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A Newly Innovated UV-Pit-Light Trap Efficacy For Sampling Beetle Within Oil Palm Plantations Of Various Age Stand Types

Ahmad Bukhary, A.K.[1*], Ruslan, M. Y.[1], Mohd. Fauzi, M. M.[1], Noorhisham, H.[2], Mohd. Yusri, M.N.[3], Muhamad Fahmi, M. H.[1], Nicholas, S.[1], Izfa Riza, H.[1], Idris, A. B[1].

[1]Universiti Kebangsaan Malaysia, Center for Insect Systematics, School of Environmental Sciences and Natural Resources, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia.

prince_bukhary87@yahoo.com, ruslanmdyusop@gmail.com, fauzi_muzamil@yahoo.com, mfahmi85@yahoo.com, nickolas_ukm09@hotmail.com, izfariza.hazmi@gmail.com, idrisyatie@yahoo.com.my

[2]Tun Razak Agricultural Research Center (PPPTR), Felda Sungai Tekam, 27000 Jerantut, Pahang, Malaysia.

nhisham.h@feldaglobal.com

[3]Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, Locked Bag 01, 16300 Bachok, Kota Bharu, Kelantan, Malaysia.

mohdyusrinaser@gmail.com

ABSTRACT

A newly innovated UV-Pit-Light trap specific for trapping beetle species within oil palm plantations is described and the results of experiments on its efficacies that were carried out within different oil palm age stands are presented. The UV-Pit-Light trap is made of two parts: a lower located 1-L plastic collection container inserted into the ground, 6V fast recharging lead-acid battery and 4-W miniature UV-bulb attached to electronic device with wire clips, with the upper located plastic stool for the basic stand and the wide plastic basin for rain and light shield. The UV-Pit-Light trap caught significantly higher beetle specimens, which also included several morphospecies from the common beetle families found in oil palm plantations with 1.5 to 2 times higher in abundances including Nitidulidae, Curculionidae, Scarabaeidae, and Tenebrionidae. Rare beetle families of Aderidae, Cerambycidae, Histeridae, and Lagriidae, which not to be found in passive pitfall trap, were caught in considerable abundances in the UV-Pit-Light trap. The short electro-magnetic wavelengths of UV-light source included many closely packed epigeal related micro-habitats, which makes the UV-Pit-Light trap specific for sampling beetles specifically related within micro-habitats of various oil palm age stand types. The use of only four units of UV-Pit-Light trap compared with 100 units of passive pitfall trap is adequate for sampling beetle species community which includes both the common and uncommon families, and include two times higher for the most abundant and common species than the passive pitfall trap. Thus, the UV-Pit-Light trap allows accurate and unbiased diversity and ecological evaluations of beetle species and proposed to be the specific trapping system for insect species dwelling within the epigeal related micro-habitats oil palm plantations.

Indexing terms/Keywords

UV-Pit-Light Trap, Passive Pitfall trap, Light Trap, Oil Palm Age Stands, Micro-habitats, sampling efficacy.

Academic Discipline And Sub-Disciplines

Entomology, Ecology, Agriculture, Biodiversity.

SUBJECT CLASSIFICATION

Environmental and Agricultural Entomology

TYPE (METHOD/APPROACH)

Original Research Work. The newly innovated UV-Pit-Light trap, modified from the passive pitfall trap.

INTRODUCTION

Pitfall trap is noted as one of the oldest, most commonly employed, and the simplest trapping method compared with other types of invertebrate-related sampling techniques (Woodcock 2005; Spence & Niemelä 1994). First developed by Hertz (1927), and shortly after by Barber (1931), originally used as opened-containers buried within the rim level to the substrate surface, anything falling into the container becomes trapped. Initially, pitfall trap was considered as a qualitative sampling procedure, and the possibility of the technique to be quantitative in sampling *epigeal* invertebrates' populations was soon apprehended (Fichter 1941). From this unexpected starting point, pitfall traps had become to be the mostly preferred for *epigeal* invertebrate sampling (Uetz & Unzicker 1976; Thiele 1977). This sampling technique is economical, saving time for setting up processes, provides high numbers of arthropods and permits various comparable numbers of statistical analyses (Spence & Niemelä 1994). They have been used in practically every terrestrial habitat; from deserts (Thomas & Sleeper 1977; Faragalla & Adam 1985), to forests (Niemelä et al. 1986; Spence & Niemelä 1994), and even to caves (Barber 1931).

Pitfall trapping technique also have been used vastly in obtaining information on the community structure of *epigeal* invertebrates (Hammond 1990; Jarosík 1992), habitat associations (Honêk 1988; Hanski & Niemelä 1990), comparative relative abundances (Desender & Maelfait 1986; Mommertz et al. 1996), explicit spatial distributions (Niemelä 1990), invertebrates activity patterns (Ericson 1978; Den Boer 1981), total population estimations (Gist & Crossley 1973; Mommertz et al. 1996), distributional range characteristics (Barber 1931; Giblin-Davis et al. 1994), and also *epigeal* forensic invertebrate studies (Kocárek 2000; Flechtmann et al. 2009). Besides explicit ecological applications, pitfall traps also implemented in some part of the pest management-monitoring programs (Heap 1988; Obeng-Ofori 1993; Rieske & Raffa 1993; Kharboutli & Mack 1993; Simmons et al. 1998). Different purposes of implementing pitfall trap had also resulted for ecologists to alter various physical-ecological aspects and designs of this simple sampling technique into more elaborated-ecological-related customs, including adjusting their shapes and sizes, according to ecological stratifications (Luff 1975; Adis 1979; Benest 1989; Spence & Niemelä 1994; Brennan et al. 1999; Work et al. 2002; Koivula et al. 2003; Santos et al. 2007; Schmidt 2010; Lange et al. 2011), fabrication materials (Luff 1975; Adis 1979; Benest 1989), addition of fences and guides (Reeves *et al.* 1983; Morrill *et al.* 1990; Holland & Smith 1999), roof coverings and enclosures (Desender & Maelfait 1986; Adis 1979; Spence Niemelä & 1994), addition of chemical and biological baits (Kocárek 2000; Wang et al. 2001; Flechtmann et al. 2009; Wang et al. 2009; Seldon & Beggs 2010), alterations of colors (Buchholz et al. 2010), improving the strength and effectiveness (Porter 2005), and adjustments of the sampling designs and intervals (Pausch et al. 1979; Perner & Scheluer 2004; Schirmel et al. 2010). These variations and differences make associations between studies almost impossible. Kim (1993) and Kremen et al. (1993) had suggested that ecologists need to develop a standard sampling technique that will result in clear comparisons of arthropod ecological studies and making better understanding pertaining to their roles as important bio-indicators.

Hébert et al. (2000), had proposed the newly invented ‘Pit-light trap’ which combined the characteristics of a portable light trap and a pitfall trap, proven to be efficient for trapping beetle species in terms of both species numbers and respective high abundances within various forest ecosystem types, excluding the undesirable direct effects of micro-habitats, as well as reducing other mentioned pitfall trap’s drawbacks from previous researches. However, anthropogenic-altered ecosystems, dissimilar to natural forests, such as the oil palm plantations, typically involved imbalanced and simplified ecological stratifications, with unknown species extinction rates, has an urgent need for stable and standard sampling tool that fit and satisfied ecological evaluations, important for producing accurate information that correctly spear-heading conservational efforts. Oil palm plantations had elaborated *epigaeic* stratification, concentrated with various micro-habitat types, with simplified intermediate and canopy stratifications. Hence, based on the successes attained by the Pit-Light proposed by Hébert et al. in 2000, and *epigaeically and* practically specific of usage, using beetle species as example, this paper describes the newly innovated UV-Pit-Light trap, comparing its effectiveness with the conventional Pitfall Trap, pertaining to (1) various oil palm age stands and micro-habitats, and (2) captures stability across annual seasons, proposing it as a standard and stable tool for monitoring insect species within altered agro-ecosystems.

