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The Distribution of an Invasive Species, *Clidemia hirta* Along Roads and Trails in Endau Rompin National Park, Malaysia

Cao Le[1], Kosuke Fukumori[2], Tetsuro Hosaka[2], Shinya Numata[2], Mazlan Hashim[3], and Takashi Kosaki[2]

Abstract

Invasive species pose a grave threat to many national parks. Construction of roads and trails for tourism may facilitate invasion of alien species. To understand the effect of road and trail construction on invasive species, we established six transects in three land-use types (forest interior and road or trail edges) in Endau Rompin National Park, Johor, Malaysia, where we measured the number of an invasive shrub, *Clidemia hirta* (Melastomataceae), canopy openness, and soil properties; compared the density of *C. hirta* between the three land-use types; and finally, identified soil and canopy variables affecting its abundance using generalized linear mixed models. *C. hirta* was found along the road and trail with density ranging from $0.0\,m^{-2}$ to $33\,m^{-2}$ (average: $3.8\,m^{-2}$), but was not found in the forest interior. Generalized linear mixed models suggested that canopy openness and soil pH negatively affected the density of *C. hirta* along the road, as did total soil nitrogen along the trail. This suggests that *C. hirta* was more abundant along dark and nutrient-poor road and trail edges. The construction of narrow roads (2.0–3.8 m) and trails (0.5–2.0 m wide) at our site would be considered a relatively minor disturbance without intensive clear cuts, and *C. hirta* seemed to prefer habitats with such minor disturbances. In the tropical rainforests, the managers or conservationists of the national park should include consideration of the effects such as minor disturbances have on invasive species.

Keywords

invasive species, tropical rainforest, soil, canopy openness, tourism impact

Introduction

Tropical forests are exceptionally rich reservoirs of biodiversity on Earth. Southeast Asia is exposed to the highest relative deforestation and logging rates globally despite the attention to policies for reducing deforestation (Bradshaw, Sodhi, & Brook, 2009; Lambin & Meyfroidt, 2011). The establishment of protected areas, with legal restrictions on land-use changes and collections of wild plants and animals, is one of the most effective strategies for minimizing forest degradation (Clark, Bolt, & Campbell, 2008).

Nevertheless, invasive species pose a grave threat to many protected areas, and even one of the most ecologically acceptable methods to protect natural areas such as ecotourism or nature tourism may facilitate the introduction of alien species into heretofore little disturbed natural habitats by bringing in large numbers of humans from far away (Poorter, Pagas, & Ullah, 2007). Poorter et al. (2007) were able to identify 487 protected area sites with invasive alien species recorded as an impact or threat; in 106 countries, protected areas have been recorded as having invasive alien species as an impact or threat, especially in Peninsular Malaysia, Singapore,

[1]Tourism Management and Planning Academy, Guangdong University of Finance and Economics, Guangdong, China
[2]Department of Tourism Science, Tokyo Metropolitan University, Tokyo, Japan
[3]Institute of Geospatial Science & Technology, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Corresponding Author:
Cao Le, Tourism Management and Planning Academy, Guangdong University of Finance and Economics, 21 Luntou Road, Haizhu, Guangzhou 510320, Guangdong, China.
Email: laku413@live.jp

South Western Australia, South Africa, the Brazilian Amazon region, and Central Himalayan Foothills of India. Furthermore, invasive species coverage and soil compaction were reported to increase along the roadsides in South Australia (Wolf & Croft, 2014). In addition, Speziale and Ezcurra (2011) found that anthropogenic disturbance facilitated the invasion of alien plants in a national park in Argentina. The constructions of access roads and trails are essential for the development of tourism in wild areas. Road construction often results in canopy openings and soil compaction and alters microclimate, soil properties, drainage patterns, and forest accessibility (Laurance, Goosem, & Laurance, 2009; Malcolm & Ray, 2000). Padmanaba and Sheil (2014) inferred that roads are assisting invasive species spread and it will become widely established in Borneo. Although ecotourism have benefits for sustainable conservation and management of natural resources in tropical countries, it can also have adverse effects.

