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Effects of Habitat Types on Butterfly Communities (Lepidoptera, Papilionoidea) in Chulabhorn Dam, Chaiyaphum Province, Thailand

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ABSTRACT.– Deforestation and conversion from forests to other land uses, such as agricultural plantations, recreation parks or urban areas, have a great impact on butterfly diversity. In this study, we compared butterfly communities across five habitat types, i.e., open area, park, dry evergreen forest, forest edge and mixed forest in Chulabhorn Dam, Chaiyaphum Province, Thailand to examine the effects of land-use change on butterfly diversity and to determine which environmental factors were associated with butterfly diversity and distribution. Rarefaction analyses showed that open area had the highest species richness, followed by forest edge, park, dry evergreen forest and mixed forest. The ranked abundance distribution curves in each habitat could be fitted to the Zipf-Mandelbrot species distribution models. The parameter beta of the model suggests that there was different niche diversification among the habitat types studied. The dissimilarity of butterfly species compositions between each habitat type was compared by using the Jaccard distance. The dissimilarity was highest between mixed forest and the other habitat types. The constrained correspondence analysis (CCA) revealed that five environmental factors, i.e., degree of human disturbance, percentages of ground cover, percentages of canopy cover, number of vegetation layers and litter depth were associated with butterfly species distribution. From this analysis, two environmental factor gradients were observed in the ordination diagram biplot: the canopy cover-ground cover gradient and the human disturbance-litter depth gradient. The results emphasize the importance of maintaining environmental heterogeneity and habitat diversity in the conservation of butterfly diversity.

KEY WORDS: butterfly, land-use, community, habitat type, environmental factors

INTRODUCTION

Deforestation and forest conversion to other land uses, such as agricultural plantations, recreation parks or urban areas, have a great impact on species diversity because changes in land use often lead to changes in the resources available for biota, the degree of anthropogenic disturbance and landscape fragmentation (Blair and Launer, 1997; Posa and Sodhi, 2006; Koh, 2007; Jonason et al., 2010). The understanding of the effects of land-use change and the impacts of human disturbance on biodiversity is important for effective management and biodiversity conservation.

Butterflies are important in both natural and agricultural landscapes because they provide essential ecosystem services such as nutrient recycling for plants, pollination for crops and other plants, and food for animals and humans (Munyuli, 2012; Chaianunporn and Khoosakunrat, 2018). Butterfly populations are sensitive to ecosystem changes caused by humans, e.g., land-use change (Öckinger et al., 2009; Forister et al., 2010), habitat fragmentation (Krauss et al., 2003; Dover and Settele, 2009), and climate change (Parmesan et al., 1999; Wilson et al., 2007; Forister et al., 2010). As butterfly growth, development and survival are affected by local weather, e.g., as ectotherms, increasing temperatures can reduce development time and change body mass, food intake, and immune activity (Karl and Fischer, 2008; Fischer et al., 2014), butterfly populations are also sensitive to local weather (Roy et al., 2001; Chaianunporn and Khoosakunrat, 2018) and climate (Forister et al., 2010; Checa et al., 2014). Thus, butterflies serve as good indicators of environmental changes and as targets for the study of the effects of different land uses on biodiversity (Blair and Launer, 1997; Koh and Sodhi, 2004; Schneider and Fry, 2005; Posa and Sodhi, 2006; Jew et al., 2015).

Chulabhorn Dam is a rockfill dam with a clay core located in Khon San District, Chaiyaphum Province, Thailand. The areas around Chulabhorn Dam have been modified from former dry evergreen and mixed forest to different types of land uses, such as power stations, residential areas, agricultural areas, recreational parks and golf courses. Consequently, the forests have been fragmented, and the forest edges have been disturbed by humans and invasive plant species. Since 2007, the forests in Chulabhorn Dam (approximately 130 hectares) have become a protected area under the Plant Genetic Conservation Project under the Royal Intuitive of Her Royal Highness Princess Maha Chakri Sirindhorn.

The diversity of habitats and land uses in Chulabhorn Dam allowed us to compare butterfly communities among habitat types. Five habitat types, i.e., open area, park, dry evergreen forest, forest edge and mixed forest were selected for study. Furthermore, we examined which environmental factors were associated with the butterfly distribution, as we hypothesized that the distribution of butterflies across the habitats was affected by environmental factors. This study should reflect the effects of change in land use on butterfly communities and provide the ecological basis for butterfly conservation.