MATERIALS AND METHODS

To assess the efficacy of pit-light trapping in various ecological settings, sampling experiments were carried out in different types of oil palm age stands, related with several micro-habitat types. Sampling was carried out for 13 months, from February 2013 to February 2014. Oil palm age stand types, replicate co-ordinates, trap numbers, and trapping efforts are summarized in Table 1. In each chosen study site, four pit-light traps (see Figure 1) were placed along with 100 passive pitfall traps, arranged within vertical grid lines, with pit-light and passive pitfalls 10m apart, and the four pit-light traps 80m apart from each other. Features of the newly innovated Pit-light trap are illustrated and described in Figure 2. The trap is made of two parts: a lower arranged 1-L horizontally wide collection container inserted into the ground which has a horizontal diameter of 15 cm and vertical diameter of 8cm, a 6-V rechargeable lead-acid battery and a modified circuit for electronic control of a 4-W miniature ultra-violet (UV) tube. The upper part of the trap consists of a 30cm wide plastic stool, to become a stand to put the 50cm wide plastic basin, function as to prevent rainwater from entering the collection container and as a light shield, to prevent UV-light electromagnetic wavelengths from radiating upwards, leading the UV-light to radiate horizontally across the *epigeal* layer. Each trap was supplied with 100 ml of diluted ethanol and detergent solution (8 parts ethanol, 5 parts distilled water, 1 part detergent) to kill and preserve the specimens. Samples were collected every day after the pit-light traps have been implemented on a nightly schedule.

For passive pitfall traps, samples were collected after 4-5 days to maximized number of catches. All Coleoptera collected were mounted and most of them were identified at the morphospecies level or any related Recognizable Taxomomic Units (RTUs) (Chung et al 2000). Nomenclature follows Borror and White (1970), as well as Triplehorn and Johnson (2005). Voucher species and the original data are stored at the Centre of Insect Systematics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM). The experiment covered an overall area of 2 ha for all the five chosen oil palm age stands. To avoid or minimize trap site differences and to investigate potential depletion due to trapping, traps were rotated after 7 days, with pit-light trapping sites becoming passive pitfall trapping sites and vice versa. In total, there were four trap-rotations per sampling month. T-tests (SAS Institute 1989) were used to compare the mean number of specimens, families and species collected in both trap types and in each study site. For concise presentation, data were grouped by oil palm age stand types and beetle species were classified as abundant, common or uncommon (total number of specimens caught greater than 100, between 10 and 100 and lower than 10, respectively). Regression analysis was used to establish the relationship between the numbers of each beetle species (overall 65 beetle morphospecies) caught in the passive versus pit-light traps. All identified beetle species’ sizes were classified as small, medium and large (length and equal to 4.5 mm, between 4.5 and 10.4 mm, and greater than 10.4 mm, respectively), based on the averaged beetle samples sizes measured. Chi-square analysis was used to compare the abundances of beetle species of each defined size and between different tropical annual seasons, captured in pit-light traps only. Curves describing the number of species collected as a function of the number of traps used were established using the species–area program of the PC-ORD data analysis package (McCune & Mefford 1997). This program subsamples repeatedly up to 500 times for each subsample size (number of traps) to determine the average number of species as a function of subsample size. All possible subsamples are considered when fewer than 500 subsamples can be drawn, which was the case with our experiments.

Table 1. Study sites, geographical coordinates, number of traps, and trapping efforts.

Oil Palm Age Stands	Geographical Coordinates	No. of Traps		Sampling Efforts (Days * Traps)	
		UV-Pit-Light	Passive Pitfall	UV-Pit-Light	Passive Pitfall
< 1 year old					
Replicate 1	N 03°54'592'' E 102°31'502''	4	100	312	18200
Replicate 2	N 03°54'474'' E 102°31'413''	4	100	312	18200
Replicate 3	N 03°54'492'' E 102°31'573''	4	100	312	18200
Replicate 4	N 03°54'382'' E 102°32'023''	4	100	312	18200
3 years old					
Replicate 1	N 03°54'052'' E 102°32'062''	4	100	312	18200
Replicate 2	N 03°54'133'' E 102°32'143''	4	100	312	18200
Replicate 3	N 03°53'582'' E 102°32'153''	4	100	312	18200
Replicate 4	N 03°53'493'' E 102°32'242''	4	100	312	18200
6 years old					
Replicate 1	N 03°54'253'' E 102°32'184''	4	100	312	18200
Replicate 2	N 03°54'234'' E 102°32'071''	4	100	312	18200
Replicate 3	N 03°54'252'' E 102°31'532''	4	100	312	18200
Replicate 4	N 03°54'163'' E 102°31'581''	4	100	312	18200
18 years old					
Replicate 1	N 03°53'592''	4	100	312	18200

	E 102°31'482"				
	N 03°54'113"				
Replicate 2	E 102°31'441"	4	100	312	18200
	N 03°54'062"				
Replicate 3	E 102°31'561"	4	100	312	18200
	N 03°53'482"				
Replicate 4	E 102°31'401"	4	100	312	18200
23 years old					
	N 03°55'024"				
Replicate 1	E 102°30'482"	4	100	312	18200
	N 03°55'001"				
Replicate 2	E 102°31'002"	4	100	312	18200
	N 03°54'532"				
Replicate 3	E 102°31'074"	4	100	312	18200
	N 03°55'042"				
Replicate 4	E 102°31'203"	4	100	312	18200

A

B

C

Fig 1: The UV-Pit-Light trap in operation form (A), and the sub-components (B) and (C).

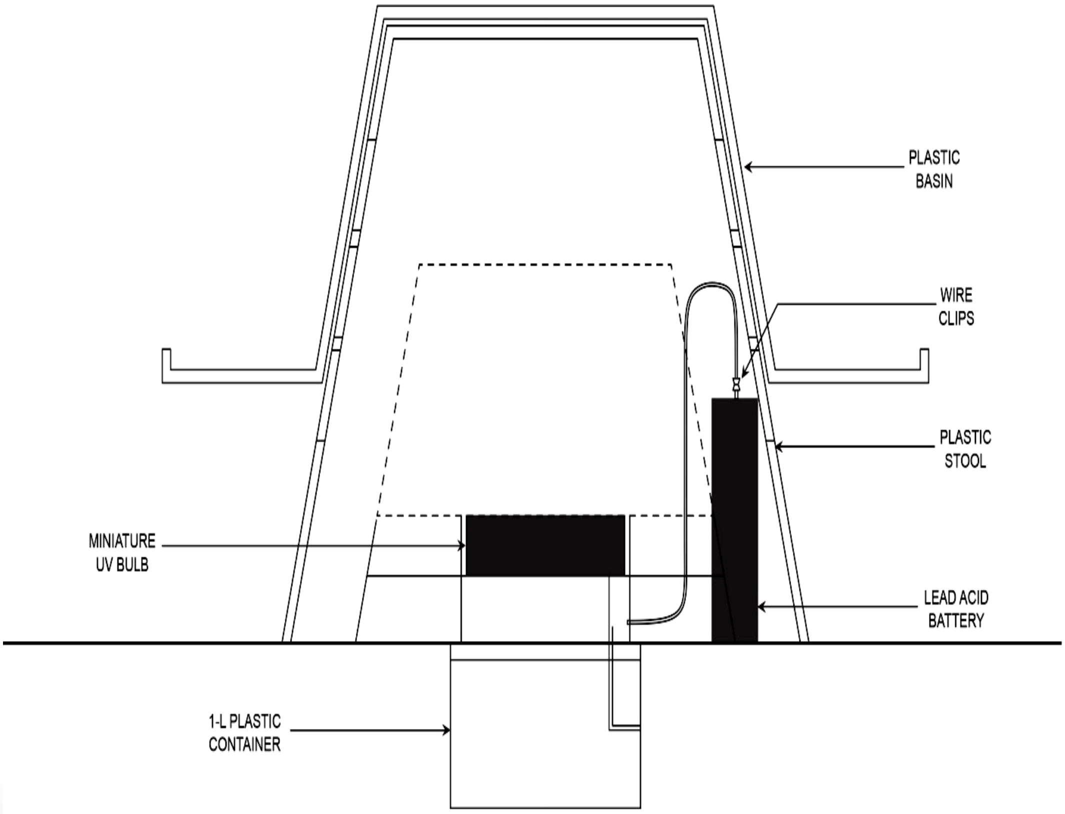


Fig 2: UV-Pit-Light structural elements.

