Dispersal Pattern of *Paederus fuscipes* (Coleoptera: Staphylinidae: Paederinae) in Relation to Environmental Factors and the Annual Rice Crop Cycle

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ABSTRACT *Paederus fuscipes* Curtis, a dermatitis linearis causing agent, has received increasing attention from the public, as it poses a serious health threat after mass dispersal into human-dominated areas. Preventive measures against this insect have so far been unsuccessful partly because of limited knowledge about its dispersal pattern. In this study, the dispersal activity of *P. fuscipes* was studied at infestation-prone residential buildings in Mainland Penang, Malaysia. The dispersal activity of *P. fuscipes* showed two peaks, that is, from February to April and August to October. Overall, there was no statistical significant correlation between dispersal and climatic parameters, that is, temperature, relative humidity, total rainfall, at all sampling localities. However, dispersal was primarily caused by human activities in rice fields, which accounted for >60% of the variability in dispersal. Particularly, rice harvesting, including straw burning, and cultivation were the major factors triggering *P. fuscipes* dispersal. These activities presumably disrupted the habitat and normal activities of *P. fuscipes* and rendered the rice fields unfavorable refuges. In addition, the beetles might also face food shortages after the disturbance of their prey base in the crop fields. The current study provides a predictive tool of *P. fuscipes* flight periods to ensure insecticide residual spraying is timed in the infestation-prone residential areas before the onset of infestation.

KEY WORDS rove beetle, Nairobi fly, *Paederus* dermatitis, generalist predator, crop management

Staphylinidae have long been known as generalist arthropod predators of several agricultural insect pests (Frank and Kanamitsu 1987, Chatzimanolis et al. 2004, Thorbek and Bilde 2004). Of the 50,000 described species distributed worldwide (Grebennikov and Newton 2009), the genus *Paederus* (Coleoptera: Staphylinidae) is notorious for its vesicant body fluid properties that cause dermatitis linearis on human skin (Frank and Kanamitsu 1987). The distribution of *Paederus fuscipes* Curtis is restricted to humid habitats such as marshes, edges of freshwater lakes and streams, and rice fields (Frank and Kanamitsu 1987, Bong et al. 2012), as the larvae are highly susceptible to desiccation (Bong et al. 2013). Adults of *P. fuscipes* are commonly found foraging on the foliage or among the tillers of the rice plants for food and seeking shelter during daytime. They move actively at night in the rice fields (Manley 1977). Nevertheless, adults reportedly disperse to human-dominated areas and survive for a certain period with limited water requirements.

The first *Paederus* dermatitis was reported at the Anjet–Kidoel lighthouse in Java, Indonesia, in 1891 (Vorderman 1901). Since the 1990s, the beetle has received increasing attention from the public. In our sampling sites, the complaints of outbreaks peaked from February to April and August to October each year (Table 1). Various studies have demonstrated the pronounced role of climatic factors such as wind, air temperature, humidity, and rainfall on insect flight behavior (Isard et al. 1999, Elliot et al. 2000, Neoh and Lee 2009). The exposed, soft, and lightly sclerotized thorax might predispose the adult *P. fuscipes* to the risk of desiccation during flight. Therefore, the flight of *P. fuscipes* is typically scheduled during humid and rainy days (Frank and Kanamitsu 1987).

Furthermore, the timing of infestations apparently coincided with the local rice harvest times (Table 1 and Table 2). We speculated that the massive dispersal of *P. fuscipes* was also partly because of the dramatic habitat change during the rice harvesting. According to Landis et al. (2000), many agroecosystem environments are unfavorable to generalist arthropod predators, particularly when intensive crop field management occurs. This is because the activity could disrupt the prey–predator system and disturb the vegetation and terrestrial structures that serve as insect habitat in crop fields (Greenslade 1964, Honek 1988, Topping and Sunderland 1994, Wallin and Ekbom 1994, Halley et al. 1996, Thomas and Jepson 1997, Kromp 1999, Melbourne 1999, Lee et al. 2001, Nicholls et al. 2001, Thorbek and Bilde 2004).

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Table 1. Complaint cases of adult *P. fuscipes* infestation from 2004 to 2010 in Mainland Penang

Year	No. cases												Total
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	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.

