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DISTRIBUTION OF INVASIVE PLANT SPECIES IN DIFFERENT LAND-USE SYSTEMS IN SUMATERA, INDONESIA

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ABSTRACT

Disturbances caused by the conversion of rain forests into agricultural systems provide an opportunity for the expansion of Invasive Plant Species (IPS). Bukit Duabelas National Park is one of the few remaining lowland forests in Jambi Province (Sumatera, Indonesia). The surrounding areas up to the national park borders have already been converted into jungle rubber agroforests as well as rubber and oil palm plantations which might lead to an increased spread of IPS into the forest. This study was aimed at compiling a list of IPS and determining their distribution and coverage of IPS in four land use systems (rain forest, jungle rubber, rubber and oil palm plantations). Spatial distribution patterns were investigated by creating a horizontal vegetation profile diagram for the permanent plots of the EFForTS project (Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems, http://www.uni-goettingen.de/crc990). The dominance of IPS was determined using Important Value Index. A total of forty IPS were identified across the four land-use systems. The numbers of IPS were the highest in oil palm (28 species) and rubber plantations (27 species), and the lowest in jungle rubber (10 species). IPS were absent in the lowland rain forest. The diversity of IPS was influenced by environmental factors, especially canopy openness. IPS with the highest ground coverage were *Dicranopteris linearis* and *Clidemia hirta*. Both of them were found in all three land-use systems outside the rain forest when the forest canopy opens due to illegal logging or other human disturbances. Therefore, reforestation of disturbed areas is recommended to prevent the spread of IPS.

Keywords: Invasive Plant Species (IPS), Bukit Duabelas National Park, *Clidemia hirta*, *Dicranopteris linearis*

INTRODUCTION

Sumatera is the second largest island in Indonesia and was once covered with forest (WWF 2010). Nowadays, the forests of Sumatera have been largely replaced by three major tree monocultures i.e. oil palms (*Elaeis guineensis*), rubber (*Hevea brasiliensis*) and *Acacia mangium* (WWF 2010). Bukit Duabelas National Park (BDNP) is one of the few remaining forests in the lowlands of Jambi Province in Sumatera under protection. Illegal logging and the conversion of the surrounding areas into jungle rubber, rubber and oil palm plantations might lead to an increase in Invasive Plant Species (IPS) in the forest. Disturbances in the ecosystem such as plantation development provide an opportunity for the

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expansion of invasive alien plants species (Raghubanshi & Tripathi 2009).

Invasive plants are generally defined as plant species that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health (CBD 2000). Invasive plants respond readily to human-induced changes of the environment, but may also cause environmental changes and economic damage through their dominance of the landscape (Pimentel 2011). In general, species distributions are determined by environmental conditions, biotic interactions, evolutionary change and dispersal ability. The success of invasive plants is assumed to be affected by several characteristics including: 1. high dispersal rate; 2. high fecundity; 3. high growth rate; 4. capability of vegetative reproduction; and 5. a high tolerance to various abiotic conditions including temperature, humidity and soil type (Velde *et al.* 2006). Anthropogenic disturbance facilitates the increases of invasive plant species richness (Gassó *et al.* 2009). Some invasive plants have a greater ability than others to colonize disturbed habitats (Freeman *et al.* 2015) and it is important to identify the most dominant IPS representing the biggest threat to invade natural ecosystems.

IPS respond positively to natural or anthropogenic environmental disturbance. Natural disturbance and land use intensity facilitate the introduction of alien plant species in an area (Uddin *et al.* 2013). Light availability and exposed soil facilitate the establishment of IPS. The objectives of this study were to examine the diversity, distribution and coverage of IPS in four land-use systems (forest, jungle rubber, rubber plantation and oil palm plantation), to investigate the most dominant species and the environmental factors influencing IPS distribution.

