and soft body crop pests at low prey density.

Keywords: Biological control; functional response; Paedarus; prey preference; rice pests

ABSTRAK

Lelompat daun hijau *Nephotettix virescens* Distant (Hemiptera:Cicadellidae), lelompat zigzag *Recilia dorsalis* Motschulsky (Hemiptera:Cicadellidae) dan lelompat pokok perang *Nilaparvata lugens* Stål (Hemiptera: Delphacidae) merupakan perosak penting ekonomi yang menyerang tanaman padi. *Paederus fuscipes* Curtis menghuraikan sebagai pemangsa semula jadi untuk kesemua spesies perosak padi di Asia Tenggara. Di dalam keadaan makmal, kami menilai pemilihan mangsa untuk pemangsa ini semasa berhadapan dengan tiga jenis perosak utama pertanian padi. *P. fuscipes* menunjukkan tindak balas fungsi jenis II untuk kesemua spesies mangsa, tetapi pada kepadatan tinggi mereka lebih menggemari *R. dorsalis*. Kadar serangan tertinggi diperhatikan pada *R. dorsalis* yang telah mati. Sebaliknya, kadar masa pengendalian tertinggi diterima oleh *R. dorsalis* yang hidup. Semasa pelbagai kepadatan diuji pada masa yang sama, pemangsa menunjukkan pemilihan yang lebih besar terhadap *R. dorsalis* dan *Ni. lugens*. Kami juga memerhatikan tindak balas perlakuan oleh pemangsa *P. fuscipes* terhadap mangsa. Percubaan untuk mencari dan menangkap banyak ditunjukkan pada spesies mangsa *Ni. lugens* yang hidup. Manakala, *P. fuscipes* menghabiskan lebih masa makan pada mangsa yang telah mati berbanding yang masih hidup. Secara keseluruhan, *P. fuscipes* menunjukkan keberjayaan dalam mengawal perosak pertanian bertubuh kecil dan lembut pada kepadatan yang rendah.

Kata kunci: Kawalan biologi; Paedarus; pemilihan mangsa; perosak padi; tindak balas fungsi

INTRODUCTION

The rove beetle, *Paederus* sp. (Coleoptera: Staphylinidae) is an economically important predator used in controlling insect pest populations in the agro-ecosystem (Frank & Kanamitsu 1987). Although, the genus *Paederus* is notorious for its vesicant paederin that causes dermatitis linearis to humans, these beetles are reckoned as effective biological control agents of crop pests (Bong et al. 2015). *Paederus* beetle is widely distributed around the world for instance in Europe, Asia, India, New Guinea, Africa and Australia except Antarctica (Frank & Kanamitsu 1987; Singh & Ali 2007). However, in Malaysia the species *Paederus fuscipes* Curtis is predominantly distributed in

the West part of the Peninsular and mostly found in the rice field areas (Manley 1977). This predator species is a common predator of small arthropod pests such as the leafhoppers (Manley 1977) thrips, planthoppers and other rice pests (Kalshoven & van der Laan 1981).

Over the years, members of the family Delphacidae (planthoppers) and Cicadellidae (leafhoppers) are major pests of rice crop, *Oryza sativa* Linnaeus in the agricultural ecosystem (Fujita et al. 2013). According to Hibino (1996), planthoppers and leafhoppers borne viruses have inflicted significant damage in rice production and epidemic proportions have been recorded in major rice growing countries such as in Asia.

The incidence of these pest species caused crop losses and some are vectors of damaging plant viruses including the rice dwarf and tungro viruses (Hibino 1996; Nault & Ammar 1989). Severe infestation of certain planthopper and leafhopper species consequently results in 'hopperburn', a condition where the rice plant turns from yellowish to brown patches of dried plants (Backus et al. 2005). This eventually can be substantial, as crops production grown for human consumption is at risk (Oerke 2006). However, as the predator's population trend followed those of crop pests, and normally start to attack immediately after germination until the reproductive phase of the rice crop (Bong et al. 2015). *Paederus fuscipes* showed potential as biological control agent of these rice pest species.

In order to establish the suitability of *P. fuscipes* to control the leafhoppers and planthoppers, a clear understanding of the natural enemy's preference on these pest species need to be conducted. A simple model of predator prey interaction strength is provided by the functional response to relate the predation rate to prey density. According to Jeschke et al. (2002), 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). Holling (1959) identified three primary types of functional responses, Type I (linear, with zero intercept), Type II (convex), and Type III (sigmoidal). In general, Type II responses are mostly associated with invertebrate predators, and are the commonly observed response in the laboratory (Zuharah & Lester 2011). To date, there is very limited information on the predator-prey interactions especially between *P. fuscipes* and the major crop pest species in Southeast Asia. Thus, it is ultimately important to be able to determine and therefore to predict *P. fuscipes* feeding behavior and their preferences on insect pests that mainly exists in the rice ecosystem, to understand the efficiency of this generalist predator as bio-control agent. This study aimed to examine *P. fuscipes* feeding behavior on three aspects based on the: functional response, prey preferences, and the predator's behavior in response to three common types of rice pest species in Malaysia; *N. virescens*, *Ni. lugens* and *R. dorsalis*.