In this study, we conducted *P. fuscipes* sampling in the infestation-prone residential areas. We aimed to investigate to what extent both climatic factors and human activities in the rice fields affected the dispersal pattern of the beetle. This study may also serve as a tool to predict *P. fuscipes* flight periods for effective preventive measures, such as residual insecticide spraying in infestation-prone residential premises before the onset of beetle dispersal.

Materials and Methods

Study Sites. The study was carried out on Mainland Penang from September 2010 to September 2011. Penang has a uniformly warm and humid climate throughout the year and receives mean annual rainfall of ≈2,670 mm. The temperature falls between 29 and 35°C during the day and 26 and 29°C at night.

The sampling sites were selected in high-rise residential buildings where cases of *P. fuscipes* infestation were numerous, namely, Desa Wawasan (DW) (5° 21′21.38″ N, 100° 26′50.82″ E, 9 m elevation) and Sri Pinang (SP) (5°26′52.89″N, 100°23′52.69″E, 10 m elevation). DW is located 1.89 km away from 1,016 ha of rice fields, whereas SP is located <500 m away from 1,036 ha of rice fields (data provided by Agriculture Department Penang).

Table 2. Rice cultivation systems in Mainland Penang, northeastern coast of Peninsular Malaysia

Rice cultivation system	Main season	Off season
Cultivation	15 Sept.	15 Mar.
Irrigation		
Wet ploughing		
Puddling and leveling		
Transplanting of seedlings	Late Sept./early Oct.	Late Mar./early April
Sowing seeds		
Manual transplanting		
Machine transplanting		
Growing	Oct.–Feb.	May–Aug.
Vegetative stage		
Reproductive stage		
Ripening stage		
Harvesting	Late Jan.–Mar.	Late July–Sept.
Cutting straw		
Burning straw		

Provided by Agriculture Department Penang, Malaysia.

Trapping Method. Two blocks of buildings at DW (designated as DWa and DWb) and one block at SP were sampled. Trap height is reported to influence the magnitude of trap catches of coleopterans and might void the reliability of a study (Cogburn et al. 1984, Key et al. 1994, Nansen et al. 2001). We first surveyed thoroughly the infested building with the naked eye. At the three locations, samples were collected between the 6th and 12th floor ($n = 6$), where the highest infestations of *P. fuscipes* were recorded. On each floor, six sticky traps (SELL Co., Jakarta, Indonesia), each measuring 28 by 19 cm, were deployed below a 36-W fluorescent lamp (Philips, Bangkok, Thailand) with a light output of 2,600 lm situated at the end of the open-air corridors. The traps were suspended ≈3 m above the floor. Insects were collected at weekly intervals and the traps were replaced with new traps. Sampling was carried out for a 1-yr period. A voucher specimen collection was deposited in the Vector Control Research Unit, Universiti Sains Malaysia.

Meteorological Data. The trapped insect counts of DW and SP were correlated with meteorological data, including hourly air temperature (°C) and relative humidity (%) from 1800 to 0600 hours (the periods of flight activity of *P. fuscipes*) (Hanna and Hamad 1975), and daily precipitation readings (millimeters) that were obtained from the Prai meteorological station (5° 21′ N, 100° 24′ E, 1.5 m elevation) and Butterworth meteorological station (5° 28′ N, 100° 23′ E, 2.8 m elevation) of the Malaysian Meteorological Department.

Rice Field Activity. Rice is cultivated twice a year in Mainland Penang (Table 2), from September to February (main season) and from March to September (off season). In each cycle, there are four main activities, that is, 1) ploughing is carried out soon after the rice fields are irrigated to 3–4 inches above soil surface. The soil is then puddled and leveled. Then the fields are inundated for 2) transplanting the seedlings. The rice takes ≈4–5 mo to 3) grow and ripen. It is then 4) harvested and the straw is burned to provide fertilizer for the fields.