MATERIALS AND METHODS

Study Site

The study was carried out in Bukit Duabelas National Park (BDNP) and in surrounding villages in Jambi Province (Sumatera, Indonesia). BDNP covers 60,500 hectares and represents one of the few remaining lowland rainforests in Jambi Province with formal protection. The topography ranges from 50 to 438 m above sea level (asl). This forest is inhabited by the nomadic tribe "Suku Anak Dalam" (Orang Rimba). Traditional activities of the Orang Rimba include shifting cultivation, hunting, fishing and honey collection. The surrounding areas outside BDNP are covered by agricultural systems, namely jungle rubber (rubber agroforestry), rubber plantation and oil palm plantation.

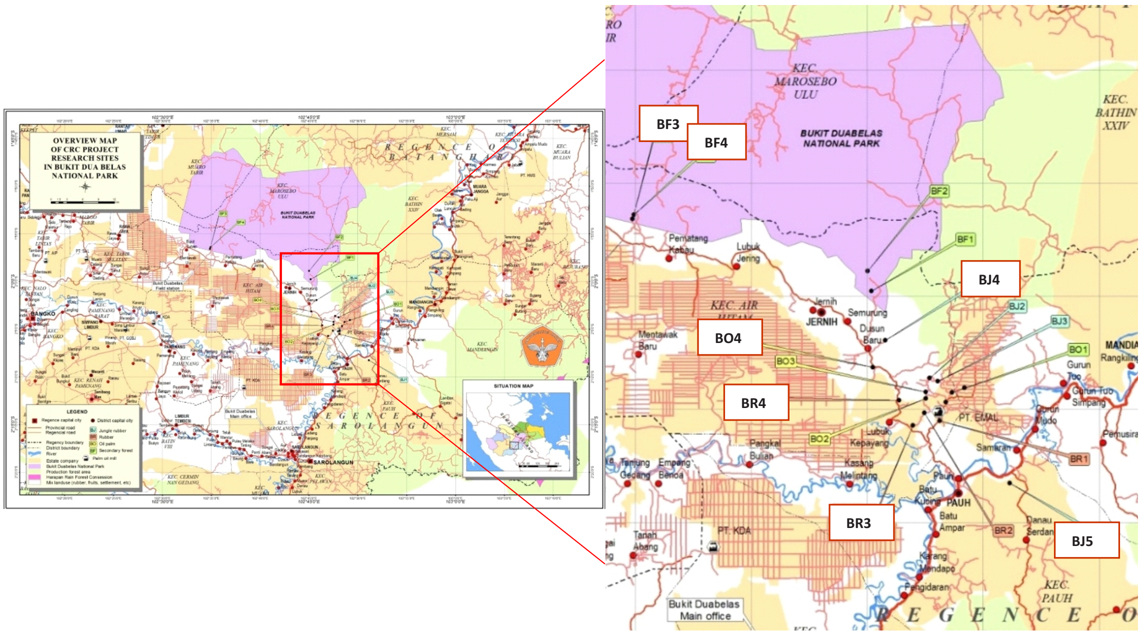

Figure 1 Study site in Jambi Province (Sumatera, Indonesia). The present study was carried out on the following plots: rain forest: BF3 & BF4; jungle rubber: BJ4 & BJ5; rubber plantation: BR3 & BR4; oil palm plantation: BO2 & BO4. (The map was created by Mohd. Zuhdi, Department of Soil Science of Universitas Jambi, Indonesia).

The research was conducted in four different land-use systems: lowland rainforest (F), jungle rubber agroforest (J), rubber plantation (R) and oil palm plantation (O). Forest plots were located inside BDNP and the other land-use systems in three surrounding villages, i.e. Dusun Baru, Lubuk Kepayang and Pauh. Vegetation surveys were carried out within the permanent plots (50 × 50 m) of the EFForTS project (Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems, http://www.uni-goettingen.de/crc990). Two replicate plots were selected for each land-use system resulting in a total of eight plots (Fig. 1).

The Abundance and Presence of IPS

Horizontal profile diagrams for all invasive plants were created by projecting their coverage onto the forest floor. Each 50 x 50 m^2 plot was divided into 25 subplots (10 × 10 m^2) to simplify the calculation and delineation of invasive plant coverage. The coverage was drawn on graph paper with a scale of 1 : 100 in the field, and the sketches were then scanned and digitized in ArcView 3.3.