MATERIALS AND METHODS

COLLECTION SITE OF *P. FUSCIPES* AND PREY SPECIES

Both predator and prey species were collected at the rice field areas at Jalan Sejahtera Indah (N 5° 29' 06" E 100° 23' 16"), Telok Air Tawar, Butterworth, Penang. Penang state is located at the northeastern coast of Peninsular Malaysia that experiences uniform tropical climate with consistent temperature that falls between 29°C and 35°C and high relative humidity during the daytime around the year which is suitable for *P. fuscipes* reproduction.

The distance of the study site location from Universiti Sains Malaysia, Georgetown is about 31 km. Weeds are often found growing scattered on the boundaries of the rice fields areas. No presence of large trees found around rice fields.

SAMPLING METHODS

Paederus fuscipes beetles were captured using UV blacklight traps (Model 812, John W. Hock Company, Florida, USA) during their most active dispersal flight between 2015 and 2215 h (Maryam et al. 2017). Trapped beetles were collected by using a mechanical insect aspirator. Collected *P. fuscipes* were then brought back and maintained in the laboratory. Species identification was based on Lott and Anderson (2011).

By using conventional light trap methods, the adult of rice insect pests were captured in abundance: the green leafhopper, *N. virescens*; zig-zag leafhopper, *R. dorsalis*; and brown planthopper, *Ni. lugens*. Conventional light trap is a trap with a light bulb generated using a portable generator and hang in front of large white sheeth. Insect pests were then collected using a mechanical insect aspirator and brought back to the laboratory. Identification was done and following Wilson and Claridge (1991). The fresh batches of prey were freshly collected a day prior to the experiment.

MAINTENANCE METHOD OF *P. FUSCIPES*

The collected adults of *P. fuscipes* were maintained in the Medical Entomology Laboratory, Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia (5° 21' 21.913" N, 100° 18' 4.575" E) at a temperature of $28 \pm 2^\circ\text{C}$, $63.8 \pm 2.0\%$ r.h. and a photoperiod of L12:D12. All subsequent experiments were conducted at the same laboratory condition. The maintenance method was adopted from Bong et al. (2012) with some modifications on the container and food provided to *P. fuscipes*. *Paederus fuscipes* beetles were maintained in a plastic container of 16.5 cm height \times 11.5 cm width in size and covered with muslin cloth to allow air ventilation as well as to prevent the beetles from escaping. A moist cotton ball was provided as water source on one side of the plastic container. On the other hand, cat foods, a good source of carbohydrate was offered to the beetles as food supply.

EXPERIMENTAL DESIGNS

FUNCTIONAL RESPONSE STUDY

The functional response of *P. fuscipes* were examined on three prey species: green leafhoppers, *N. virescens*; brown planthoppers, *Ni. lugens* functional; and zig-zag leafhoppers, *R. dorsalis*. These pests were chosen in this study because they are the main pests during the vegetative phase of the rice plants and were found to be the most

abundant pests in the rice fields. A preliminary study feeding test was conducted to examine the maximum consumption rate per 24 h of *P. fuscipes* on different types of prey species. Preliminary study showed that the maximum number of prey consumed within 24 h. by *P. fuscipes* was less than ten individuals. Hence, the density treatments of prey at 1, 3, 5, and 10 individuals were offered to *P. fuscipes* in separate experiments. Two prey conditions were also tested; using alive and dead (carcass) prey. Carcass of prey was included as *P. fuscipes* adults are polyphagous and also known to feed on animal matter (Frank & Kanamitsu 1987). A total of 24 experiments were run separately crossed all three variables (prey types, prey densities, prey conditions) as stated and replicated for ten times (with total of 240 experiments). This study was adapted by Zuharah and Lester (2011) with some modifications on the number of prey densities.

A single *P. fuscipes* beetle was placed in a plastic container measuring 5.6 cm in length \times 4.6 cm in width with a moist cotton ball on one side of the plastic container. *P. fuscipes* was starved for 24 h prior to the experiment. On the other side of the container, prey item of mentioned densities was placed and left for 24 h. After 24 h, the remaining prey item was counted and recorded. New individual of *P. fuscipes* predator and a new batch of prey were used in each separate experiment.

Using the equation by Juliano (2001), we determine the shape of the functional response which relates the proportion of prey eaten (N_e) to amount of prey offered (N_0). The polynomial function was fitted to the data that describes the relationship between both prey eaten (N_e) and the amount of prey offered (N_0) as follows:

$$\frac{N_e}{N_0} = \frac{\exp L_0 + L_1 N_0 + L_2 N_0^2 + L_3 N_0^3 + L_4 N_0^4}{1 + \exp L_0 + L_1 N_0 + L_2 N_0^2 + L_3 N_0^3 + L_4 N_0^4} \quad (1)$$

where N_e the number of prey eaten; N_0 the initial number of prey available; and thus N_e/N_0 is the probability an individual is eaten.

To estimate the handling time and attack rate for each prey, Roger's equation (1972) was used. The 'random-predator' equation of Rogers (1972) was best to describe the results as no prey was replaced during the course of the experiment:

$$N_e = N [1 - \exp [a (T_h N_e - T)]] \quad (2)$$

where N_e is the number of prey eaten; N is the initial number of prey available (number of prey offered); a is the instantaneous attack rate; T is the total available time; and T_h is the 'handling time' (or the time required to handle a prey item). Equation 2 has been used by many studies (Zuharah & Lester (2011)) as it permits an analysis of the functional response despite the depletion of prey by the predators. The attack coefficient, a and handling time, T_h were estimated from the functional response data using a standard non-linear least squares technique.