Even though undisturbed tropical rainforests have rarely suffered from invasion by alien species (Fine, 2002; Levine, 2000), *Clidemia hirta* (L.) D. Don. (Melastomataceae), which originated in South America, provides one exception, as it has colonized undisturbed tropical forests in Southeast Asia (Peters, 2001). *C. hirta* is a highly invasive plant presenting a conservation nuisance, and it is prevalent throughout the Pacific Ocean and Indian Ocean, including several islands (Cronk & Fuller, 1995; Rejmánek, 1996; Wester & Wood, 1977). In Hawaii, *C. hirta* may be replacing endemic species that had been predominant, leading to their extinction (Wester & Wood, 1977). Both humans and wild animals have been implicated in the spread of *C. hirta*. Ground disturbance by wild pigs (*Sus scrofa*) has played a vital role in the establishment of *C. hirta* and other alien species in Hawaii (Smith, 1992). At Pasoh, in Peninsular Malaysia, the distribution of *C. hirta* was found to be related to soil disturbance by wild pigs and to openings in the canopy (Fujinuma & Harrison, 2012; Peters, 2001). Thus, canopy openness and soil disturbance appear to be the key factors affecting the distribution of *C. hirta*.

Understanding suitable environments for invasive species colonization is a means to fundamentally predict and prevent the invasion of invasive species. However, few studies have quantitatively described suitable environments for *C. hirta* colonization in Southeast Asia. We attempted to clarify the effect of soil and canopy variables on *C. hirta* invasion and provide available information to managers of the national parks. Therefore, we established six transects in three land-use types (forest interior and road or trail edges) in Endau Rompin National Park (ERNP), Johor, Malaysia, where we measured the number of *C. hirta*, canopy openness, and soil properties; compared the density of *C. hirta* between the three land-use types; and finally, identified soil and canopy variables affecting its abundance using generalized linear mixed models (GLMMs). In this study, we address the following questions to provide useful information for the management of roads and trails: (a) Is the abundance of *C. hirta* higher along roads and trails than in the forest interior? (b) Which environmental factors have effect on the abundance of *C. hirta* along roads and trails?

Methods

Study Site

We conducted our study in the Peta area of ERNP in Johor state, Peninsular Malaysia (2°31′N, 103°24′E, 40 m a.s.l.; Figure 1). The Peta area covers 19,562 ha. The mean annual temperature is 27°C and it receives 2,000 to 3,600 mm of precipitation annually with peak rainfall occurring between October and March (Department of Irrigation and Drainage, Malaysia). The dominant plant family is the Dipterocarpaceae. The major soil base materials are igneous rock, volcanic rock, metamorphic rock, and sedimentary rock (Idris, Azman, & Rosedean, 1987). ERNP is managed by the Johor National Parks Corporation (JNPC) and has been open to the public since September 1993. Approximately 4,000 visitors enter the Peta area each year (JNPC unpublished data). Approximately 20% to 30% of these visitors come from western countries, and the rest are domestic or Singaporean tourists. The largest number of tourists visit the park in May (500–700 visitors/month), while the fewest come in December and January (<100 visitors/month). The park provides opportunities for various tourist activities, including camping, jungle trekking, night walking, swimming, canoeing, river rafting, and nature education. In the Peta area, jungle trekking from the Kuala Jasin campsite to the Upeh Guling waterfall and swimming at Tasik Air Biru near the Kuala Marong campsite are popular activities (Aihara, Hosaka, Yasuda, Hashim & Numata, 2016).

Study Species

C. hirta is native to Central and South America and the Caribbean Islands (Wester & Wood, 1977). It is known to have invaded many islands in and countries adjacent to the Pacific Ocean and Indian Ocean, including Hawaii, the Seychelles, Fiji, India, Tanzania, Singapore, and Peninsular Malaysia (Cronk & Fuller, 1995; Wester & Wood, 1977). *C. hirta* is a densely branching woody shrub with a maximum height of 2 to 3 m, and it has opposite leaves that are 5 to 18 cm long (Wester & Wood, 1977). A large plant may produce more than 500 fruits per year (Smith, 1992), which are purple-to-black berries 6 to 8 mm long with an ellipsoidal shape,