RESULT AND DISCUSSION

A total of 14104 individual beetles representing 65 morphospecies and from 26 families were successfully captured throughout the study. Nearly in all types of oil palm age stands, by far, the UV-Pit-Light trap was more efficient in sampling individuals Coleoptera compared with the passive pitfall trap, capturing for 1.5 to 2.6 times more specimens (Table 2). Significantly more specimens were caught per trap in 4 out of 5 selected study sites (oil palm age stands) at probability level of $P < 0.05$, and the probability levels of the remaining site to be at 0.53 (Table 2). With only four UV-Pit-Light traps were employed, along with 100 passive pitfall traps across all five different oil palm age stands, overall, the UV-Pit-Light trap caught more specimens compared with the passive pitfall traps.

The similar trends can be observed for the mean number of species, families, and subfamilies caught by the UV-Pit-Light trap to be expected higher compared with the passive pitfall traps. Morphospecies ranged from 1.4 to 1.7 times higher captures (Table 6), while the families ranged from 1.0 to 1.3 times higher captures, and the subfamilies ranged from 1.3 to 1.6 times higher captures, all compared with the passive pitfall trap (Table 3, 4, and 5). All of the species, families, and subfamilies captured by the UV-Pit-Light trap were all significantly higher than the passive pitfall trap, with 4 out of 5 selected oil palm age stands showing the level of significant probability level at $P < 0.05$, and the probability of the remaining oil palm age stand to be ranged from 0.82 - 0.96. From all cases of individuals, morphospecies, families, and subfamilies, only the oil palm of the age 18 years old evidently showed no significant differences between the captures of UV-Pit-Light trap and the passive pitfall trap employed, throughout the 13 months of the study period.

The variation coefficients (COV) were generally higher for the UV-Pit-Light trap compared with the passive pitfall trap, where 3 out 5 oil palm age stands showing this pattern, in terms of the number of individuals and the number of morphospecies. For the case of number of individuals, the oil palm age stand 6 years and 18 years old showing lower variation coefficients, while the number of morphospecies, the oil palm of the age 3 and 6 years old showing lower variation coefficient (Table 2 and 3).

Table 2. Mean (±s.d.) number of Coleoptera caught per trap types (UVPLT vs PPF) in five different studied oil palm age stands.

Age Stand	Number of Specimen		p^b	Range		COV (%)	
	UVPLT	PPF		UVPLT	PPF	UVPLT	PPF
< 1 year old	75.0±41.3	47.4±25.9	0.0001	135-13	90-9	55.1	54.6
3 years old	132.5±68.4	50.6±25.5	0.0001	226-17	80-6	51.6	50.4
6 years old	168.9±127.2	76.9±57.9	0.0040	474-47	216-18	75.3	75.3
18 years old	146.4±97.2	132.6±92.4	0.5260	287-24	383-35	66.4	69.7
23 years old	153.6±91.3	101.4±55.7	0.0020	341-48	204-41	59.4	54.9

[b] t-test comparing mean number of Coleoptera specimens caught in UV-Pit-Light Trap vs Passive Pitfall Trap (UVPLT vs PPF).

Table 3. Mean (±s.d.) number of Coleoptera species caught per trap types (UVPLT vs PPF) in five different studied oil palm age stands.

Age Stand	Number of Species		p^b	Range		COV (%)	
	UVPLT	PPF		UVPLT	PPF	UVPLT	PPF
< 1 year old	17.5±5.9	12.9±4.2	0.0001	26-7	19-6	33.7	32.6
3 years old	18.4±5.4	11.2±4.3	0.0001	27-10	19-6	29.2	38.5
6 years old	20.2±6.4	12.0±5.0	0.0001	31-12	20-5	31.7	41.9
18 years old	16.4±7.1	16.2±6.2	0.9390	28-9	27-6	43.3	38.0
23 years old	16.0±5.6	11.4±1.2	0.0001	26-8	19-4	34.7	10.8

[b] t-test comparing mean number of Coleoptera species caught in UV-Pit-Light Trap vs Passive Pitfall Trap (UVPLT vs PPF).

Table 4. Mean (±s.d.) number of Coleoptera families caught per trap types (UVPLT vs PPF) in five different studied oil palm age stands.

Age Stand	Number of Families		p^b	Range		COV (%)	
	UVPLT	PPF		UVPLT	PPF	UVPLT	PPF
< 1 year old	11.4±3.7	9.1±3.0	0.0001	16-5	12-4	32.2	33.2
3 years old	11.4±3.3	8.5±2.6	0.0010	17-6	14-6	29.0	30.1
6 years old	12.9±2.9	9.6±3.0	0.0001	19-10	15-5	22.7	31.4
18 years old	11.6±4.7	11.4±3.8	0.8180	19-6	17-6	40.8	32.9
23 years old	11.6±3.4	9.2±3.1	0.0001	19-7	15-4	29.5	33.6

[b] t-test comparing mean number of Coleoptera families caught in UV-Pit-Light Trap vs Passive Pitfall Trap (UVPLT vs PPF).

Table 5. Mean (±s.d.) number of Coleoptera subfamilies caught per trap types (UVPLT vs PPF) in five different studied oil palm age stands.

Age Stand	Number of Subfamilies		p^b	Range		COV (%)	
	UVPLT	PPF		UVPLT	PPF	UVPLT	PPF
< 1 year old	14.8±5.8	11.1±4.2	0.0010	23-5	16-4	38.8	38.2
3 years old	15.9±4.8	10.5±3.9	0.0001	23-8	18-6	30.0	37.3
6 years old	17.5±5.4	11.2±4.3	0.0001	28-11	19-5	31.1	38.2
18 years old	14.2±6.1	14.2±5.0	0.9630	24-7	22-6	42.9	35.4
23 years old	14.2±4.5	10.4±3.7	0.0001	24-8	18-4	31.7	35.7

[b] t-test comparing mean number of Coleoptera subfamilies caught in UV-Pit-Light Trap vs Passive Pitfall Trap (UVPLT vs PPF).

However, the variation coefficients were much lower for the cases of families and subfamilies, with only 1 – 2 oil palm age stands out of 5 chosen oil palm age stands showing higher variation coefficients, with only the oil palm of the age 18 years old showing higher variation coefficients for the case of families, and the oil palm of the age < 1 year and 18 years old showing higher variation coefficients for the case of subfamilies (Table 4 and 5). These findings are contrasted with the findings by Hébert et al. (2000), where in most cases, the pit-light traps showed the lower variation coefficients. Since this newly innovated UV-Pit-Light trap focuses on the beetle species dwelling within the epigeal-related micro-habitats, it is expected to have higher variation coefficients for the number of individuals and beetle morphospecies, dwelling within these mixtures of both anthropogenic and naturally occurring microhabitats together.

Many morphospecies from the common beetle families found in oil palm plantations such as Nitidulidae, Scarabaeidae, Curculionidae, Staphylinidae, Anthribidae, Tenebrionidae, and Erotylidae were all mainly caught by the UV-Pit-Light trap, and these families were caught with 2 times greater in terms of abundances in the UV- Pit-Light trap than in the passive pitfall trap. The number of individuals and morphospecies from different families captured in each type of oil palm age stand were simplified in Table 6. Several morphospecies from the families Aderidae, Histeridae, Lagriidae, and Cerambycidae were absent in passive pitfall trap, but caught in the UV-Pit-Light trap. To illustrate the potential of UV-Pit-Light trap, the total number of specimens for the 18 most abundant morphospecies (≥ 100 individuals) caught in both the UV-Pit-Light trap and the passive pitfall trap are shown in Table 7.