MATERIALS AND METHODS

Study site

Chulabhorn Dam (Latitude: 16.536267, Longitude: 101.650036; Fig. 1) is located in Khon San District, Chaiyaphum Province, Thailand. It was built across the Phrom River, a tributary of the Mekong River, by the Electricity Generating Authority of Thailand (EGAT) in January 1970, and it has supplied electricity to the power system since October 1972 (Electricity Generating Authority of Thailand, 2006). Within the dam area, there are diverse types of natural habitats, such as dry evergreen forest and mixed forest, and human-created habitats, such as parks, plantations and golf courses. In this study, the following five habitat types were selected for the study of butterfly communities in Chulabhorn Dam:

1) Open area (O) – Open area is an open habitat or grassland with no or only a few trees.

2) Park (P) – Park is defined as an area that was deforested and converted into a park by planting different tree species such as *Codiaeum variegatum* (Euphorbiaceae), *Albizia saman* (Fabaceae), *Butea monosperma* (Fabaceae), *Cassia fistula* (Fabaceae), *Pterocarpus macrocarpus* (Fabaceae), *Senna floribunda* (Fabaceae), *Tectona grandis* (Lamiaceae), and *Swietenia macrophylla* (Meliaceae). Some invasive plant species were observed in park areas such as *Chromolaena odortum* (Asteraceae), *Mimosa pudica* (Fabaceae) and *Lantana camara* (Verbenaceae).

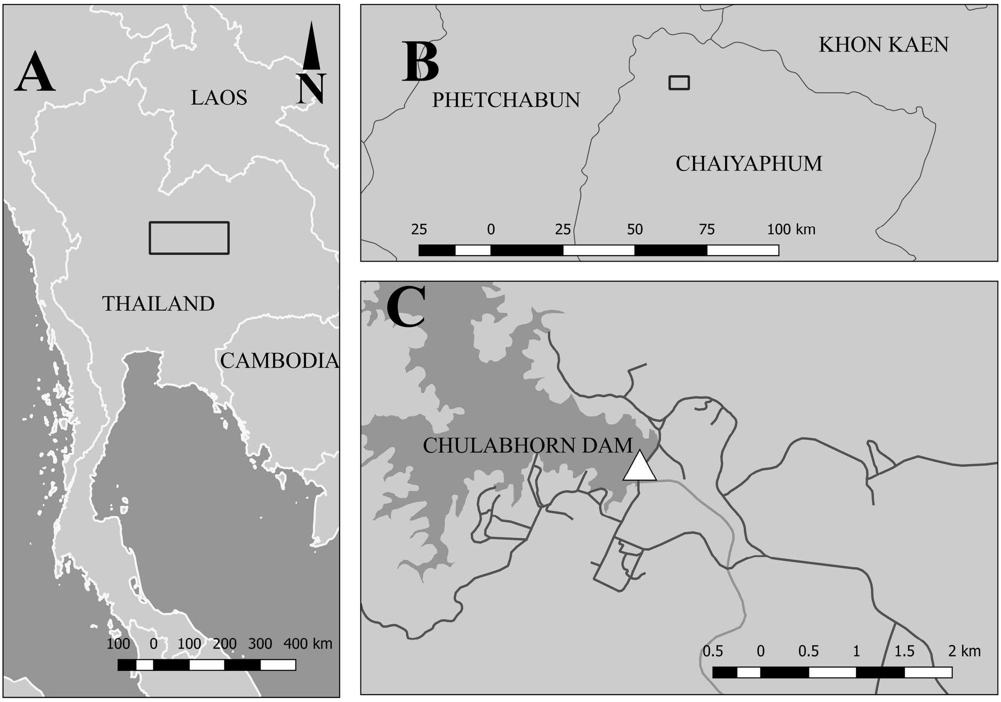

FIGURE 1. (A) Map of Thailand. The black square indicates the area represented in Panel B. (B) Chaiyuphum Province and nearby provinces. The black square indicates the area represented in Panel C. (C) Map showing the locations of Chulabhorn Dam. Dark and light gray lines represent streets and waterways, respectively.

3) Dry evergreen forest (DEF) – The dry evergreen forest consists of several tree species. The dominant species is *Hopea ferrea* (Dipterocarpaceae). Some invasive tree species can also be found, such as *Leucaena leucocephala* (Fabaceae).

4) Forest edge (FE) – The edge of the dry evergreen forest that has been modified to dirt road or forest path.