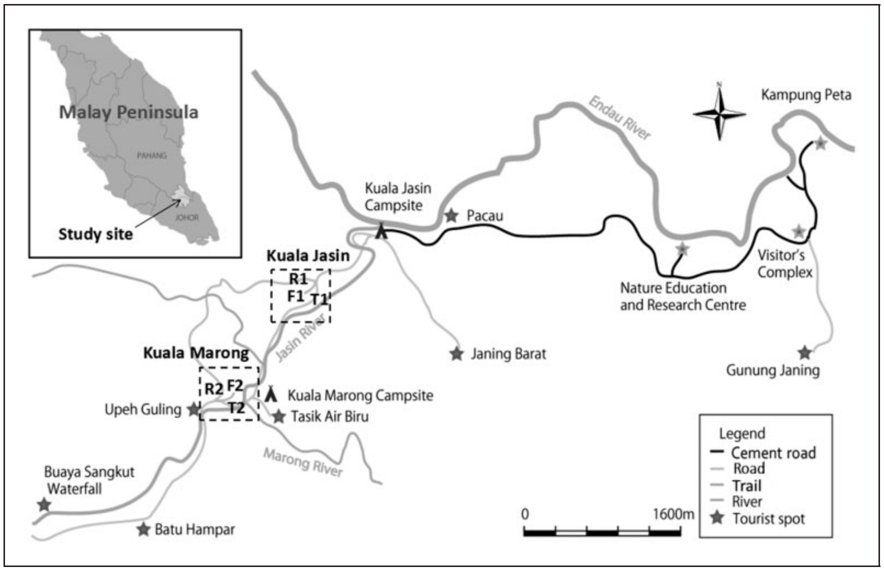


Figure 1. Location of the study sites in Endau Rompin National Park. R, T, and F indicate road, trail, and forest, respectively, and numbers represent study sites (1: Kuala Jasin and 2: Kuala Marong).

each containing over 100 coffee-colored seeds dispersed by animals such as small birds (DeWalt, Denslow, & Ickes, 2004). *C. hirta* does not undergo clonal reproduction. The breeding system of *C. hirta* may include both sexual reproduction and apomixis (Renner, 1989).

Data Collection

We carried out sampling of *C. hirta* abundance, and canopy and soil properties in September 2012 at the Kuala Jasin and Kuala Marong campsites, both located near the junction of a road and a trail. Employees of the national park did not manage *C. hirta* in the study sites. Tourist activities such as trekking were more common at Kuala Marong than at Kuala Jasin because Kuala Jasin is an entrance to the jungle for tourists, while Kuala Marong is a sightseeing area. Each site contains three land-use types (Figure 1): forest, trail, and road. Both of trail and road were unpaved. There is little tourist activity in the forest area. The road (2–7 m wide) was constructed for logging during the 1970s to 1980s in some areas of the park (Stecker, 1996) and opened to tourists after the national park was established. Vehicles pass the study sites along the road once or twice per week. The trail (0.5–2 m wide) was constructed for jungle trekking and is closed to vehicles.

We established six transects (300 m each) in each of the three land-use types at Kuala Jasin and Kuala Marong, where we measured the number of *C. hirta*, canopy openness, and soil properties. Each transect was divided into thirty 10 -m sections (Appendix). We counted the number of *C. hirta* individuals within 1×10 m quadrats along both sides of the trail. Along the road, *C. hirta* was too abundant for that method, so we counted plants within 1×1 m quadrats. We also counted the number of *C. hirta* within 2×10 m plots in the forest, which were each 5 m away from the nearest trail transect. We took hemispherical photographs of the forest canopy with a fish-eye lens converter (Fish-eye Converter FC-E8, Nikon) mounted on a digital camera (Coolpix990, Nikon) at the center of each section and quantified canopy openness using HemiView Canopy Analysis Software v.2.1. (Delta-T Devices Ltd., Cambridge, UK). We collected 180 topsoil samples with three replicates (total samples: 540) using a cylindrical soil sampler (100 cc) on both sides of each section. Each soil sample was air-dried and passed through a 2-mm pore-size sieve for chemical analysis. We measured bulk density, pH, and total nitrogen (TN). These soil properties are important for the survival and performance of plants (Schoenholtz, Miegroet, & Burger, 2000). The fresh soil samples were oven-dried at 105°C for 24 h and weighed for bulk density calculation. Soil pH was measured with a glass electrode using a soil-to-water ratio of 1:5 after shaking for 1 h. Soil samples were finely ground in preparation for TN analysis via an elemental analyzer (NC-800-13 N; Sumika Chemical Analysis Service Co., Osaka, Japan).