Arguments that the efficacy and efficiency of the passive pitfall trap could be increased by lengthening the sampling months, and over time, the passive pitfall trap will attained the ideal number of morphospecies and individuals similar to the UV-Pit-Light trap, findings from the species-area curves for overall 13 months of sampling for all 5 chosen oil palm age stands showed that overall, the UV-Pit-Light trap still achieved the higher number of morphospecies and individuals compared with the passive pitfall trap (Figure 4A-J). Even with only 4 units UV-Pit-Light trap compared with the 100 units of passive pitfall trap, the UV-Pit-Light trap still caught desirable numbers of beetle species and individuals. 4 units of UV-Pit-Light trap were set to reduce any inter-trap interactions from the radiating electro-magnetic ultra-violet wavelengths throughout the study plot. The species-area curves also were compared between different tropical annual seasons, mainly involved the hot and dry season, continued with wet and rainy season, common in tropical climate, as to assess the efficacy and stability of UV-Pit-Light within different seasonal forms. Ideally, across both types of tropical annual seasons, the UV-Pit-Light trap was able to catch higher number of individuals and morphospecies compared with the passive pitfall trap (Figure 3A-J). The trending of the species-area curved constructed showed that the UV-Pit-Light trap to have the more tendency to reach the plateau compared with the passive pitfall trap, indicating that smaller number of employed UV-Pit-Light trap are sufficient to produce optimal sampling efforts. Many other researchers still depending on the existing passive pitfall traps for community modeling of insect species within oil palm plantations, before the innovation of UV-Pit-Light trap, hence, to test any comparable results from previous researches employing the passive pitfall traps with this newly innovated UV-Pit-Light trap can be achieved by making comparable abundance-regressions of UV-Pit-Light trap versus the passive pitfall trap (Figure 4A-E). The *r-sq* values for abundance-regressions for all 65 morphospecies and 5 selected oil palm age stands ranged from 52.6% - 99.0%. For all the chosen oil palm age stands, 4 out of 5 selected oil palm age stands showed higher abundance-regression values. The *r-sq* values for abundance-regressions was lowest in the oil palm of the age 18 years old, while highest in the plot of < 1 year old of age. From both the variation coefficients, for the number of individuals and the *r-sq* values of abundance-regressions, the oil palm of the age 18 years old showed higher variations and lower abundance-relationships between the UV-Pit-Light trap and the passive pitfall trap. The oil palm of the age 18 years old have different community structures for the beetle species dwelled within epigeal- related microhabitats with others that widely spread across the oil palm plantations floors and not related with any existing microhabitats.

The possibility that the UV-Pit-Light trap may have selection on the beetle species sizes, overlapped with the tendency for capturing higher beetle species abundances during tropical rainy season per selected oil palm age stands has also been verified. The results indicated that, the distribution of small, medium, and large sized beetle species is nearly identical for species caught in the UV-Pit-Light trap, showing that the UV-Pit-Light trap is not biased for beetle species of a particular size. For the case of all chosen oil palm age stands and for the assumptions of higher capture tendency during the rainy season for small sized beetle species, the oil palm of the age < 1 year old rejected the null hypothesis (χ^2 = 3006.295, df = 192, P < 0.05), followed by the oil palm of the age 3 years old (χ^2 = 14491.32, df = 192, P < 0.05), 6 years old (χ^2 = 25867.29, df = 192, P < 0.05), 18 years old (χ^2 = 29000.47, df = 192, P < 0.05), and 23 years old (χ^2 = 32398.25, df = 192, P < 0.05). Similar results attained for the medium sized beetle species, where all of the chosen oil palm age stands clearly rejected the null hypothesis, with the oil palm of the age < 1 year old (χ^2 = 1367.999, df = 372, P < 0.05), followed by 3 years old (χ^2 = 7974.608, df = 372, P < 0.05), 6 years old (χ^2 = 7548.462, df = 372, P < 0.05), 18 years old (χ^2 = 1866.714, df = 372, P < 0.05), and 23 years old (χ^2 = 2051.053, df = 372, P < 0.05). The null hypothesis is also rejected for the case involved the large sized beetle morphospecies, as for the oil palm of the age < 1 year old (χ^2 = 2115.68, df = 180, P < 0.05), followed by the oil palm of the age 3 years old (χ^2 = 2060.618, df = 180, P < 0.05), 6 years old (χ^2 = 1835.107, df = 180, P < 0.05), 18 years old (χ^2 = 1632.22, df = 180, P < 0.05), and 23 years old (χ^2 = 1738.525, df = 180, P < 0.05).

In terms of elucidating the efficacy of UV-Pit-Light trap to discern true epigeal-related and discarding any unrelated highly active flying insect species that may be commonly attracted by the UV-light source, results showed that the UV-Pit-Light trap successfully reducing the captures of any highly active flying insects species, especially from the Order Diptera, Hymenoptera, and Lepidoptera (Table 8). Order Lepidoptera, which is to be one of the most common Order to be captured in high numbers by most light traps in insect studies, had become much more reduced in the occurrences and captures in the UV-Pit-Light trap acts related microhabitats with others that widely spread across the oil palm plantations floors and not related with any existing microhabitats.

The possibility that the UV-Pit-Light trap may have selection on the beetle species sizes, overlapped with the tendency for capturing higher beetle species abundances during tropical rainy season per selected oil palm age stands has also been verified. The results indicated that, the distribution of small, medium, and large sized beetle species is nearly identical for species caught in the UV-Pit-Light trap, showing that the UV-Pit-Light trap is not biased for beetle species of a particular size. For the case of all chosen oil palm age stands and for the assumptions of higher capture

tendency during the rainy season for small sized beetle species, the oil palm of the age < 1 year old rejected the null hypothesis (χ^2 = 3006.295, df = 192, P < 0.05), followed by the oil palm of the age 3 years old (χ^2 = 14491.32, df = 192, P < 0.05), 6 years old (χ^2 = 25867.29, df = 192, P < 0.05), 18 years old (χ^2 = 29000.47, df = 192, P < 0.05), and 23 years old (χ^2 = 32398.25, df = 192, P < 0.05). Similar results attained for the medium sized beetle species, where all of the chosen oil palm age stands clearly rejected the null hypothesis, with the oil palm of the age < 1 year old (χ^2 = 1367.999, df = 372, P < 0.05), followed by 3 years old (χ^2 = 7974.608, df = 372, P < 0.05), 6 years old (χ^2 = 7548.462, df = 372, P < 0.05), 18 years old (χ^2 = 1866.714, df = 372, P < 0.05), and 23 years old (χ^2 = 2051.053, df = 372, P < 0.05). The null hypothesis is also rejected for the case involved the large sized beetle morphospecies, as for the oil palm of the age < 1 year old (χ^2 = 2115.68, df = 180, P < 0.05), followed by the oil palm of the age 3 years old (χ^2 = 2060.618, df = 180, P < 0.05), 6 years old (χ^2 = 1835.107, df = 180, P < 0.05), 18 years old (χ^2 = 1632.22, df = 180, P < 0.05), and 23 years old (χ^2 = 1738.525, df = 180, P < 0.05).

In terms of elucidating the efficacy of UV-Pit-Light trap to discern true epigeal-related and discarding any unrelated highly active flying insect species that may be commonly attracted by the UV-light source, results showed that the UV-Pit-Light trap successfully reducing the captures of any highly active flying insects species, especially from the Order Diptera, Hymenoptera, and Lepidoptera (Table 8). Order Lepidoptera, which is to be one of the most common Order to be captured in high numbers by most light traps in insect studies, had become much more reduced in the occurrences and captures in the UV-Pit-Light trap acts as light shield gives the UV-Pit-Light extra effectiveness, compared with the pit-light trap proposed by Hébert et al. (2000), which has smaller horizontal covering, allowing more blue fluorescence light emissions throughout the study areas, incorporating the intermediate- and canopy-strata specific beetle species captures, not parallel with the original functions and purposes of the passive pitfall trap. Overall, the UV-Pit-Light trap showed its efficacies over all types of environmental alterations.

Table 6. Total Numbers (first number) and number of species (second number, after /) of Coleoptera from different families captured in UVPLT and PPF in five different oil palm age stand types.