PREY PREFERENCE

The prey preference by *P. fuscipes* beetles were tested on three types of rice field pests: green leafhoppers, *N. virescens*; brown planthoppers, *Ni. lugens*; and zig-zag leafhoppers, *R. dorsalis*. A single *P. fuscipes* beetle was placed in a 5.6 cm in height \times 4.6 cm in width plastic container. In this experiment, a specific proportion of pest species was offered, and a moist cotton ball was placed at one end of the plastic container. All prey was acclimatized for 10 min, prior to the introduction of *P. fuscipes* predator.

In this experiment, *P. fuscipes* beetle was presented with a mixture of; adults of *N. virescens* and *Ni. lugens*, adults of *N. virescens* and *R. dorsalis*, and adults of *Ni. lugens* and *R. dorsalis* at ratios of 0:6; 1:5; 2:4; 3:3; 4:2; 5:1; 6:0. The experiment was designed using two conditions of prey: alive and dead. A total of 42 experiments were run separately crossed all three variables (mixture of prey types, prey ratios, prey conditions). Each particular trial was replicated for five times (with a total of 210 experiments). *Paederus fuscipes* was starved for 24 h prior to the experiment. After 24 h of exposure, the remaining prey item was counted and recorded.

Prey preference was measured with a model developed by Chesson (1974) and Manly (1982) modification for the description of prey depletion. The predicted preference (α) for each predator was determined using attack constant from the functional response experiment using this multiplicative model as shown on Zuharah and Lester (2011):

$$\alpha_{Ni} = \frac{\alpha_{Ni}}{\alpha_{Ni} + \alpha_{N} - (\alpha_{Ni} \alpha_{N})} \quad (3)$$

where α_{Ni} was the predicted preference for *Ni. lugens*; α_{Ni} and α_{N} were the attack constants for *Ni. lugens* and *N. virescens*, respectively. Equation (3) was used to predict preference of *P. fuscipes* on *R. dorsalis*. Manly's α ranges in value between zero and one, and the value of 0.67 represents no preference for either prey species predicted from the functional response in this study.

PREDATOR'S BEHAVIOR

Capture behavior of the predator on prey was set-up in this study. Three behaviors of *P. fuscipes* was observed; searching frequency (the searching rate spent by foraging predator to locate the prey item at a distance for the first time before it starts capturing its prey), prey capturing (the number of attempt done by predator to finally approach and capture the selected prey with its mandibles and start feeding), and prey ingestion (the duration of time spent by predator in feeding).

Predator's general modes of locomotion in catching its prey items were observed and recorded. Here, we evaluated on how fast these predators need to search and finally start to feed on its specific prey at a duration of time spent (min.). The context 'prey ingestion' is a behavioral description for the duration of time predator beetle spent in feeding once it starts capturing its prey and held it by

means of its mandibles until the escape movements of the prey become weary. Occasionally, the feeding process occurred in for a few times and may pause in between feeding to drink from the moist cotton. Data was recorded throughout the feeding process until the whole prey item was completely consumed or partially eaten by the predator within an hour.

If *P. fuscipes* beetle did not show any reaction towards the prey item and did not feed on it within an hour, the trial was discarded, and data were not included into the statistical analysis. Predator's searching, capturing and feeding behavior was observed on two different sets of prey conditions (alive and dead). *P. fuscipes* was offered with single alive or dead prey of the adult of *N. virescens*, *Ni. lugens* or *R. dorsalis* in separate experiments. *P. fuscipes* was starved for 24 h prior to the experiment. A total of six treatments were done separately crossed all two variables (prey types and prey conditions). Each experiment was replicated for ten times (with a total of 60 replicates).

STATISTICAL ANALYSIS

To compare the differences between the number of prey (*N. virescens*, *Ni. lugens* and *R. dorsalis*) and condition of prey (alive and dead) that were consumed by the *P. fuscipes* beetles, two-way ANOVA was used. Whereas, a Student's *t*-test was performed to determine any significant difference in the preference of predators between these two species tested for each experiment. The predator's behavior of searching, capturing and ingestion was all examined using the two-way analysis of variance (ANOVA). Independent variables were the types of prey species (*N. virescens*, *Ni. lugens* or *R. dorsalis*) and prey conditions (alive or dead). Data analyses was done using SPSS version 20.0. Normality test was conducted for all data at the 0.05 significance level by using Shapiro-Wilk test prior to two-way ANOVA analyses. If the criteria for normality were not met, the data was normalized using log transformation.

RESULTS

FUNCTIONAL RESPONSE STUDY

After determining the shape of the response curve on the plotted graph produced from the experiment, all curves showed the Type II functional response of Holling (1959). *P. fuscipes* functional response on *N. virescens*, *Ni. lugens* and *R. dorsalis* prey species was significantly different ($F = 10.461$; $df = 2, 234$; $P < 0.05$). The response graph showed predator consumed significantly higher number of *R. dorsalis* prey presented alive and dead compared to other prey species ($P < 0.05$; Figure 1(A)). Interestingly, *P. fuscipes* consumed a similar number of both live *R. dorsalis* and *Ni. lugens* except at high prey densities once *R. dorsalis* was presented in dead condition (Figure 1(A) and Figure 1(B)). Whereas, *N. virescens* was the least consumed prey species with a significantly lower number of alive and dead

prey consumptions by *P. fuscipes* predator ($P < 0.05$; Figure 1(C)).