Data Analysis

To address the first research question, we compared the density of *C. hirta* (number of individuals/m^2) among quadrats using the Kruskal–Wallis test. Since different land-use types (i.e., forest, trail, and road) shared borders at each site, comparisons within each site allowed us to evaluate the effect of land-use type while minimizing the effects of spatial differences. To answer the second research question, we evaluated the effect of canopy and soil variables on the density of *C. hirta* along the road and the trail using GLMMs with negative binomial distribution error structures. For correcting data sampled over different temporal and spatial extents, the site ID was considered a random effect, and the area of the quadrat an offset term. We established GLMMs for the road and trail combined and separately. Explanatory variables included bulk density, pH, TN, and canopy openness. Before starting GLMMs, a Pearson correlation coefficient among the explanatory variables was determined, and we did not find the multicollinearity problem. To select the most parsimonious model, we assessed models with all possible combinations of variables based on the Akaike Information Criterion (AICc) for small sample sizes (Chambers & Hastie, 1997). The model with the lowest AICc value is the most plausible considering the trade-off between model fit and the number of parameters included. In this analysis, models within 4 AICc points of the best model are considered supported (Burnham & Anderson, 2002). Relative variable importance was used to assess the relative importance of each explanatory variable. All statistical analyses were performed with R 2.12.2 (R Development Core Team, 2009) and its packages glmmADMB (Bolker, Skaug, Magnusson, & Nielsen, 2012) and MuMIn (Barton, 2013).

Results

The Distribution of C. hirta Among Land-Use Types

A total of 1,877 *C. hirta* individuals were recorded at both Kuala Jasin and Kuala Marong sites (mean density: 3.8 m^{-2}). Of this, 1% were found along the trail at Kuala Jasin, 41% along the trail at Kuala Marong, and 58% along the road at Kuala Marong, while *C. hirta* was absent in all other transects. The density of *C. hirta* was significantly ($F = 3.8$, $p = .02$) higher along the trail than along the road and in the forest at Kuala Jasin (Figure 2(a)). On the other hand, it was significantly ($F = 78.6$, $p < .001$) higher along the road (13.7 m^{-2}) than along the trail (1.3 m^{-2}) and in the forest at Kuala Marong (Figure 2(b)).

Canopy and Soil Variables

Canopy openness was significantly ($F = 258.5$, $p < .001$) higher on the road than on the trail at Kuala Jasin (Figure 3(a)) but significantly ($F = 16.4$, $p < .001$) lower on the road than on the trail at Kuala Marong (Figure 3(b)). We showed that the road (2.2–7.0 m wide) was wider than the trail (0.5–1.0 m) at Kuala Jasin but not at Kuala Marong where the road (2.0–3.8 m) and trail (0.8–2.0 m) were similarly narrow. Overall, the canopy openness of trail transects was low (8.6% ± 0.6%) compared with that of road (21.5% ± 1.0%).

Soil bulk density was significantly higher (Kuala Jasin: $F = 238.0$, $p < .001$; Kuala Marong: $F = 98.3$, $p < .001$) on the road than in the forest and on the trail at both sites (Figure 3(c) and (d)). Soil pH was significantly higher on the road than in the forest at both sites, but the lowest and highest values were found on the trail at Kuala Jasin and Kuala Marong, respectively (Kuala Jasin: $F = 43.4$, $p < .001$; Kuala Marong: $F = 44.5$, $p < .001$; Figure 3(e) and (f)). TN was the lowest on the road and higher in the trail and forest transects of both sites (Kuala Jasin: $F = 199.1$, $p < .001$; Kuala Marong: $F = 2.7$, $p = .05$; Figure 3(g) and (h)).

Effects of Canopy and Soil Variables on the Distribution of C. hirta

The canopy and soil variables driving *C. hirta* colonization differed between the road and the trail; soil pH and