	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5	
Families	**UVPLT**	**PPF**	**UVPLT**	**PPF**	**UVPLT**	**PPF**	**UVPLT**	**PPF**	**UVPLT**	**PPF**
Aderidae	1/1	1/1							1/1	1/1
Anthicidae	8/2	5/2	1/1	1/1	5/1	1/1				
Anthribidae			69/1	26/1	12/1	6/1	10/1	9/1	9/1	6/1
Cantharidae	109/1	69/1	1/1	1/1	26/1	10/1	9/1	10/1	15/1	10/1
Carabidae	12/1	7/1	33/2	13/2	140/2	62/2	12/2	12/2	10/3	7/3
Cerambycidae							1/1	1/1	1/1	1/1
Chrysomelidae	12/5	8/5	61/5	24/5	40/6	18/5	18/5	18/5	11/4	9/4
Cicindelidae	14/1	9/1	80/2	31/2	16/1	8/1	6/2	6/2	2/1	2/1
Coccinellidae	35/2	22/2	250/3	94/2	185/3	88/3	62/2	53/2	32/1	22/1
Cucujidae	18/1	11/1	6/1	2/2	18/1	8/1	7/1	6/1	5/1	4/1
Curculionidae	84/4	53/4	201/4	77/3	204/6	89/5	206/4	203/4	268/5	175/5
Derodontidae	3/1	2/1	1/1				2/1	2/1		
Dytiscidae	181/6	114/6	47/5	19/5	62/5	27/5	51/6	52/6	82/5	57/5
Elateridae	17/2	10/2	16/2	7/2	8/2	3/2	8/2	8/2	16/2	12/2
Endomychidae			9/1	3/1	30/1	13/1	6/1	5/1	12/1	8/1
Erotylidae	16/1	10/1	27/1	10/1	228/1	98/1	54/1	52/1	55/1	37/1
Eucnemidae	5/1	3/1	1/1		1/1		2/2	2/2		
Haliplidae	6/1	4/1	14/1	6/1	13/1	5/1	20/1	19/1	18/1	11/1
Histeridae			1/1				1/1	1/1		
Hydrophilidae	27/2	17/2	10/2	5/2	19/1	9/1	9/1	8/1	18/1	13/1
Lagriidae							1/1	1/1		
Mordellidae	6/2	4/2	23/3	8/2	55/2	26/2	70/1	65/1	25/2	15/2
Nitidulidae	281/3	178/3	740/4	283/4	974/3	455/2	1283/4	1133/4	1328/3	867/3
Scarabaeidae	53/2	32/2	54/2	20/2	88/3	42/3	30/2	22/2	51/3	34/3

Staphylinidae	79/5	49/5	71/3	28/3	70/3	29/3	35/4	35/4	35/4	26/4
Tenebrionidae	13/2	9/2	4/1	2/1	3/2	1/1	5/2	4/2	5/1	4/1

Table 7. Total number of specimens caught in UV-Pit-Light trap (UVPLT) vs Passive Pitfall trap (PPF) for the 18 most abundant Coleoptera morphospecies (number of specimens ≥ 100).

Morphospecies		**UVPLT**	**PPF**
Anthribidae			
Anthribinae	sp1	100	47
Cantharidae			
Cantharinae	sp1	161	100
Carabidae			
Trechinae	sp1	197	94
Coccinellidae			
Scymninae	sp1	549	272
Curculionidae			
Scolytinae	sp1	876	540
Dytiscidae			
Copelatinae	sp1	107	68
Copelatinae	sp3	130	87
Copelatinae	sp5	76	49
Hydroporinae	sp1	64	37
Erotylidae			
Erotylinae	sp1	381	207
Haliplidae			
Haliplinae	sp1	71	44
Hydrophilidae			
Hydrophilinae	sp2	12	7
Mordellidae			
Mordellinae	sp1	165	112
Nitidulidae			
Carpophilinae	sp1	4253	2717
Nitidulinae	sp1	327	182
Scarabaeidae			
Scarabaeinae	sp1	222	119
Staphylinidae			
Paederinae	sp1	171	91
Aleocharinae	sp2	77	49

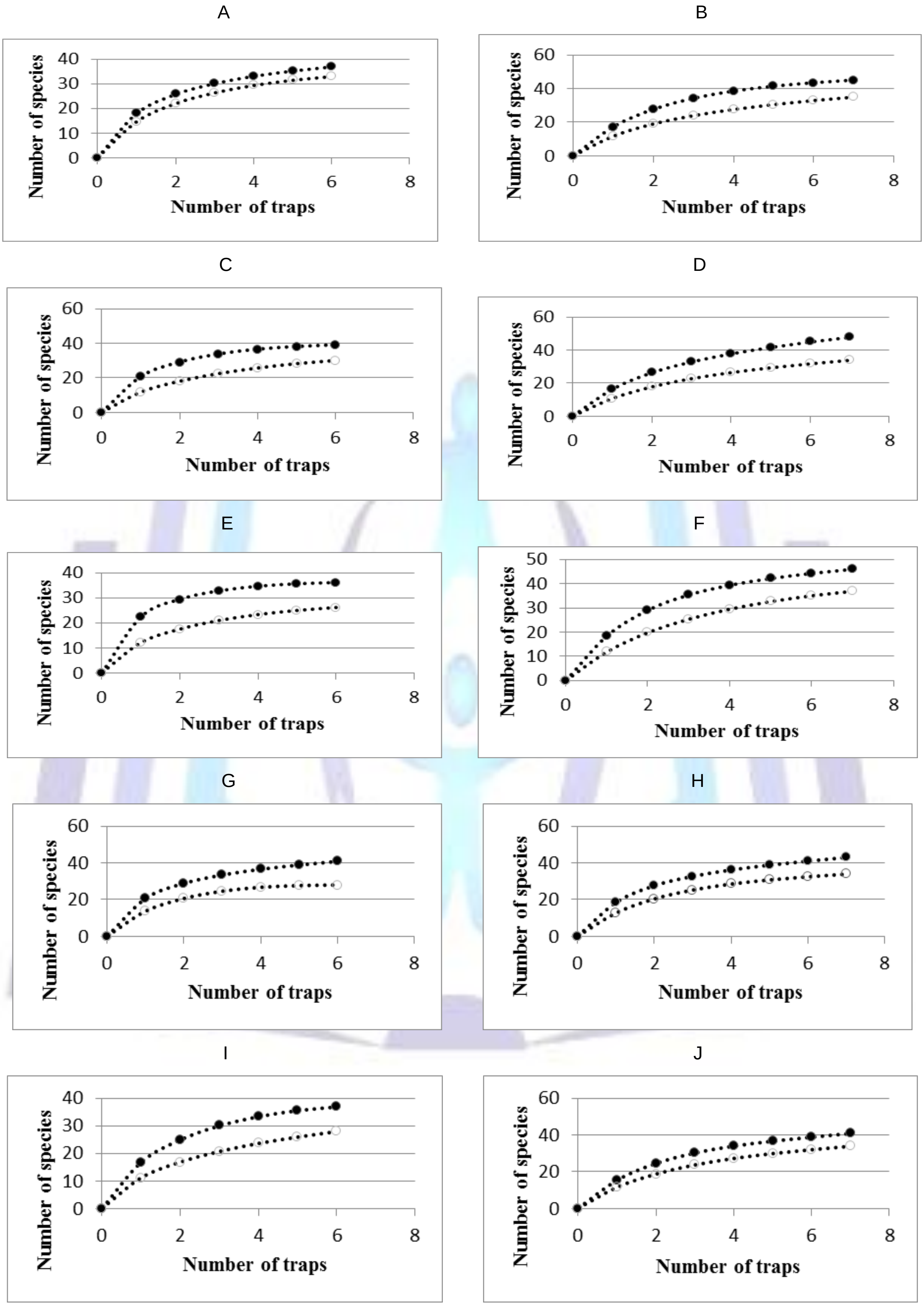
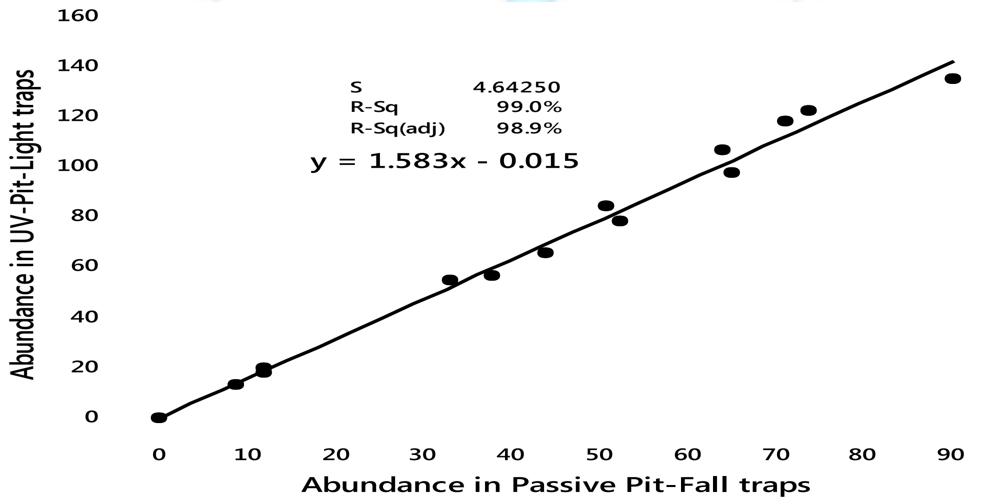