Statistical Analysis. As no significant difference was detected between the selected (6th and 12th) floors (see Results), the captures at each floor were pooled and averages per trap were calculated. Weekly aver-

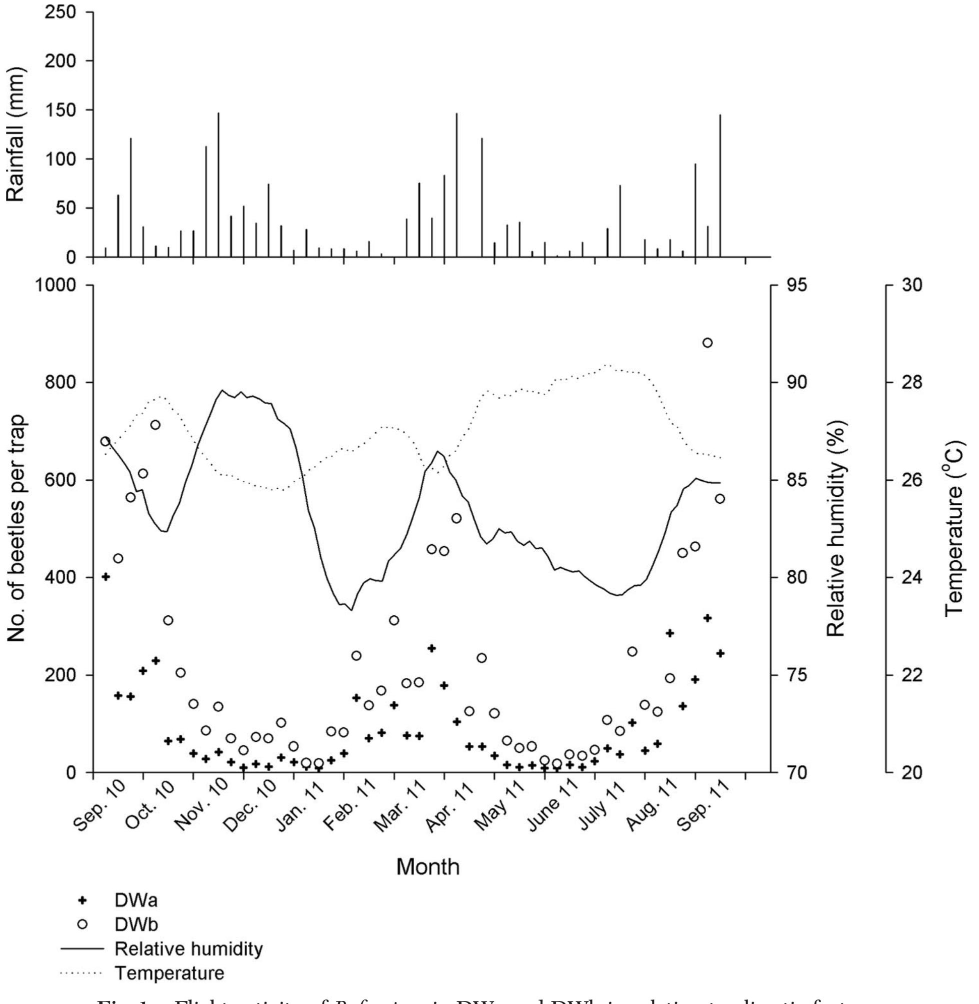

Fig. 1. Flight activity of *P. fuscipes* in DWa and DWb in relation to climatic factors.

ages were used for the meteorological variables. Each rice field activity of cultivation, seed transplanting, growing, and harvesting was numerically scored as 1 (occurrence) or 0 (no occurrence).

Before the statistical analysis, all data were checked for normality. When the criteria of normality were not met, a Log_{10} transformation was performed. The data were then subjected to Pearson rho analysis to examine the correlation between captures and weekly mean meteorological variables, and Spearman rho analysis to investigate the correlation with rice field activities.

The weekly trap data were then regressed against weekly mean meteorological variables and rice field activity variables by using stepwise multiple linear regression. All analyses were performed by using SPSS analysis version 11.0 (SPSS Inc., Chicago, IL) and at $\alpha = 0.05$.

Results

Because no significant differences between the beetle captures at each floor sampled were detected in DWa ($F = 0.770$; df = 4, 20; $P = 0.557$), DWb ($F = 2.102$; df = 4, 19; $P = 0.121$), and SP ($F = 2.271$; df = 4, 20; $P = 0.097$), the numbers of trapped beetles at each floor of the buildings were pooled.

In total, 6,28,513 *P. fuscipes* were caught throughout the sampling period. The highest number of trapped beetles was recorded in SP and DWb with 2,92,439 and 227,629 individuals, respectively. The number caught in DWa was 1,08,445 individuals, approximately two-fold lower compared with SP and DWb. The flight patterns of *P. fuscipes* at the three locations were comparatively similar, with peak flight activity from February to April and from August to October (Figs. 1 and 2). The highest mean weekly capture was 1,100 individuals per trap. However, small flights occurred from May to July and November to January.