The dominance of IPS was determined using Important Value Index (IVI), based on the frequency and coverage of invasive plants. To calculate the IVI, the percentage values of the relative frequency and relative dominance were summed and calculated with the following formulas (Cox 1972).

$$\text{IVI} = \text{Relative Frequence} + \text{Relative Dominance} \qquad (1)$$

$$\text{Relative frequence} = \frac{\text{Number of sample plots where a certain species was distributed}}{\text{Number of total sample plots}} \text{ x } 100\ \% \qquad (2)$$

$$\text{Relative dominance} = \frac{\text{Sum total of a certain species in the total sample plots}}{\text{Sum total cover of all species inthe total sample plots}} \text{ x } 100\ \% \qquad (3)$$

Environmental Data

Air temperature and air humidity were measured using thermohygrometers (Galltec Mela, Germany) installed in a meteorological station located in the center of each plot at 2 m above ground. Data were measured hourly and recorded in a data logger (LogTrans16-GPRS, UIT, Germany). The same station also measured soil temperature and soil moisture at 0.3 m depth (Trime-Pico 32, IMKO, Germany). For this analysis, the average of all data recorded for 16 months from June 2013 were used. The canopy cover was calculated from hemispherical photographs taken at 1.2 m above the ground from 32 positions within each plot (Canon EOS 700D SLR camera with a SIGMA 4.5 mm F2.8 EX DC circular fisheye lens). The photographs were taken in early morning (5:00 - 7.00 AM), late afternoon (5:00 - 7:00 PM), evenly overcast days to avoid direct sunlight entering the lens, as described in Drescher *et al.* (2016). To obtain non-overexposed, high contrast photographs, exposure was determined following the histogram-exposure protocol after Beckschäfer *et al.* (2013). The photographs were processed with the software "ImageJ" (Rasband 2014).

Data Analysis

Cluster analysis was carried out to compare the IPS community within the ecosystem. The cluster analysis was conducted based on IVI and calculated into similarity index, which was then converted into dissimilarity index with single linkage clustering. The formulas are as follows (McGarigal *et al.* 2000):

$$\text{IS} = \frac{2\text{C}}{\text{A} + \text{B}} \qquad (4)$$

$$\text{D} = 1 - \text{IS} \qquad (5)$$

where:
IS = Similarity Index;
A = total IVI of IPS in ecosystem A;
B = total IVI of IPS in ecosystem B;
C = the comparison of total IVI of IPS in ecosystem A and B;
D = dissimilarity index.

One-way ANOVA with Tukey-test were used to identify significant differences in the number and coverage of IPS as well as the differences of environmental data among the ecosystems. Principal Component Analysis (PCA) was conducted to observe the relationships between environmental factors and the number and coverage of IPS. One way ANOVA with Tukey-test and PCA were performed using XSLSTAT 2014 software (a Microsoft Excel add-in).

RESULTS AND DISCUSSION

Diversity of IPS within the Different Land-Use Systems

A total of forty IPS were identified in the four land-use systems. Oil palm plantations had the highest richness of IPS (28 species), closely followed by rubber plantations (27 species). In jungle rubber agroforests, the number of IPS was much lower than in the monocultures (10 species), and IPS were absent in rain forest (Table 1 and 2).

Cluster analysis separated the IPS community into three distinct groups (Fig. 2), but oil palm and rubber plantations had the most similar IPS communities. Oil palm and rubber plantations were characterized by a similarly intensive management resulting in comparatively high numbers and compositions of IPS.