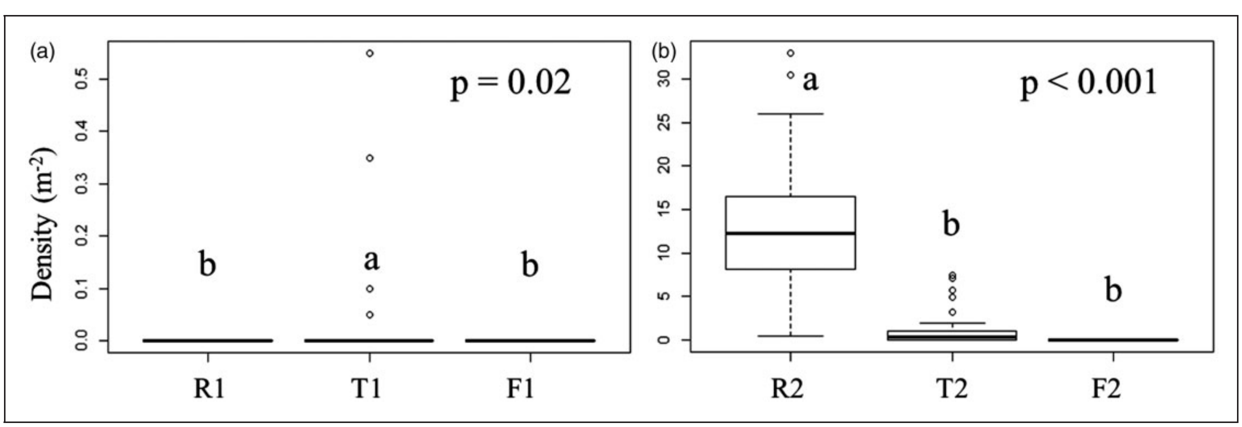


Figure 2. The difference in density of *C. hirta* at (a) Kuala Jasin and (b) Kuala Marong. R, T, and F indicate road, trail, and forest, respectively, and numbers represent study sites (1: Kuala Jasin and 2: Kuala Marong).