Overall, the consumption rate on different prey conditions presented alive and dead was found to be significantly different ($F = 77.896$; $df = 1, 234$; $P < 0.05$). Dead prey item was consumed in a greater number compared to alive prey (Table 1). *P. fuscipes* was found to have significantly higher handling time of their most consumed prey species of live *R. dorsalis* (9.7 ± 1.65 , $n = 10$) and lower handling time on dead *R. dorsalis* (4.9 ± 0.82 , $n = 10$) compared to two other prey species *N. virescens* and *Ni. lugens* ($P < 0.05$). Interestingly, the highest attack rate on dead and alive preys presented by *P. fuscipes* predator was prominently seen on *R. dorsalis* (0.4 ± 0.03 , $n = 10$), and *Ni. lugens* (0.2 ± 0.02 , $n = 10$), respectively.

TABLE 1. The average number (mean \pm SE) of alive and dead prey consumed per day by *P. fuscipes* predator ($n = 10$)

Prey/Prey condition	Alive	Dead
	(mean \pm SE)	
<i>Recilia dorsalis</i>	2.2 \pm 0.25a	3.7 \pm 0.26a
<i>Nilaparvata lugens</i>	2.1 \pm 0.3a	2.7 \pm 0.26a
<i>Nephotettix virescens</i>	1.0 \pm 0.26a	2.4 \pm 0.37b

*Same letter represents no significant differences between row for each prey species (Student's *t*-test, $p > 0.05$)

PREFERENCE OF PREY

It was observed that *P. fuscipes* preferred *R. dorsalis* $>$ *Ni. lugens* $>$ *N. virescens*. *P. fuscipes* preferred mostly to feed upon the *R. dorsalis* compared to *N. virescens* even at low number of individuals, once given a choice between this two prey species ($t = 2.10$; $df = 138$; $P = 0.037$; Figure 2). Nevertheless, the preference of *P. fuscipes* consumption rate was primarily higher on dead *R. dorsalis* compared to the live *R. dorsalis* with (6.2 ± 4.60 , $n = 5$) and (4.7 ± 3.55 , $n = 5$) consumed individuals.

Similar situation was also observed when *Ni. lugens* was offered together with *N. virescens*, significantly higher preferences were observed on *Ni. lugens* instead of *N. virescens* species ($t = 3.59$; $df = 138$; $P < 0.05$). *P. fuscipes* consumed significantly more on *Ni. lugens* for both prey conditions even at proportionally fewer *Ni. lugens* to *N. virescens* at ratio of 1:5 (Figure 3(A)). However, dead *Ni. lugens* was consumed comparatively more than the alive ones at all levels except when the ratio was at 5:1. Number of dead and alive *Ni. lugens* prey consumed was with means of 8.0 ± 4.78 , $n = 5$ and 4.1 ± 2.27 , $n = 5$ individuals correspondingly.

Interestingly, once *R. dorsalis* and *Ni. lugens* prey were offered together to the *P. fuscipes* predator. No significant variation was observed between these two species ($t = 1.29$; $df = 138$; $P = 0.201$; Figure 4). *P. fuscipes* consumed both dead prey species at equal rates on 1:5 ratio.

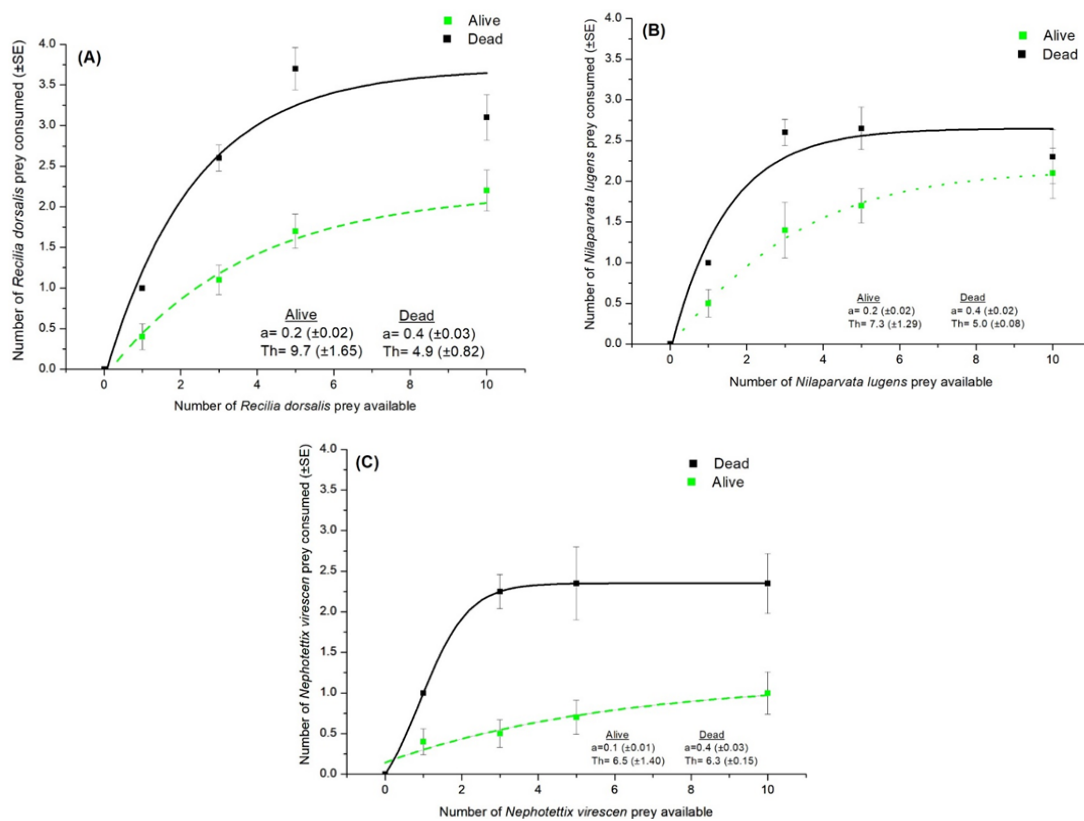


FIGURE 1. *Paederus fuscipes* displayed the Type II (convex) functional response model against alive and dead (A) *Recilia dorsalis*, (B) *Nilaparvata lugens*, (C) *Nephotettix viscerans*. Data were plotted with means of 95% confidence intervals