Principal component analysis results (PCA) showed that IPS coverage was higher in plots with high canopy openness (Fig. 3). The highest

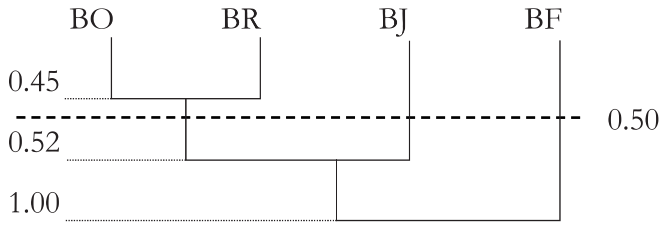

Figure 2 IPS community differences within ecosystems in Bukit Duabelas National Park separated by cluster analysis based on IVI values

Table 1 Diversity of families, genera and species of invasive plants in four land-use systems

Ecosystem type	Number of family	Number of genera	Number of species
Forest	0	0	0
Jungle rubber	6	10	10
Rubber plantation	13	24	27
Oil palm plantation	13	27	28

Table 2 Average species numbers and total coverage (%) of IPS per plot ($50 \times 50\ m^2$) in the four land-use systems

Data	BF (Forest)	BJ (Jungle rubber)	BR (Rubber plantation)	BO (Oil palm plantation)
Average of IPS number per plots (50 × 50 m)	0.00±0.00	8.00±2.83	19.50±0.71	21.00±9.52
Average of IPS total cover (%) per plots (50 × 50 m)	0.00±0.00	43.04±12.54	25.10±30.04	71.80±14.29

Table 3 Environmental data of the four land-use systems (forest, jungle rubber, rubber and oil palm plantations)

Environmental data	Natural forest	Jungle rubber	Rubber plantation	Oil Palm plantation
Air temperature	24.47±0.44	25.05±0.38	25.58±0.36	25.44±0.72
Humidity	91.87±1.61	87.61±2.07	82.58±2.00	83.76±2.42
Soil moisture	25.00±2.40	30.39±2.08	43.54±5.52	35.39±4.73
Soil temperature	25.18±0.28	25.34±2.09	25.33±1.04	26.35±0.93
Canopy Openness	2.14±1.13	5.40±3.12	15.22±6.90	18.70±9.43

Notes: Air temperature, humidity, moisture and soil temperature data are means of 10 replications±standard deviation.
Data of canopy openness are means of 60 replications±standard deviation

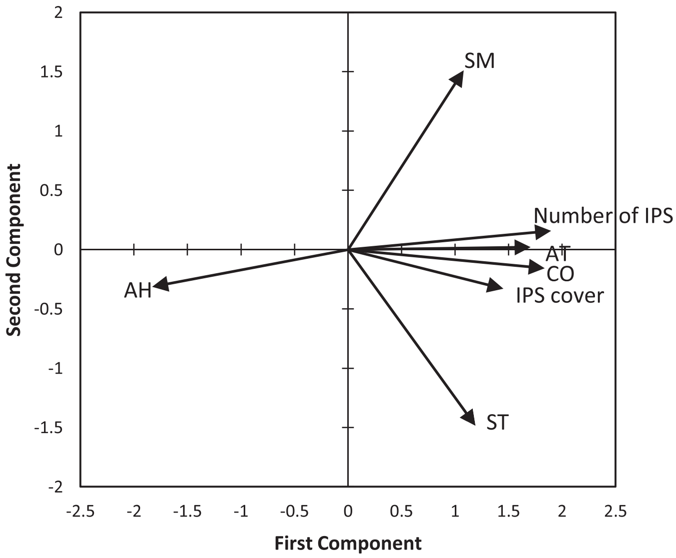

Figure 3 Principal Component Analysis (PCA) on relationship between the number and coverage of IPS to environmental factors: air temperature (AT), air humidity (AH), soil temperature (ST), soil moisture (SM) and canopy openness (CO)

coverage of IPS was found in oil palm plantation which also had the highest canopy openness (18.70%; Table 3). Based on Yaap *et al.* (2010), oil palm plantation, structurally, was less complex than natural forest, with a uniform tree age structure, lower canopy, less stable microclimate and intensively human disturbance. Dominant species in plantation are typically invasive species and pest (Yaap *et al.* 2010). Most of the IPS are shade intolerant. Fine (2002) reviewed that the number of invasive plant species was positively related to disturbance which increased light levels. Additionally, the number and coverage of IPS correlated with air temperature (Fig. 3); higher numbers of IPS were found where air temperature was high.