Fig 3: Species-area curves of beetle species for 13 months of sampling period: Oil palm age stand of < 1 year (A-B), 3 years (C-D), 6 years (E-F), 18 years (G-H), and 23 years old (I-J). ┈●┈UV-Pit-Light trap ┈○┈Passive Pitfall trap

In this study, it is proved in all aspects; UV-Pit-Light trap has the superiority over the passive pitfall trap. Heap (1988) was the first to invent both the initial physical structure and the term 'pit-light' trap, depicting a new trap type that combined both the dual qualities of a pit-light trap and a passive pitfall trap, specific for discerning any ground dwelling arthropod pest species. Later, Hébert et al. (2000), which invented a new type of pit-light trap, specifically for discerning beetle species across different forest stand types (Luminoc ®). Heap (1988) had used the UV-light source, but the placement of the UV-light source was not parallel to the soil surfaces, reducing the effectiveness and neglecting the most important quality of a pit-light. The right concept of a pit-light trap is to have the applied light sources to be placed as close as possible to the soil surfaces of the studied ecosystems, parallel to the epigeal layer or stratum. Moreover, the pit-light trap constructed by Hébert et al. (2000), was overall improving the pit-light constructed by Heap (1988), with slight modifications of the placement of the light source, but the light source itself to be vertically arranged, and still not parallel to the soil surfaces. Although it can be argued that, the construction of the pit-light trap by Hébert et al. (2000) was to reduce the impact of micro-habitats on the catching ability of the pit-light of beetle species and hence produce unbiased results for forest biodiversity evaluations, however, neglecting micro-habitats, especially in forest ecosystems, was considered incomplete, as forest stands has several complex stratifications, and the pit-light trap was observed to focus beetle species dwelling the intermediate and canopy strata. The newly innovated UV-Pit-Light trap in this study is much more focused on the true dual quality of a pit-light trap, which (1) using shortest light electro-magnetic wavelength radiation for the medium of attraction for intended insect

A



B

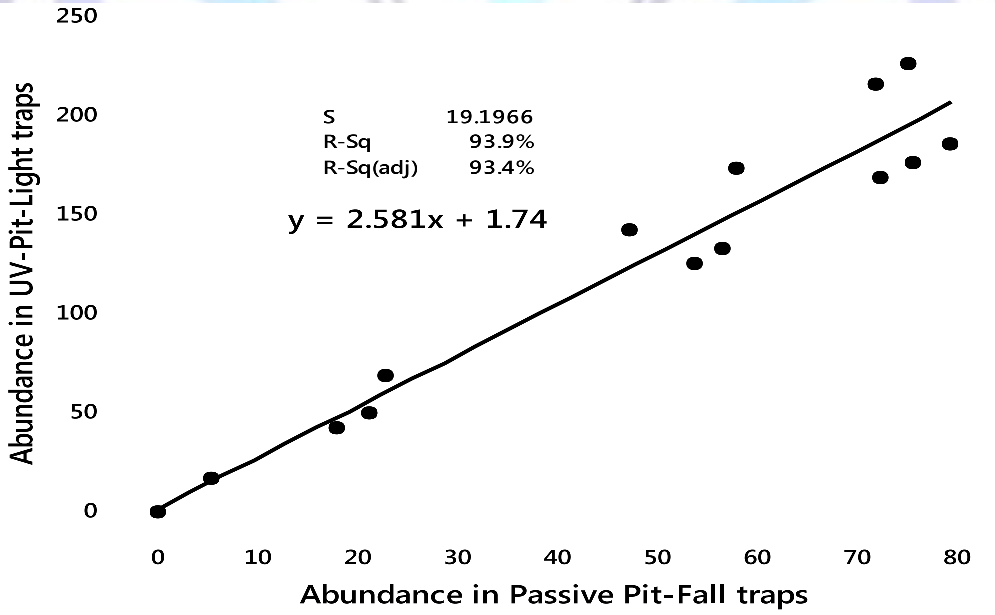
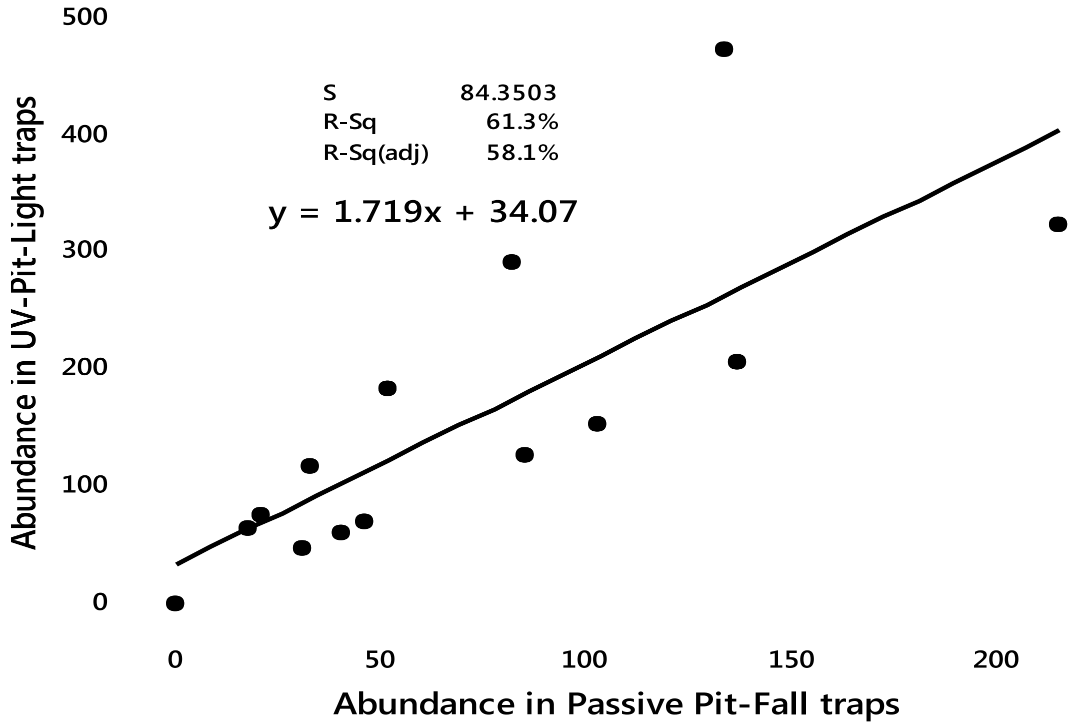


Fig 4: Abundance-regressions of beetle species for 13 months of sampling period between UV-Pit-Light trap and passive pitfall trap: Oil palm age stand of < 1 year (A) and 3 years (B).