5) Mixed forest (MF) – The mixed forest is dominated by *Fagus* spp. (Fagaceae), *Dipterocarpus obtusifolius* (Dipterocarpaceae) and *Pinus kesiya* (Pinaceae).

Butterfly sampling

The butterflies in each habitat type were sampled by netting technique. Four 5x100-m^2 transects were established within each habitat type on forest trails or dirt roads. The distance between each transect was at least 50 m. Butterflies that presented in the transect were collected by netting with a 30 cm diameter sweep net by the same two collectors in all transects. Each transect collection lasted 15 minutes on average. All butterflies caught in a transect were kept in a plastic box until the transect survey was completed to avoid double counting. The number of individuals of each species was recorded. Butterfly species that could not be identified in the field were killed, brought back to the laboratory and then identified using Jeratthitikul et al. (2009), Kimura et al. (2011, 2014, 2016) and Ek-Amnuay (2012). The others were released after each transect survey. We conducted these transect surveys between 10:00 and 16:00 on calm weather days from January to December 2017. Each transect was visited four times, twice in the dry season (January to March and October to December) and twice in the wet season (April to September).

Environmental factors

The coordinates and elevation of each transect were measured by Global Positioning System (GPS) at the start, middle and end points of a transect. The percentages of ground cover and litter cover were measured within five 1-m^2 squares along each transect. The squares were placed every 20 m within the transect. The percent canopy cover of 10 m^2 at the beginning and end of each transect was estimated by using a densiometer. The litter depth was averaged from the four corners of a 1-m^2 square at the beginning and the end of each transect. The number of vegetation layers (including emergent trees, upper canopy, lower canopy, shrub understory and ground layer) was estimated in an area of ca. 30 m beside each transect at the start and end points of each transect. Tree and sapling density and diversity were surveyed once in July 2017 on two plots of 10 m^2 at the start and end points of each transect. The Shannon-Wiener index (see below) was calculated for each plot for tree diversity. The tree density and diversity for each transect were averaged from the values of these two plots. The dissimilarity of tree species composition among habitat types was calculated using the same method as that of butterfly species composition described below. A human disturbance score system that ranged from 1 (no apparent disturbance) to 7 (highest level of disturbance) was developed. In this system, the human disturbance score was given for each transect by using the number of pedestrians and vehicles passing during the survey, observing the presence of trails, roads, or other construction within 50 m around a transect and other traces of human activities such as weed control or watering (Supplementary Table S1).

Data analyses

The data analyses were performed by using the 'vegan' package (version 2.5-3) (Oksanen et al., 2018) in the statistical software R (version 3.5.2) (R Core Team, 2018). The Shannon-Wiener index and Pielou's evenness were calculated to represent species diversity and species evenness, respectively, in each habitat type by using the following equations:

$$H = -\sum_{i=1}^{S} p_i \ln(p_i) \qquad \text{for species diversity}$$

where p_i is the proportional abundance of species i in each habitat type, and S is the total number of species in each habitat type, and

$$E = \frac{H}{\ln(S)} \qquad \text{for Pielou's evenness}$$

The ranked abundance distribution curves were created for each habitat type and total samples. Each data set was fitted to one of the species distribution models (brokenstick, log-normal, preemption, Zipf and Zipf-Mandelbrot model) by using the function 'radfit' in the 'vegan' package, which selects a model by using Akaike's information criteria (AIC). As a result, the Zipf–Mandelbrot models were fitted to the species abundance distributions in all data sets. The form of the Zipf-Mandelbrot model is

$$a_r = Nc(r+\beta)^{-\gamma} \quad ,$$

where a_r is the expected abundance of a species at rank r, N is the total number of individuals (site total), and c is a scaling constant. The parameters beta (β) and gamma (γ) can be interpreted as the potential diversity of the environment or niche diversification and the ecosystem predictability, respectively (Spatharis and Tsirtsis, 2013; Oksanen et al., 2018).

Sample- (transect) and individual-based rarefaction curves of each habitat type were constructed by using the 'rarefy' function in the 'vegan' package to compare species richness among habitats (Gotelli and Colwell, 2001). The dissimilarity of butterfly species composition among habitat types was measured by using the Jaccard distance (*J*). Hierarchical clustering was performed with an average linkage clustering strategy (Oksanen, 2015).