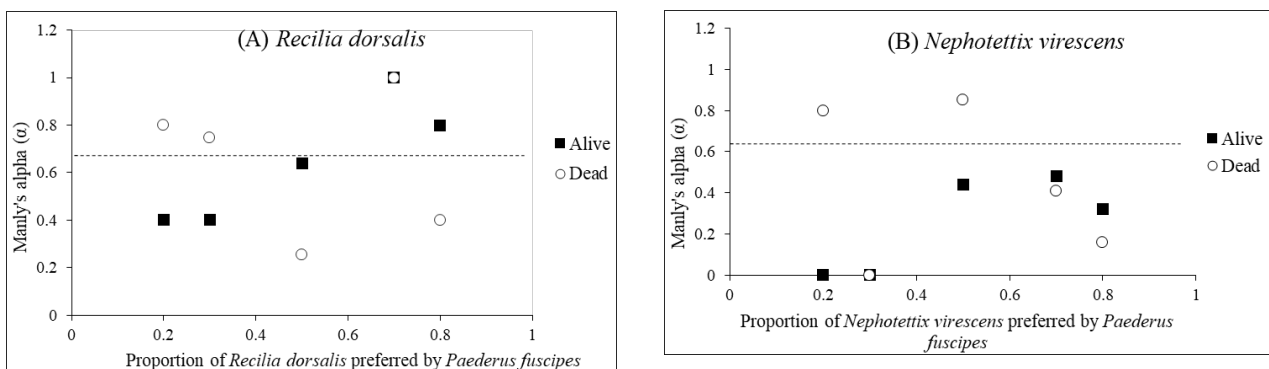


FIGURE 2. The preference of *P. fuscipes* on two combinations of prey between (A) *R. dorsalis* and (B) *N. virescens* presented alive and dead indicated by Manly's alpha (α) (mean). Values above $\alpha = 0.67$ (defined by the broken horizontal line) indicate preference

Overall, dead prey (6.7 ± 3.95 , $n = 5$) was consumed more compared with live *R. dorsalis* prey (4.0 ± 3.37 , $n = 5$) (Figure 4(A)).

PREDATOR'S BEHAVIOR

SEARCHING BEHAVIOR FREQUENCY OF *P. FUSCIPES* ON ITS PREY

The predators initially start to show searching behavior by inspecting its surrounding environment and by also stalking the potential food item at a distance. *P. fuscipes* then

displayed a slow forward movement towards the prey while spontaneously raising the tip of their abdomen when walking, mimicking a tail-raising behavior of a threaten scorpion when it is being alarmed. The locomotion pattern of moving back and forth from the prey happened for a few minutes with a few attempts before the beetle start attacking its prey, and this is counted as searching behavior. This behavior was displayed for either alive or dead prey conditions.

The searching rate observed on the live prey of brown planthopper, *Ni. lugens* was with mean of 15.3 ± 2.67 , $n = 10$. While, the searching rate observed on *P. fuscipes* predator on the dead prey of green leafhopper, *N. virescens*

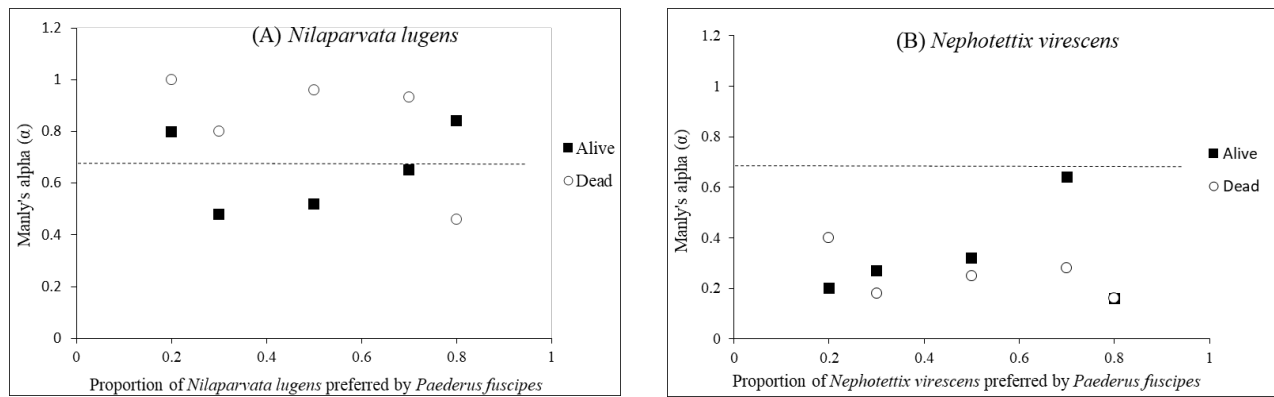


FIGURE 3. The preference of *P. fuscipes* on two combinations of prey between (A) *Ni. lugens* and (B) *N. virescens* presented alive and dead indicated by Manly's alpha (α) (mean). Values above $\alpha = 0.67$ (defined by the broken horizontal line) indicate preference