Air temperature and light influence many plant processes. The interaction of this abiotic factor could influence growth rate, flowering period, seed dormancy and characteristic of plant morphology (Booth *et al.* 2010). In this study, air temperature and light are a strongly regulatory force for IPS distribution. Some invasive species are more successful in disturbed habitat because they are able to take advantage of the high light levels. Besides light intensity, Ibàñez *et al.* (2009) revealed that relatively warmer areas correlated with invasive plants occurrence.

IPS were not found in the rain forest of Bukit Duabelas National Park. Their absence might be due to high canopy cover in the forest, leading to low light penetration as well as cooler and more humid conditions in the understory. These conditions might not support IPS growth. A more open canopy causes higher soil evaporation and increases in air temperature (Lambers *et al.* 2008) which may support IPS growth. Canopy openness and air temperature were lower in the forest than in the other land-use systems (Table 3). Junaedi and Dodo (2014) revealed that most IPS could not reach the forest interior where the canopy cover was still relatively intact. IPS prefer forest edges or forest gaps and are more successfully in infesting open and disturbed areas with high light levels where the native species are not as competitive. Disturbance, therefore, creates habitats that are more suitable for IPS than for native species. This shift from native to invasive species could influence the ecosystem balances. Thus, abiotic factors seem to be more important for the successful plant invasion than biotic factors (Booth *et al.* 2010; Peters 2001). Lower propagule pressure might be additional factor in the forest compared to the three other land-use systems. However, Peters (2001) showed an interesting interplay between abiotic conditions, soil disturbance and wild pig activity affecting the spread of *C. hirta* in a forest reserve in Malaysia.

Species composition of IPS differed between the four land-use systems (Table 4). More than 60% of the IPS in jungle rubber did not occur in rubber and oil palm plantations, while 30% of the IPS in rubber plantation were not found in oil palm plantation. Agroforestry systems such as jungle rubber are characterized by a relatively high diversity of native tree species and high canopy cover and this may cause lower numbers of IPSs. In contrast to jungle rubber, the tree crops in rubber and oil palm plantations are planted in regular distances of several meters to each other and the space in-between is weeded regularly. This condition appears to be most suitable for IPS and may also explain the higher similarity of IPS-communities in the two monoculture systems.

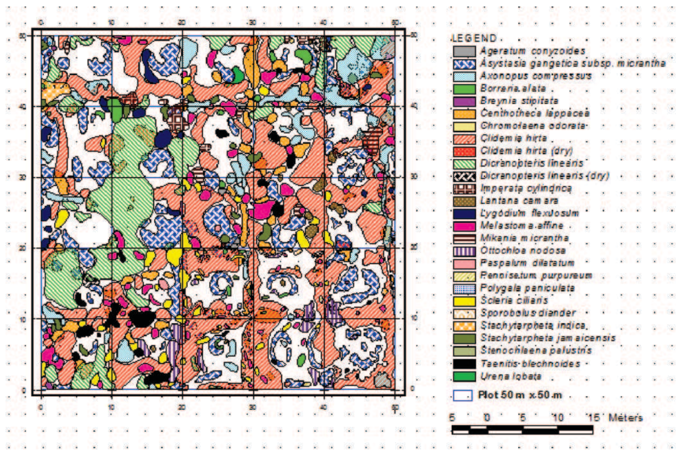

Figure 4 Distribution pattern of IPS at oil palm plantation plot (BO2)