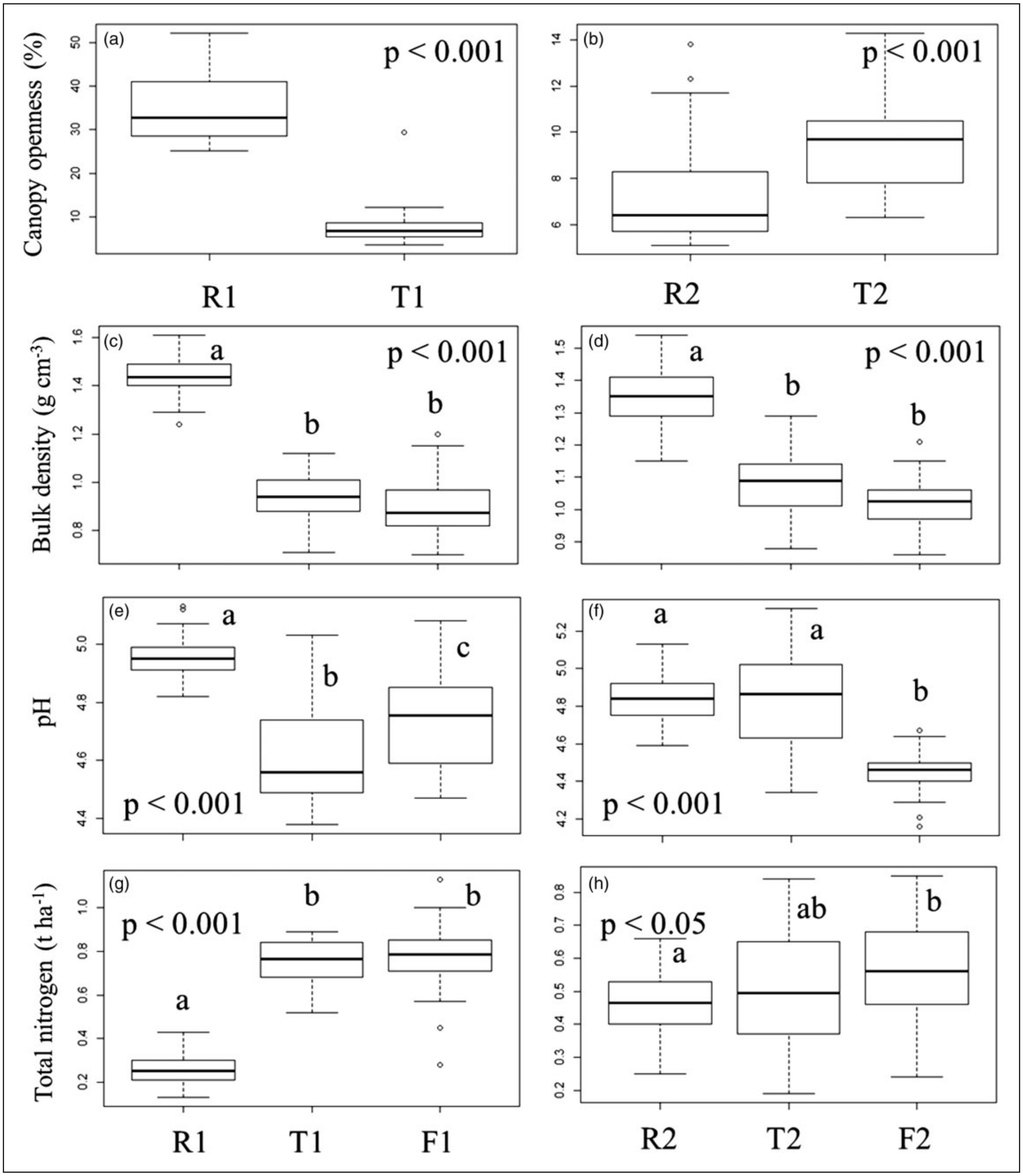


Figure 3. Differences in canopy and soil variables at each site. Here, (a) canopy openness in Kuala Jasin, (b) canopy openness in Kuala Marong, (c) bulk density in Kuala Jasin, (d) bulk density in Kuala Marong, (e) pH in Kuala Jasin, (f) pH in Kuala Marong, (g) total nitrogen in Kuala Jasin, and (h) total nitrogen in Kuala Marong. R, T, and F indicate road, trail, and forest, respectively, and numbers represent study areas (1: Kuala Jasin and 2: Kuala Marong). Letters indicate significant differences among sites ($p < .05$, Steel–Dwass test).

canopy openness had a negative impact on the density of *C. hirta* along the road, while TN had a negative impact along the trail. When the trail and road data were combined, the density of *C. hirta* was negatively affected by canopy openness and TN (Table 1), with the greatest impact from canopy openness.

C. hirta was found in quadrats where canopy openness was 5.1% to 14.3% (7.3% ± 2.3%, mean ± *SD*;

Table 1. Generalized Linear Mixed Model Coefficients of Canopy and Soil Variables to Explain *C. hirta* Density Patterns Among Transects by Model Averaging (<4 AICc).

Treatment	Variables	Estimate	*SE*	z	RVI
Road	Canopy openness	−5.266	1.394	3.753***	1.000
	pH	−2.684	0.811	3.243**	1.000
	Total nitrogen	0.229	0.672	0.336	0.300
	Bulk density	0.087	0.398	0.215	0.200
Trail	Canopy openness	−0.186	0.214	0.861	0.600
	pH	0.018	0.124	0.139	0.180
	Total nitrogen	−1.002	0.235	4.189***	1.000
	Bulk density	−0.043	0.147	0.288	0.230
All	Canopy openness	−2.740	0.584	4.646***	1.000
	pH	−0.267	0.311	0.855	0.590
	Total nitrogen	−0.886	0.359	2.449*	0.900
	Bulk density	0.244	0.498	0.489	0.400

Note. *SE* = standard error of the mean. RVI = relative variable importance; AICc = Akaike's information criterion for small sample sizes; all factors were standardized.
*$p < .05$. **$p < .01$. ***$p < .001$.

Figure 4(a)). The density of *C. hirta* was higher at sites with compacted (bulk density: 1.4 ± 0.1 g cm^{-3}), moderately nutrient-poor (TN: 0.5 ± 0.1 t ha^{-1}), and acidic soils (pH: 4.9 ± 0.1; Figure 4(b) to (d)).

Discussion

Comparison of the Abundance of C. hirta Among Land-Use Types

In our study, *C. hirta* was found only along the road and trail. No individuals were found on the forest floor only 5 m away from the trail. Therefore, it is evident that the road and trail provided suitable habitats for *C. hirta* in our study area. Abundant nonnative plants have also been found along roads and trails in protected areas and national parks around the world, such as Chile (Pauchard & Alaback, 2004), Vietnam (Tan, Thu, & Dell, 2012), and Indonesia (Kudo, 2014). Therefore, the colonization of protected areas by alien species using roads and trails appears to be common across the tropics. Since roads and trails are essential infrastructure for tourism and management of national parks, careful management of invasive species is needed. This is especially important for species like *C. hirta*, which can colonize undisturbed forest (Fujinuma & Harrison, 2012; Peters, 2001).

Roads and trails as vectors can contribute to the invasion of protected areas by alien species in two ways: through providing migration corridors for alien plants by people and vehicles from outside (Von der Lippe & Kowarik, 2007; Niggemann, Jetzkowitz, Brunzel, Wichmann, & Bialozyt, 2009) and through the creation of novel environments that are suitable for alien plants (Greenberg, Crownover, & Gordon, 1997). Tourists may transport seeds over long distances on their clothes, equipment, vehicles, and pets (Pickering & Mount, 2010). Future studies should be undertaken to elucidate the seed dispersal mechanism of *C. hirta* from outside and into national parks.