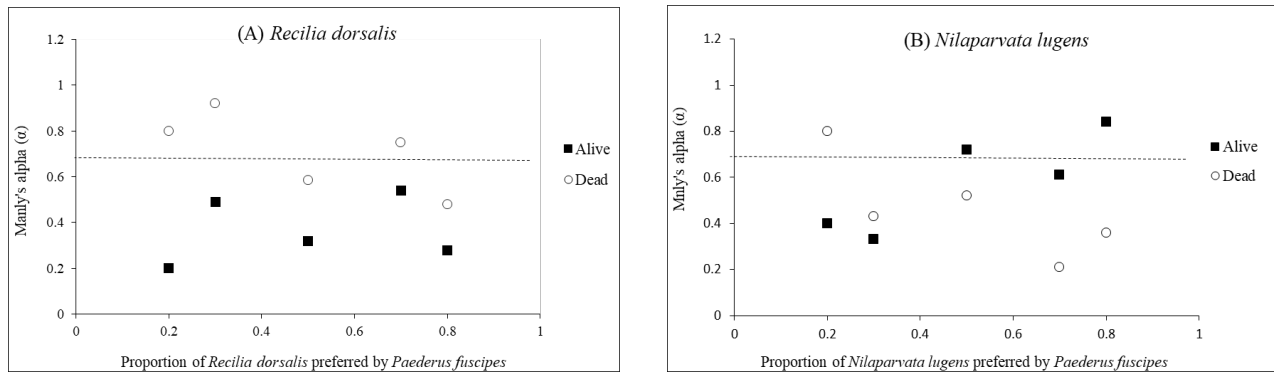


FIGURE 4. The preference of *P. fuscipes* on two combinations of prey between (A) *R. dorsalis* and (B) *Ni. lugens* presented alive and dead indicated by Manly's alpha (α) (mean). Values above $\alpha = 0.67$ (defined by the broken horizontal line) indicate preference

was with a mean number of 9.5 ± 3.2 , $n = 10$. Beetle was observed to immediately attack after a short searching rate on dead prey items rather than on alive prey. However, two-way ANOVA showed no significant interaction between the types of prey species and prey conditions on the searching behavior frequency of *P. fuscipes* ($F = 1.530$; $df = 2, 54$; $P = 0.226$; Figure 5(A)).

CAPTURING BEHAVIOR OF *P. FUSCIPES* ON ITS PREY

P. fuscipes was seen pursuing the prey by running close to it in a series of fast runs and sudden stops for a while, and wait for the prey movement response that was presented alive or dead. The moment the predator was about to start capturing the prey, the number of attempts by the predator was counted. Generally, *P. fuscipes* predator displayed no significant difference on the capturing attempts for both alive and dead prey items ($P > 0.05$; Figure 5(B)). However, the number of attempts shown by *P. fuscipes* predator on alive *Ni. lugens* prey species was with a mean number of 4.6 ± 1.15 , $n = 10$. Based on the capturing activities of *P. fuscipes* on the dead prey items, the attempt rate observed on *N. virescens* was with a mean of 3.3 ± 0.40 , $n = 10$. Similarly, no statistically interaction was found in the

capturing behavior of *P. fuscipes* based on the types of prey species and prey conditions ($F = 0.841$; $df = 2, 54$; $P = 0.437$).

FEEDING BEHAVIOR OF *P. FUSCIPES* ON ITS PREY

Paedarus fuscipes finally approached and quickly responded by start seizing the prey with its strong mandible while feeding on it slowly until they released it, as it is defined as the time spent on feeding behavior. Results indicated that the time spent on feeding was significant on the dead prey items compared to the alive prey ($P < 0.05$; Figure 6). However, no significant interaction was found on all types of prey species offered regardless of the conditions of prey items consumed by the *P. fuscipes* beetle ($F = 0.516$, $df = 2, 54$, $P = 0.600$). Nonetheless, *P. fuscipes* beetles are insatiable feeders that feed on both alive and dead prey items.

DISCUSSION

The present study showed that the predatory behavior of *P. fuscipes* followed the Type II functional response for all