C



D

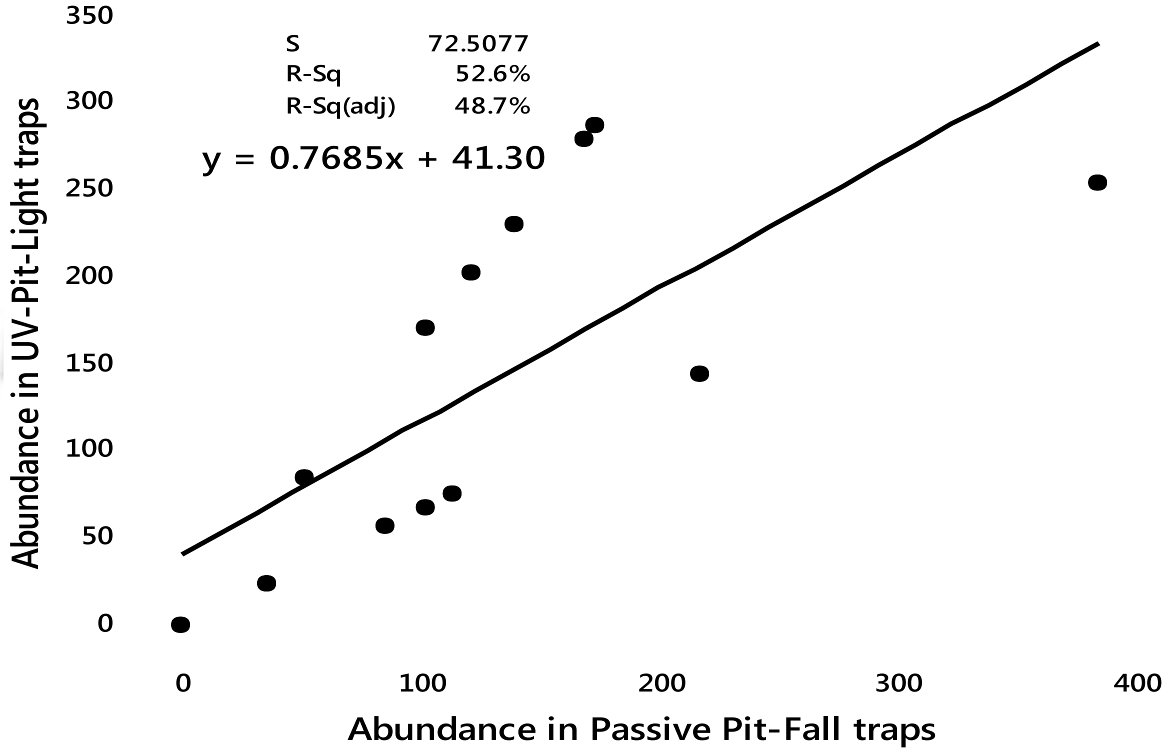


Fig 5: Abundance-regressions of beetle species for 13 months of sampling period between UV-Pit-Light trap and passive pitfall trap: Oil palm age stand of 6 years (C) and 18 years (D).

E

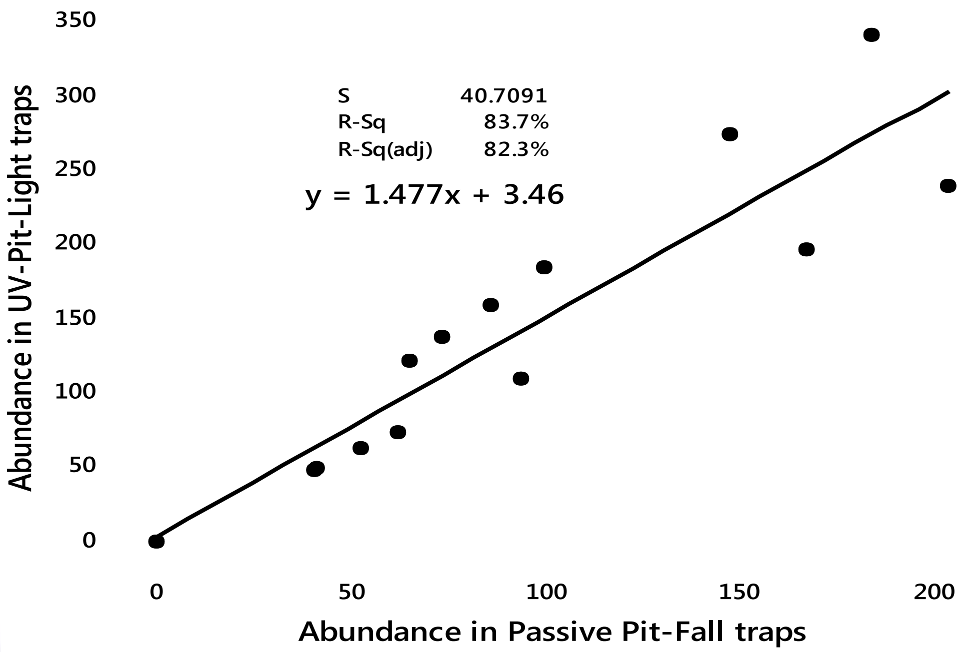


Fig 6: Abundance-regressions of beetle species for 13 months of sampling period between UV-Pit-Light trap and passive pitfall trap: Oil palm age stand of 23 years old (E).

species, related with the conventional light trap and (2) considerations of the microhabitats and other structural diversity close to the application of the pit-light trap, which involved the epigeal layer, and farther from the intermediate and canopy stratifications, related with the conventional passive pitfall trap. Even if the pit-light trap constructed by Hébert et al. (2000) was to reduce the impacts of microhabitats to the captures of beetle species, it is practically plausible to maintain the true nature and quality of a previous version of passive pitfall trap, which focused on the insect species dwelling specifically on the epigeal surfaces. Unlike the oil palm plantations, which were severely altered and simplified, with much concentrated micro-habitats on the epigeal layer, and most life requirement and feeding sources of beetle species focused within these micro-habitats, the innovation of UV-Pit-Light trap has specifically met the demands for micro-habitat-specific evaluations. In addition, the light source for Luminoc ® was in the form of blue fluorescence, with longer electro-magnetic wavelengths compared with the shorter ultra-violet electro-magnetic wavelengths of the UV-Pit-Light trap. The right choice of light sources as well as the correct placement of the light sources together, will contribute to the overall effectiveness of the UV-Pit-Light trap. The newly innovated UV-Pit-Light trap constructed in this study, clearly improved and completing both the pit- light traps constructed by Heap (1988) and Hébert et al. (2000). One interesting aspect of the new UV-Pit-Light trap compared with the other previous versions of pit-light trap is it can detect the variability of the dependency of beetle species on the micro-habitats of different oil palm age stands. The oil palm of the age 18 years old, which showed the highest variation coefficients (COV), proving that within this oil palm age stands, and most beetle species dwelled within the micro-habitats and not spatially dispersed throughout the age stands. Other oil palm age stands showed lower variation coefficient values, indicating the less dependency on the existing microhabitats, to be much more dispersed spatially throughout the epigeal layer of the age stands. This is very important findings as becoming the initial indicator that will spearhead further decisions regarding the conservational efforts and further observe any impacts of management systems that could disturb or alter the viability of microhabitats for beetle species survival. Apart from giving true insight on the beetle species captured based on the availability and dependency on epigeal-related microhabitats, the UV-Pit-Light trap application also resulted in the increased capture of beetle individuals, compared with the passive pitfall trap, which in turn can give different interpretations to the diversity status of beetle species per oil palm age stand. The use of only four units of UV-Pit-Light traps is adequate to sample the overall Coleoptera community per oil palm age stand (per plot and per replicate), compared with the passive pitfall traps even with 100 units, cannot reach the actual beetle species abundances and true community structures successfully achieved by the UV-Pit-Light trap (Figure 5).