Canopy and Soil Variables Changes Along Roads and Trails

Construction and utilization of roads and trails in tropical rainforests can substantially affect surrounding microenvironments especially the light conditions (Laurance et al., 2009). These effects vary with the size of clearings and the land-use type. Our results suggest that *C. hirta* requires the place with some sunlight to colonize but not closed canopy areas in the forest. This indicates that *C. hirta* cannot compete with forest tree species but can create sufficient light conditions into forest, seedlings, and saplings of *C. hirta* will survive and begin to establish in the available habitats. Hence, reducing the invasion risk is to control the light conditions through alter the road width.

Long-term use of roads for vehicles leads to soil compaction that can persist for decades (Vora, 1988). Although trampling can cause soil compaction (Belnap, 1998), our results suggest that soil compaction along the trail was similar to interior forest and was minor compared with that along the road. Human utilization may affect vegetation in the vicinity of roads and to a lesser extent along trails. Our findings show that soil compaction changes were greater and more pervasive near roads than trails because compaction strongly depends on the amount of pressure applied.

Tropical forest soils are typically acidic due to the high precipitation rate (Jenny, 1994), and many native species are adapted to the highly acidic soil (Van & Mirmanto, 1985). Litter plays a relatively more important role in nutrient cycling and forest floor protection in the tropics rainforests (Sayer, 2006). Litter removal can increase soil pH by reducing the amount of organic acid, which is produced from litter (Mo, Brown, Peng, & Kong, 2003). Soil pH was higher on the road and trail than on the forest, except for the trail at Kuala Jasin. Thus, removal or loss of leaf litter during road construction and utilization may increase soil pH.

TN along the road was lower than along the trail and forest sites, implying that decreased vegetation cover and greater run-off from the soil surface may impact TN (Janeau et al., 2014; Misra & Teixeira, 2001). Litter removal constitutes a great disturbance to the forest nutrient balance, and soil nitrogen can decrease fairly rapidly after a single litter removal treatment (Sayer,