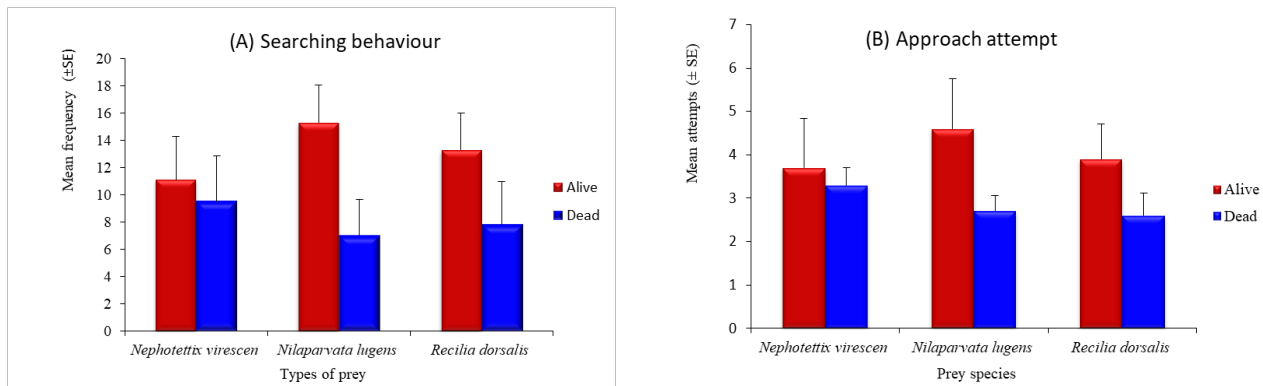


FIGURE 5. The (A) searching behavior frequency, (B) attempt to approach by *P. fuscipes* on three types of prey species (*N. virescens*, *Ni. lugens* and *R. dorsalis*) presented in two conditions (alive and dead)

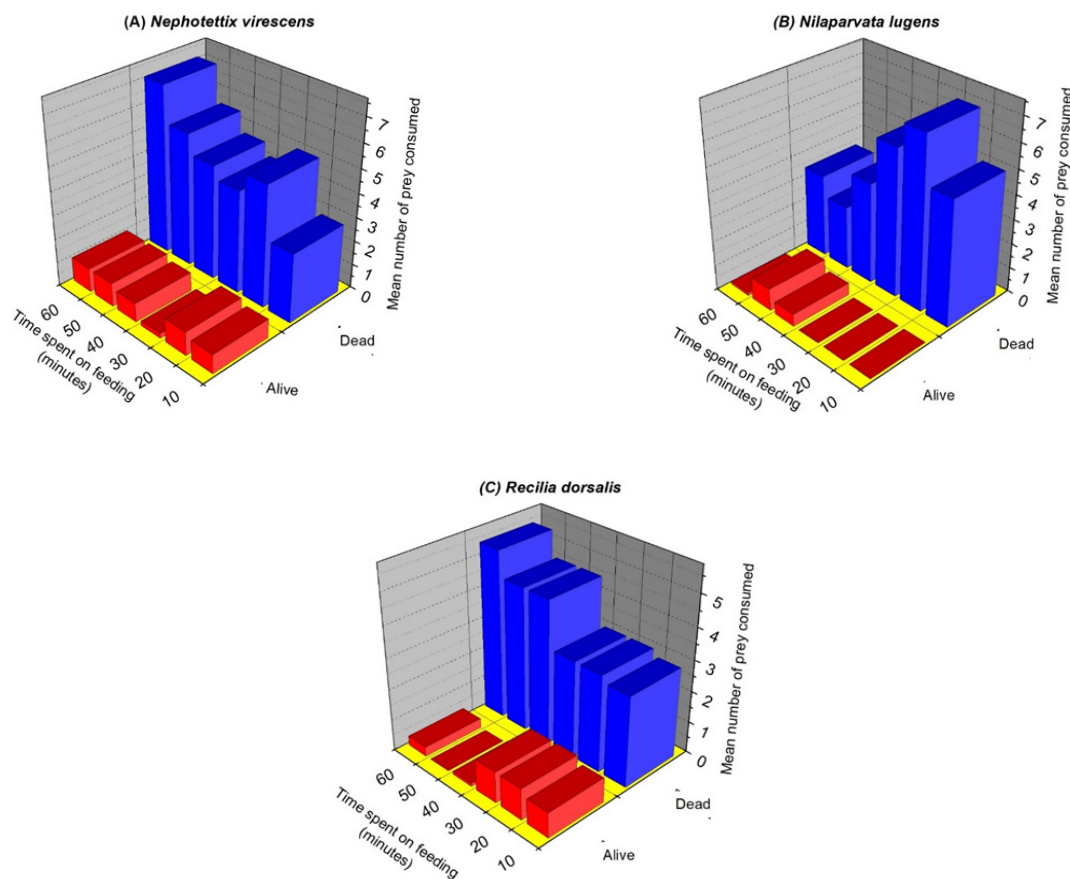


FIGURE 6. The predation behavior of *P. fuscipes* based on three types of prey species (a) *N. virescens*, (b) *Ni. lugens*, and (c) *R. dorsalis*. Prey was offered in alive and dead conditions in relation to time (min.) spent on feeding

of the three types of dead and alive prey species. Such behavior denoted that the prey consumption by *P. fuscipes* rises significantly but at a declining rate with an increasing number of prey densities. In a Type II response, predators are expected to capture and feed on prey without initial delay in learning ways to circumvent difficulties unlike the Type III functional response. This proposed that the offered alive and dead prey in the current study showed no defense strategies and are immobile in such a way that that the *P. fuscipes* was feeding *ad libitum*, not needing to improve prey intake at high prey density.

Interestingly, this exponential response curve has also been found on many other insects and arthropods species (Murdoch 1969; Xiao et al. 2013; Zuharah & Lester 2011). According to some literatures, predators that displayed the Type II functional response are generally known as successful biological control agents (Reis et al. 2003; Timms et al. 2008; Xiao & Fadamiro 2010). Though, Holling (1965) stated that only a Type III functional response showed by predators were able to contribute to the regulation of prey populations and allow long term persistence between predators and their prey. Hence, the

exhibition of the Type II response by *P. fuscipes* indicated that this predator presented better potential for biological control of insect pests at low prey density. This is one of the main factors which will control the early foundation of insect pest population below the economic level once infestation of rice pest starts during the nursery stage of the rice crop.