Overall, the UV-Pit-Light trap is able to sampled beetle species 2 times greater in abundances compared with the passive pitfall traps, although the trapping effort of the UV-Pit-Light trap is 60 times lower than the passive pitfall trap. In addition, the passive pitfall trap does not have any clear discerning capacity on the impacts of microhabitats, although pitfall traps covered most of the oil palm plantations' floors, and included the closest epigeal-spatial locality for existing microhabitats. The passive pitfall trap showed less variability for the beetle species specifically focused on the micro-habitats on the epigeal layer. With only four units of the UV-Pit-Light trap, most of the characteristics of beetle community shaped by the existing microhabitats can be inferred clearly. Furthermore, as oil palm plantations have various age stands and are arranged to be nearly adjacent to each other, the implementation of UV-Pit-Light trap does not produce any results of inter-age stands or inter-plot beetle community inter-mixtures, dissimilar with other types of canopy- or intermediate-height constructed light trap which tend to capture unrelated and tourist beetle species and unspecific for certain types of oil palm age stand, hence, producing biased results and further wrongly spearheading conservational efforts for certain species that facing higher rates of extinctions than others.

Compared with the results obtained by the Luminoc ® Pit-light trap invented by Hébert et al. (2000), which stressing on the ability of pit-light trap to capture high numbers of Carabidae and Staphylinidae, related with previous studies implementing passive pitfall traps, the UV-Pit-Light trap in this study had proved that only Staphylinidae to be captured in high numbers while not for Carabidae, showing that the UV-Pit-Light trap has the capacity to differentiate and discern any beetle families that facing reductions and increment at the same time, and able to quantify the adaptability of these beetle families to the existing microhabitats per oil palm age stand. Understanding different beetle species statuses under different circumstances is very crucial for making correct conservational decisions (Didham et al. 1998; Myers et al. 2000; Gardner 2010; Hjältén et al. 2012; Lassauce et al. 2012), proved by the capability of UV-Pit-Light trap. Abundance-regressions of beetle species between UV-Pit-Light trap and passive pitfall trap (Figure 4) to be highly correlated to each other, showing that the UV-Pit-Light trap to be comparable with the passive pitfall trap for all types of oil palm age stands, while maintaining its efficacy in discerning variations of beetle species statuses according to different degrees of adaptability to both existing natural and anthropogenic microhabitats.

Even if the results of this newly innovated UV-Pit-Light trap on the captures of adult Lepidopteran pests species was low (Table 8 and Table 9), which will make interpretations regarding the spatial movement of these Lepidopteran pests to be unclear, however, preliminary testing prior to this study had encountered several cases of the captures of a few species of lepidopterans' larvae, especially the nettle caterpillars. It is noted that the pruning activities, which becoming an important part of the management systems, set by oil palm plantation managers, had left several individuals of these lepidopterans' larval pests, feeding on the foliar structures of the mature fronds. The heaps of pruned mature and old oil palm fronds will become new microhabitats for beetle and other insect species and leaving close to the canopy stratum, eventually closer to the epigeal layer.

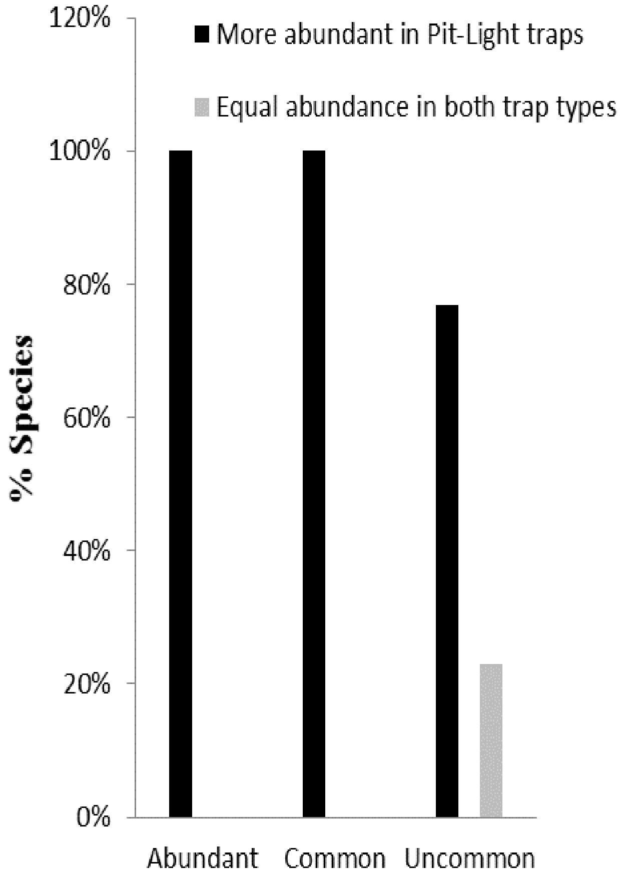


Fig 7: Percentage of abundant (n ≥ 100), common (10 ≤ n < 100), and uncommon (n < 10) of Coleoptera species captured more abundantly in UV-Pit-Light traps vs passive pitfall traps.

The UV-light source from the applied UV-Pit-Light trap attracted these lepidopterans' larvae, hence, showing the efficacy of UV-Pit-Light trap in trapping any epigeal-related insect species, hence, it is suggested that the UV-Pit- Light trap can become an essential trapping method for both pest management, biodiversity, and ecological study purposes. It is for the very first time that the UV-Pit-Light trap, a type of modified pit-light trap from the previous versions by Hébert et al. (2000) and Heap (1988) to be applied within the context of agro-ecosystem, pertaining to oil palm plantations, in which both cases of

Table 8. Mean ± Standard Deviation (S.D.) Species Numbers of Orders of highly active flying insect species per oil palm age stands captures by the UV-Pit-Light Trap.

Order	Mean ± S.D.	Max	Min
Diptera			
	P1 0.615±0.768	2	0
	P2 3.077±1.935	8	0
	P3 1.308±1.437	4	0
	P4 3.000±1.958	7	0
	P5 0.154±0.376	1	0
Hymenoptera			
	P1 1.154±1.345	4	0
	P2 1.923±2.597	7	0
	P3 0.769±1.481	5	0
	P4 1.000±1.297	3	0
	P5 0.308±0.480	1	0
Lepidoptera			
	P1 0.462±0.716	2	0
	P2 0.692±0.751	2	0
	P3 0.385±0.506	1	0
	P4 0.615±0.870	3	0
	P5 0.462±1.127	4	0

insect pest species monitoring and evaluations of ecological aspects of insect species according to management systems and micro-habitats' utilizations are both equally important, parallel to the contexts of productivity and long-term oil palm industry sustainability, and the UV-Pit-Light trap has the dual quality to satisfy both factors at the same time.

Table 9. Mean ± Standard Deviation (S.D.) Abundances of Orders of highly active flying insect species per oil palm age stands captures by the UV-Pit-Light Trap.

Order	Mean ± S.D.	Max	Min
Diptera			
	P1 0.846±1.405	5	0
	P2 3.077±0.537	8	0
	P3 1.385±0.385	4	0
	P4 3.000±1.958	7	0
	P5 0.154±0.376	1	0
Hymenoptera			
	P1 1.154±1.345	4	0
	P2 2.308±2.955	8	0
	P3 0.846±1.725	6	0
	P4 1.462±2.025	5	0
	P5 0.308±0.480	1	0
Lepidoptera			
	P1 0.615±1.044	3	0
	P2 0.692±0.751	2	0
	P3 0.385±0.506	1	0
	P4 0.615±0.870	3	0
	P5 0.538±1.391	5	0

CONCLUSION

It is proposed that the UV-Pit-Light trap to become the specific trapping system for the purposes of bio-monitoring and inventory processes for the agro-ecosystem of oil palm plantations in the future. As the insect species studied within oil palm plantations in previous years much focused on the survival of insect species within certain forest-specialist micro-habitats (Dumbrell et al. 2005; Fayle et al. 2010), it is also of equal importance to observe the survival of insect species within oil-palm-specific micro-habitats.

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Author's biography with Photo

Ahmad Bukhary bin Ahmad Khair is a Full-time Researcher and PhD student of the Center of Insect Systematics, Faculty of Science and Technology, University Kebangsaan Malaysia, Malaysia. His research interests include ecological, environmental, and agricultural entomology. He is also has other research interests including invertebrate biology and entomological community ecology. He had attended and presented at various international symposiums and conferences pertained to the field of entomology.