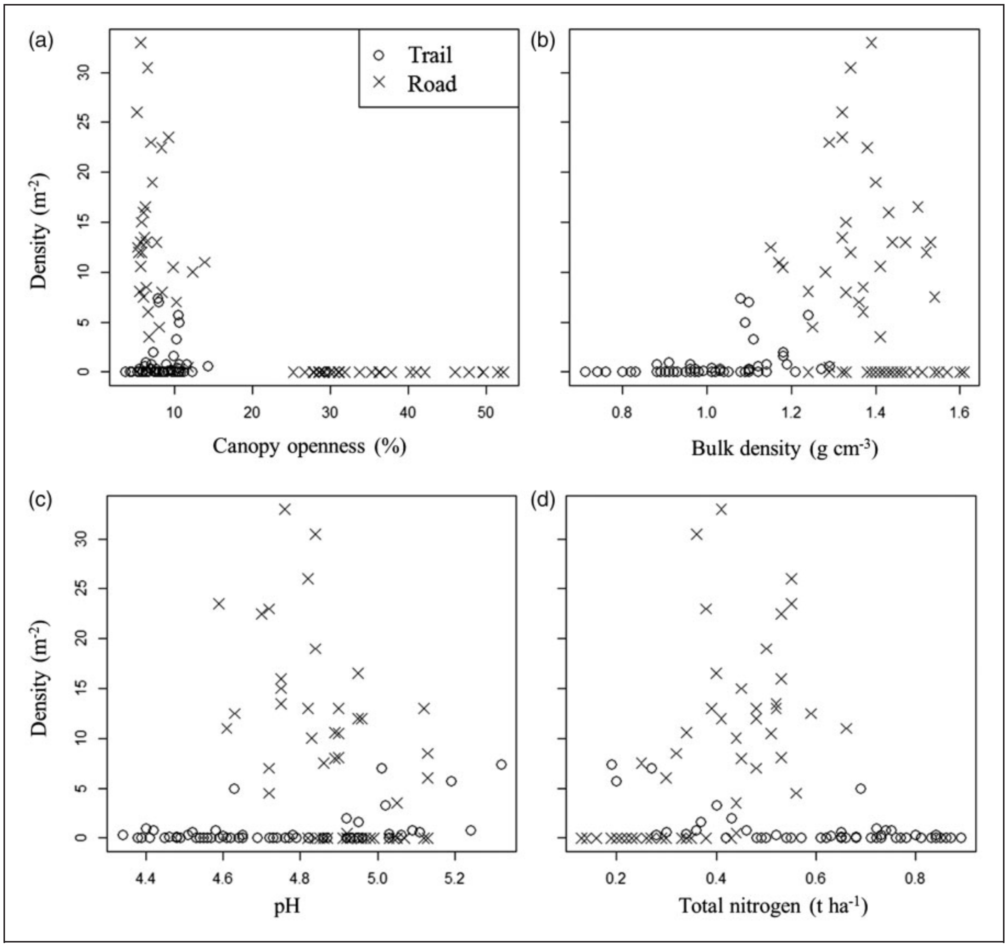


Figure 4. Relationship between the density of *C. hirta* and canopy and soil variables along the road and trail transects: (a) canopy openness, (b) bulk density, (c) pH, and (d) total nitrogen.

2006). Our results show that road construction disturbed the forest floor and soil and provided suitable conditions for the establishment of *C. hirta*.

Construction of narrow roads and trails and treading by tourists are minor disturbance compared with deforestation and selective logging, but *C. hirta* is likely to prefer such minor land modification, and consistent with the predictions of the Intermediate Disturbance Hypothesis (Connell, 1978). The moderate levels of disturbance can reduce the local species and create empty niches for invasive species; road construction gives invasive species a chance to propagate following the disturbance. To sum up, these results indicate that the overall level of canopy and soil variables changes much greater along the road than along the trail.

Relationship Between Canopy and Soil Variables and the Distribution of C. hirta

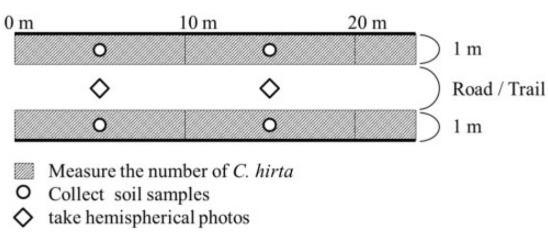
Canopy openness was the most important environmental factor impacting the density of *C. hirta* along roads and trails (Table 1). Canopy openness in the study area was highly variable, but *C. hirta* was only found at sites with lower canopy openness (Figure 4(a)). This species primarily grows along trails, roads, and at the edge of clearings and is seldom found in open areas with full sunlight in its native habitat in Venezuela (Peters, 2001) and Trinidad (Taylor, 1928). Therefore, this species is an edge specialist in both its original and new habitats.

Soil properties also had an important influence on colonization by *C. hirta*. Soil pH was the second most important factor affecting *C. hirta* distribution along the road (Table 1). *C. hirta* was abundant at road edges with lower soil pH values, although soil pH at road edges was generally higher than on the forest. This implies that *C. hirta* is capable of withstand slightly acid soils. Previous studies have also suggested optimum soil pH levels and ranges for some invasive plants, although these values vary among species (e.g., Kerr & Ruwanza, 2016; Soti, Jayachandran, Koptur, & Volin, 2015). TN was the only significant factor for predicting the abundance of *C. hirta* at trail edges (Table 1), probably because canopy openness along the trail was consistently suitable for *C. hirta*. *C. hirta* was more abundant at nutrient-poor trail edges. Invasive plants often perform better in resource-poor environments than in their native ranges (Funk & Vitousek, 2007; Parker, Torchin, & Hufbauer, 2013) and dominate on nutrient-poor soils (Christian & Wilson, 1999; Leary, Hue, Singleton, & Borthakur, 2006). This implies that the maintenance of leaf litter at trail edges is one possible way to prevent invasion by alien species.

Implications for Conservation

In conclusion, our results suggest that the distribution of *C. hirta* was concentrated along the road and trail, indicating strong effects from light and soil conditions on the invasion of protected areas by alien species in ERNP. The edges of the road and trail with relative dark environment and soil nutritional deficiency can contribute to colonization by *C. hirta*. These perspectives highlight that interrelationships of species' traits and light and soil conditions may be a good predictor of invasion success. As discussed earlier, there are two ways to control the spread of this species: (a) reducing the light conditions through altering the road width and (b) reducing soil pH and increasing soil TN through building fences along the road/trail to prevent leaf litter loss, which may be a possible management option that mitigate invasion of *C. hirta*. Since *C. hirta* may use roads and trails to colonize undisturbed forests, the national park managers or conservationists in Southeast Asian tropical rainforests should consider the effects of such minor disturbances on *C. hirta*.

Appendix



Layout of invasive alien plant and soil research.

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Declaration of Conflicting Interests

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Orcid ID

Cao Le http://orcid.org/0000-0002-3938-7690

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