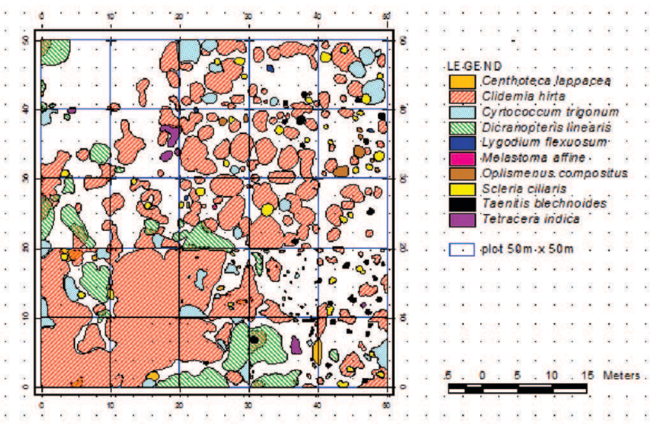

Figure 5 Distribution pattern of IPS at jungle rubber plot (BJ5)

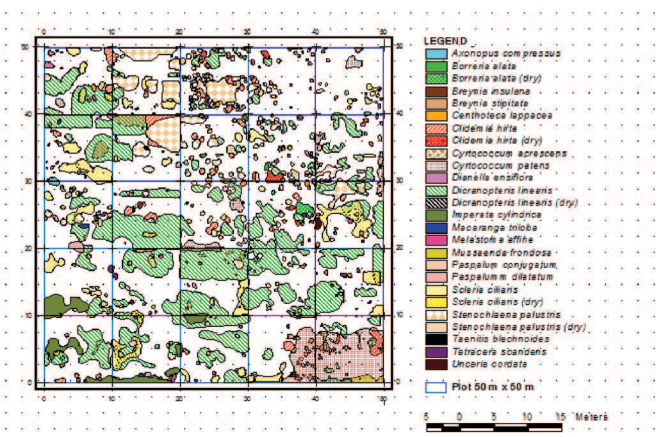

Figure 6 Distribution pattern of IPS at rubber plantation plot (BR4)

Table 4 Important Value Index (IVI) of IPS in four land-use systems in Bukit Duabelas National Park. The species with the highest IVI are highlighted in bold; the native species were indicated by asterisk (*)

No.	Species	IVI (%)			
		BF	BJ	BR	BO
1	*Clidemia hirta*	0	34.23	7.3	45.76
2	*Asystasia gangetica*	0	0	2.64	11.76
3	*Dicranopteris linearis**	0	28.84	17.45	11.25
4	*Centhoteca lappacea*	0	6.81	5.41	8.05
5	*Axonopus compressus*	0	0	5.53	7.83
6	*Scleria ciliaris**	0	13.18	8.23	7.35
7	*Melastoma malabathricum*	0	12.62	5.47	6.7
8	*Ottochloa nodosa*	0	0	0	6.69
9	*Paspalum dilatatum*	0	0	5.51	5.81
10	*Taenitis blechnoides**	0	12.79	5.41	5.74
11	*Lygodium flexuosum**	0	6.38	0	5.46
12	*Stachytarpheta jamaicensis*	0	0	0	5.46
13	*Breynia stipitata*	0	0	5.36	4.94
14	*Imperata cylindrica**	0	0	6.46	3.44
15	*Borreria alata*	0	0	5.38	3.16
16	*Mikania micrantha*	0	0	0	3.11
17	*Stachytarpheta indica*	0	0	0	3
18	*Lantana camara*	0	0	0	2.95
19	*Ageratum conyzoides*	0	0	2.63	2.75
20	*Mussaenda frondosa*	0	0	2.64	2.73
21	*Urena lobata*	0	0	2.65	2.58
22	*Uncaria cordata**	0	0	2.7	2.56
23	*Bridelia insulana*	0	0	2.65	2.48
24	*Pennisetum polistachyon*	0	0	0	2.48
25	*Sporobolus diander**	0	0	0	2.46
26	*Polygala paniculata*	0	0	0	2.45
27	*Stenochlaena palustris**	0	0	7.78	2.45
28	*Borreria laevis*	0	0	2.94	0
29	*Chromolaena odorata*	0	2.45	0	0
30	*Cyperus difformis*	0	0	2.64	0
31	*Cyrtococcum acrescens*	0	0	2.66	0
32	*Cyrtococcum patens*	0	0	7.47	0
33	*Cyrtococcum trigonum*	0	9.94	2.65	0
34	*Dianella ensiflora*	0	0	2.65	0
35	*Fimbristylis dura*	0	0	2.64	0
36	*Macaranga triloba*	0	0	2.78	0
37	*Oplismenus compositus*	0	6.57	0	0
38	*Paspalum conjugatum*	0	0	2.67	0
39	*Tetracera scandens**	0	0	2.77	0
40	*Tetracera indica**	0	14.05	0	0
	Total	0	147.85	133.08	171.4