In general, correlation coefficients were low between the weekly climatic parameters and flight activity in all localities. However, there was a significant but marginally predictive correlation between the capture rate in DWb and weekly total rainfall ($r = 0.295$; $P = 0.019$) (Figs. 1 and 2).

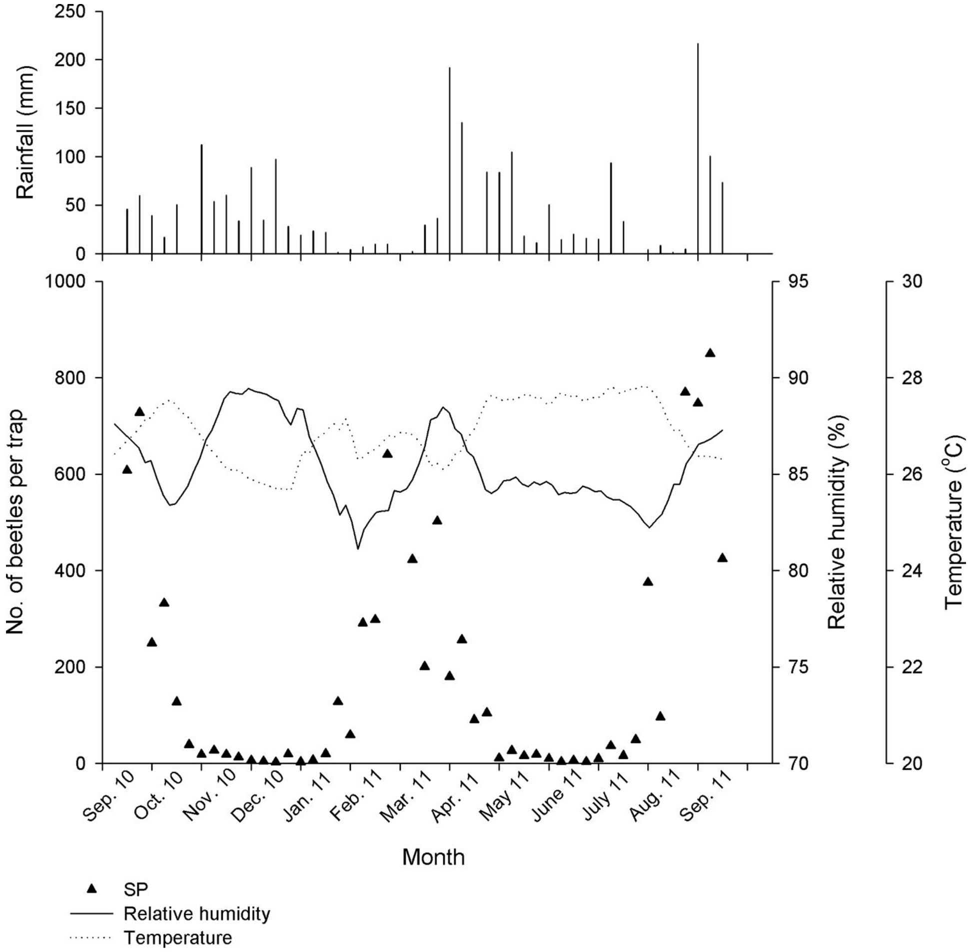

Fig. 2. Flight activity of *P. fuscipes* in SP in relation to climatic factors.

The flight activities were most closely related to human activities in the rice fields. Most flights occurred during harvesting, cultivation, and transplanting of seedlings during the main and off seasons (Fig. 3). For example, in DW, flight patterns were highly positively correlated with harvesting (DWa: $r = 0.649$, $P < 0.001$; DWb: $r = 0.519$, $P < 0.001$) and cultivation (DWa: $r = 0.510$, $P < 0.001$; DWb: $r = 0.607$, $P < 0.001$), and significantly but more weakly with transplanting of seedlings (DWa: $r = 0.258$, $P = 0.035$; DWb: $r = 0.350$, $P = 0.006$). In SP, highly significant positive correlations were detected between flight and harvesting ($r = 0.720$; $P < 0.001$), but the correlation with cultivation was positive but relatively weak ($r = 0.392$; $P = 0.003$). Fewer beetles dispersed during the rice growing periods (DWa: $r = -0.692$, $P < 0.001$; DWb: $r = -0.677$, $P < 0.001$; SP: $r = -0.632$, $P < 0.001$).