According to Ganjisaffar and Perring (2015), even though the functional response is an important aspect of natural enemy behavior, it is not the only factor that determines the success or failure of a bio-control agent. A predator's functional response may vary under various biotic and abiotic conditions, predator numerical response, and competition amongst diverse predators present in the environment as well as its searching ground (Fernández-Arhex & Corley 2003; Gontijo et al. 2012; Parajulee et al. 2006).

The study on prey preferences showed that *P. fuscipes* preferred mostly *R. dorsalis* followed by *Ni. lugens* when they had choices between *R. dorsalis* vs. *N. virescens*, and *Ni. lugens* vs. *N. virescens*. This indicates that *P. fuscipes* predators feed on a variety of prey items but preferred mostly on small and soft-bodied insects as part of their diet. They also practice scavenging besides being predacious in nature. Dead *R. dorsalis* was found to be the most consumed prey. The predator consumed the highest number of *R. dorsalis* or showed greater preference towards it due to the small size body which increased the consumption rate of *P. fuscipes*. According to Peters (1983) and Schmidt-Nielsen (1984), the bioenergetics of animals is known to be influenced by the body size. Fundamentally, if a prey item could not sustain the energy needed by the predator, the predation rate escalates, and the predator will consume or kill more prey to gain more nutrients to stay alive (Vézina 1985). The 'predation rate' is the role of proportion of predator's basic energy demands of maintenance, growth and reproduction to the energy supplied by each prey for its continuous survival chances (Schoener 1968). Kundu et al. (2014) also specified that the quantity and the characteristics of the prey species influenced the preference of predator towards a given prey type in an ecosystem.

The handling time is a good indicator of predation rate as it estimates the cumulative effect of time taken during capturing, killing, subduing, and digesting of prey items (Holling 1966, 1959). In the current study, it was discovered that the shortest handling time was observed on dead *R. dorsalis*, suggesting that *P. fuscipes* gave much stronger predatory response on defenseless and smaller prey item. The time taken to handle the dead green leafhopper, *N. virescens* was considerably higher compared to other prey species. This suggests that due to *N. virescens* being larger in size compared to *Ni. lugens* and *R. dorsalis*. *Paederus fuscipes* took more time to consume *N. virescens*. According to Hoyle and Keast (1987) and Werner (1974), handling time increased rapidly with increasing prey size, and declined considerably with smaller size of prey. Thus, it is true as in the case of *P. fuscipes* feeding behavior.

However, the predator's handling time is vice versa once presented with both live *R. dorsalis* and *N. virescens* prey. The handling time rises on the offered live *R. dorsalis*, but decreased when live *N. virescens* was presented. This could be explained by the following reasons: *P. fuscipes* was able to capture *N. virescens* without difficulty as it displayed little movement due to its larger size, *P. fuscipes* sight ability increases as *N. virescens* is in green colour and bigger in size which making it more susceptible to predation compared to *R. dorsalis*. Overall, *P. fuscipes* preferentially consumed more on *R. dorsalis* and *Ni. lugens* prey compared to *N. virescens*. This preference was supported by the higher attack rate by predator on both prey species presented dead and alive.

P. fuscipes preferential selection over *R. dorsalis* and *Ni. lugens* prey could also be related to the predator's size (Lafferty & Kuris 2002). Allan et al. (1987) study on other predators showed that smaller predator normally favour smaller size prey for their consumption. Moreover, under the 'optimal foraging theory', Stephens and Krebs (1986) indicated that predators will normally select prey that gives the best energy in returns. Hence, *P. fuscipes* might have not waste their energy on relatively larger prey with hard and thick stratum such as *N. virescens* as a lot of energy is needed in handling the prey. By feeding on smaller prey items will decreased the prey handling time (Gerling et al. 1990) which subsequently increased predator's resource food intake in a shorter period of time (Nylin & Gotthard 1998). As a general rule, *P. fuscipes* showed higher preference towards the smaller dead prey compared to the larger alive ones.

Overall, *P. fuscipes* spent more time focusing, and feeding on the presented dead prey item as they do not need to spend time foraging for their prey. Conversely, more effort on catching and ambushing was needed on the presented alive prey items before beetles can finally start to feed. Although once live prey was captured, beetle still need to scuffle on consuming the prey item as it is also struggling to escape. Thus, lower feeding time was shown by *P. fuscipes* for the alive prey items. Overall, the whole feeding process may last up from one to several minutes depending on the types of prey and their condition.

Basically, predator's intermittent locomotion during its searching behavior where pausing during bouts of movement that often involved in acceleration or deceleration in relation to prey movement is a unique behavior. According to Kramer and McLaughlin (2001), stops in between locomotion during searching behavior may promote retrieval from fatigue, improve prey recognition, and reduce detection by other organisms. These foraging characteristics allow *P. fuscipes* rove beetles to be an efficient predator especially to smaller insect pests.

CONCLUSION

As a conclusion, *P. fuscipes* beetles are predacious, and also practice scavenging in their feeding habits to gain

adequate nutrients for their optimal fitness. This feeding trait of *P. fuscipes* is an advantage in continuing its life span in nature following its dispersal towards human settings during rice harvesting stage. For instance, *P. fuscipes* may feed on encounter phytophagous prey dead or alive that is also found in human settings due to the light attraction factor. However, *P. fuscipes* may be more successful in the control of small and soft-bodied crop pests at low prey density particularly during the nursery stage of rice.

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