Spatial Distribution Patterns of IPS within the Land-Use Systems

The horizontal profile diagram provided information on current distribution of IPS. The highest coverage of IPS were in oil palm plantation (74%), followed by jungle rubber (45%) and rubber plantations (30%) (Fig. 4, 5 and 6, respectively). The invasive plants in jungle rubber were evenly distributed within the plots (Fig. 5). High coverage of invasive plants in oil palm plantations is due to the relatively open canopy compared to other land-use systems. However, the invasive plant coverage in rubber plantation was lower than that in jungle rubber, whereas the canopy in jungle rubber was more closed than that in rubber plantations.

The species dominance was analyzed based on the Important Value Index (IVI) (Table 4). *Clidemia hirta* was the most dominant species in jungle rubber followed by the native invasive species *Dicranopteris linearis* and *Tetracera indica*. *C. hirta* was also the most dominant species in oil palm plantation followed by *Asystasia gangetica* and *D. linearis*. In rubber plantations, the most dominant species was *D. linearis*, followed by *Scleria ciliaris* and *Stenochlaena palustris*.

Based on the IVI values, the most important invasive species were *D. linearis* and *C. hirta* and this was also confirmed by the horizontal profile diagrams (Fig. 4, 5 and 6). Both species were found in all three agricultural land-use systems i.e. jungle rubber, rubber and oil palm plantations. The distribution pattern of *C. hirta* is spread generally random and in small colonies. The preferred habitat of *C. hirta* is humid tropical lowland (Dawson 2008). In some cases, *C. hirta* has been introduced intentionally into Botanical Gardens, such as Peradeniya (Sri Lanka) in 1894, Amani (Tanzania) in 1930 and Wahiawa (Hawaii) in 1941 (Dawson 2008). *C. hirta* is dispersed well due to its edible fruits being eaten by birds and other animals and its large numbers of seeds (more than 100 seeds/fruit). In addition, the seeds are able to stay dormant for 4 years in the soil (Dawson 2008). In its native range in South America, this species tends to grow in open areas (Gerlach 2006). Our plots were dominated by *C. hirta* up to the heavily shaded areas in the center of the jungle rubber plots (Fig. 5).

Dicranopteris linearis is a native species and became weed because of deforestation and forest conversion into agricultural systems. In open canopy areas, the distribution pattern of *D. linearis* is clumped in a huge colony. However, *D. linearis* also occurred in jungle rubber where the canopy coverage was relatively high compared to that in rubber and oil palm plantations, *D. linearis* mainly grow in lighter conditions along the plot borders and in canopy gaps (Fig. 5). *D. linearis* is also abundant along roadsides and along the trail leading to the forest.

CONCLUSIONS

There were strong differences in species numbers and community composition of IPS in the four land-use systems studied. Canopy cover and associated changes in abiotic conditions were probably the main factor influencing IPS distribution. IPS infestation was higher in open areas such as oil palm and rubber plantations than that in areas with less light i.e. jungle rubber and rain forest. Canopy cover was the highest in natural forest where IPS were completely absent. *D. linearis* and *C. hirta* were found to be the most widely distributed IPS. Some activities that facilitated disturbances, i.e. land-use change, illegal logging and forest fire should be prevented. Immediate action of reforestation of disturbed areas in the national park should be applied. The IPS which were established in the plantations should also be prevented from spreading into the national park. It is necessary to prohibit visitors entering the national park from the fully IPS invaded pathway from the plantations. Immediate action needed to destroy IPS infestation to BDNP.

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