Stepwise regression analysis indicated that rice harvesting, cultivation, and growth were main predictors of flights that accounted for 69% of the variability of the trapped beetles in DWa ($F = 36.74$; df = 3, 46; $P < 0.001$), 63% in DWb ($F = 28.20$; df = 3, 46; $P < 0.001$), and 70% in SP ($F = 37.45$; df = 3, 45; $P < 0.001$) (Table 3). The coefficients (B) indicated rice harvesting [DWa: t (46) = 5.84, $P < 0.001$; DWb: t (46) = 4.11, $P < 0.001$] and cultivation [DWa: t (46) = 5.84, $P = 0.002$; DWb: t (46) = 3.95, $P < 0.001$] contributed equally to the variability of the trapped beetles in DW, whereas in SP, harvesting [t (45) = 6.81, $P < 0.001$] was the major factor in triggering dispersal. Again, rice growth had the least impact at the three sites [DWa: t (46) = 2.52, $P = 0.015$; DWb: t (46) = 2.13, $P = 0.039$; SP: t (45) = 2.30, $P < 0.026$].

Discussion

As a rule, warm and very humid conditions are favored by staphylinids for flying (Gnaspini et al. 2000, Chatzimanolis et al. 2004). Previous studies documented that *Paederus* spp. flew during rain or on humid days to reduce the risk of desiccation during flight (Papasarathorn et al. 1961, Hanna and Hamad 1975, Frank and Kanamitsu 1987). In Penang, at least, the weather conditions are warm and humid all year round. Minor variation in the climate was not enough to have an impact on flight activity; conditions were

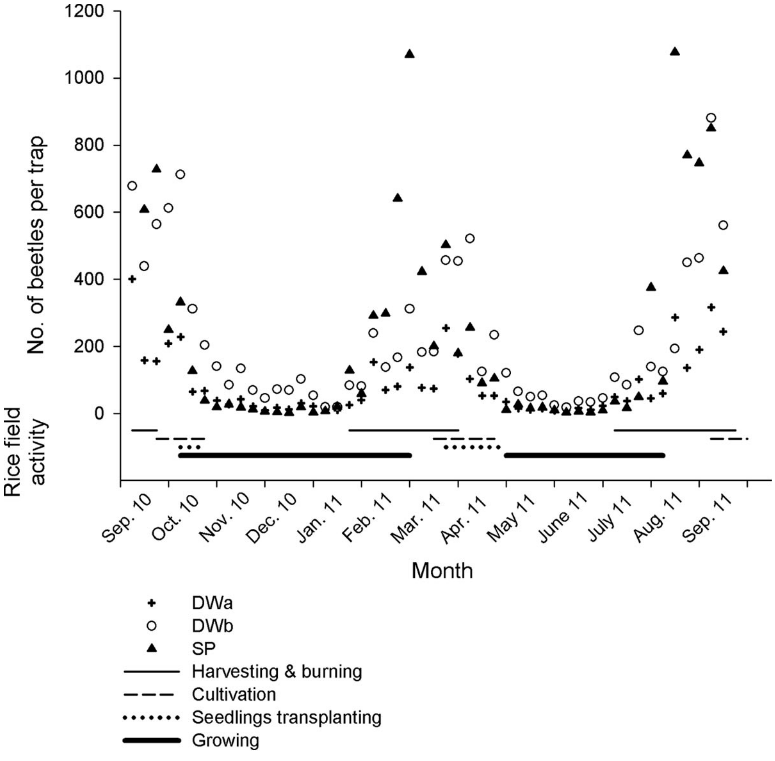

Fig. 3. Flight activity of *P. fuscipes* in relation to annual rice crop cycle.

suitable for the flight of *P. fuscipes* most of the time. Unlike tropical regions, the flights are climate-dependent in temperate or subtropic regions, as the cases of outbreak were typically reported during warmer months (Banney et al. 2000, Zargari et al. 2003, Huang et al. 2009).

Paederus dispersal was initiated when the habitat of the beetles in the rice field was severely disrupted by people, particularly during rice harvesting and when fields were plowed. This conclusion is further supported by little or no beetle flight activity during the crop growing period, when vegetation was abundant and rice fields experienced only limited disturbance. During harvesting, cutting of rice stalks and straw deprives the adult beetles of their main foraging sites (Manley 1977). The situation becomes worse when chaff and straw are burned to fertilize the land. The heat and smoke from the burning rendered the rice fields unfavorable as insect refuges. In addition, turning over, pulverizing, and leveling the irrigated soil in the rice fields intensively deteriorated the habitat of *P. fuscipes.* Similarly, Alderweireldt (1994) and Samu et al. (1996), who studied soil-dwelling Linyphiid spiders as predators in agroecosystems found that alterations in soil structure during cultivation rendered the habitat unsuitable for web construction and forced the

Table 3. Stepwise multiple regression of rice field activity variables against flight activity of *P. fuscipes*

Site	Details of included variables					Significance of final regression model			
	Variable	B	SE	t	P	Adjusted r^2	df	F	P
DWa	*Constant*	1.57	0.13	12.27	<0.001	0.69	3, 46	36.74	<0.001
	Harvesting	0.51	0.09	5.84	<0.001				
	Cultivation	0.37	0.11	5.84	0.002				
	Growing	−0.29	0.11	−2.52	0.015				
DWb	*Constant*	2.02	0.13	15.35	<0.001	0.63	3, 46	28.20	<0.001
	Harvesting	0.37	0.09	4.11	<0.001				
	Cultivation	0.45	0.11	3.95	<0.001				
	Growing	−0.25	0.12	−2.13	0.039				
SP	*Constant*	1.55	0.22	7.06	<0.001	0.70	3, 45	37.45	<0.001
	Harvesting	0.99	0.15	6.81	<0.001				
	Cultivation	0.46	0.19	2.44	0.019				
	Growing	−0.45	0.20	−2.30	0.026				

$y = B(x_1) + B(x_2) + B(x_3) + B_{constant}$, y is trapped beetles and x_1 is harvesting, x_2 is cultivation, and x_3 is growing.

spiders to migrate. Thomas and Jepson (1999) also found that the aerial dispersal of Linyphiid spiders from cereal fields was greater than from grass fields, probably because of differences in crop management systems, for example, harvesting techniques or insecticide applications.

The lack of food that accompanies habitat destruction would also force *P. fuscipes* to disperse. Adult *P. fuscipes* prey on nymphal and adult plant hoppers (Manley 1977, Jahn et al. 2007) and detritivores such as Collembola (Marcussen et al. 1999, Bilde et al. 2000) in the rice fields. The populations of both insects massively decreased at harvest, as the vegetation serves as their food source and reproductive sites (Menge and Sutherland 1976, Bell et al. 1991, Hendrix et al. 1986, Schoenly et al. 1996, Petersen 2002). Consequently, adult *P. fuscipes* migrated first to adjacent and less disturbed rice field margins soon after harvesting, and later dispersed during dusk to residential areas (Miyamoto 1934, Hanna and Hamad 1975). This agreed with observation made by Thorbek and Bilde (2004), who claimed that plowing caused no direct mortality of staphylinids, but immediate emigration from tilled crop fields significantly decreased the population of staphylinids. Hossain et al. (2002) found that adults of generalist arthropod predators moved quickly from harvested alfalfa field to unharvested refuges after the decrease in population of crop pest *Helicoverpa* spp.

Apparently, adult flights to DWa, DWb, and SP started to decrease when seedlings were transplanted. Adults migrated to rice fields and remained there throughout the rice growing period (Manley 1977). Although transplanting of seedlings was shown to have a slightly positive correlation with adult dispersal activity, this might result from cultivation and planting being carried out simultaneously in different sections of the rice growing areas.

Evidently, burning of the rice stubble elicits mass dispersal of *P. fuscipes* from the fields to residential areas. Nevertheless, to date, no better alternative for this ancient low-cost crop management system is available. The method of microbial rice stubble degradation was proposed in recent years; however, it is not as cost effective as field burning. Similarly, direct insecticide application to the crop field against *P. fuscipes* is not feasible, as this agriculturally beneficial arthropod predator needs to be conserved. Thus, insecticide application in infested human settings might be the only option. The current study provided a predictive tool of *P. fuscipes* flight periods. This ensures insecticide residual spraying can be timed in the infestation-prone residential areas before the onset of beetle dispersal.

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