The constrained correspondence analysis (CCA) was performed to relate species to environmental variables (ter Braak, 1986; Oksanen, 2015). The community data (abundance of each butterfly species) in each transect (site) were used as dependent variables. The site and species were arranged along environmental gradients or constraints (independent variables). The site and species scores were calculated by a reciprocal averaging approach. The solution obtained from correspondence analysis has two or more axes. The first axis consists of the ordering of species and sites that produces the maximum possible correlation between site and species scores. Second and higher axes also have maximal site-species correlations subject to the constraint that the axes are orthogonal (Palmer, 1993). Eight environmental variables were selected for a constrained model, namely, percentages of ground cover, percentages of litter cover, percentages of canopy cover, litter depth, number of vegetation layers, degree of human disturbance, tree density, and tree diversity. A model was chosen by stepwise model selection using a permutation test with 999 permutations and AIC as the selection criterion (function 'ordistep' in 'vegan' package; Oksanen et al., 2018). The selected model was assessed by using a permutation test for constrained correspondence analysis (the 'anova.cca' function in the 'vegan' package) with 999 permutations (Oksanen, 2015).

RESULTS

A total of 1,005 individuals of 130 butterfly species were recorded on transects in this study. Fifty-seven butterfly species belonged to the family Nymphalidae, 33 species to the family Lycaenidae, 18 species to the family Pieridae, 14 species to the family Papilionidae and 9 species to the family Hesperiidae (Supplementary Table S2). The most abundant species were *Eurema hecabe hecabe* (Pieridae: 17.4% of all observations), *Appias albina darada* (Pieridae: 9.5%), *Ypthima baldus baldus* (Nymphalidae: 5.7%), *Eurema blanda silhetana* (Pieridae: 3.7%) and *Euploea modesta modesta* (Nymphalidae: 3.6%).

The Zipf–Mandelbrot models were fitted to species abundance distribution curves in all habitat types (Fig. 2). The parameter beta (β) of the model was lowest in O (1.64e-06) and DEF (5.86e-06). It was highest in P (2.86). The parameter gamma (γ) was lowest in O (0.99) and highest in MF (1.27).

Both sample- and individual-based rarefaction analyses showed that O had the

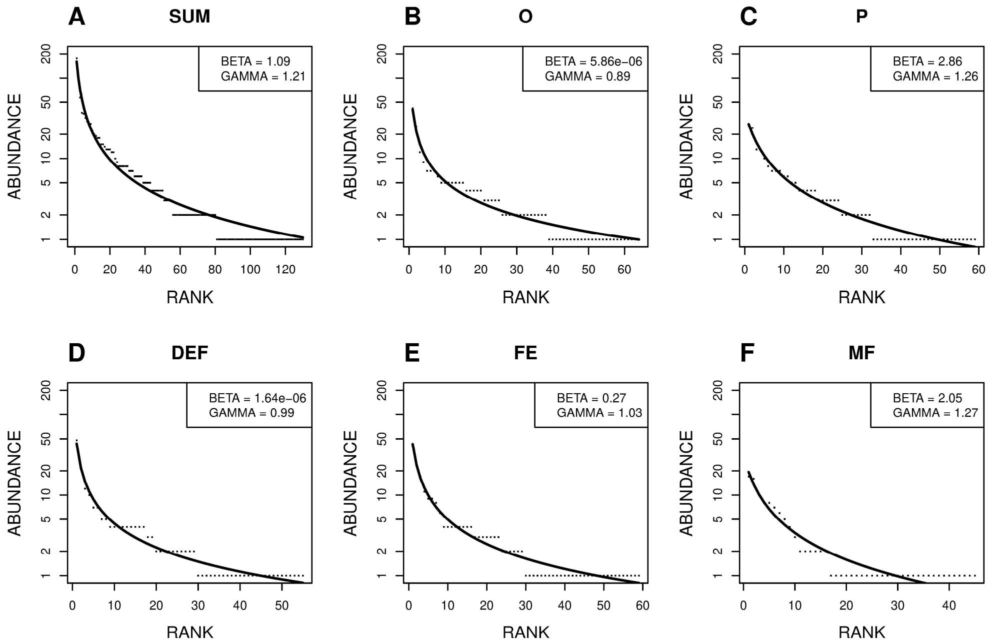

FIGURE 2. Fitted Zipf-Mandelbrot models (solid lines) of logarithmic arithmetic species abundance against species rank order for each habitat type (points). The parameters beta and gamma of each model are shown within the box on the upper right: (A) Total butterfly samples; (B) Open habitat and grassland (O); (C) Park (P); (D) Dry evergreen forest (DEF); (E) Forest edge (FE); (F) Mixed forest (MF).

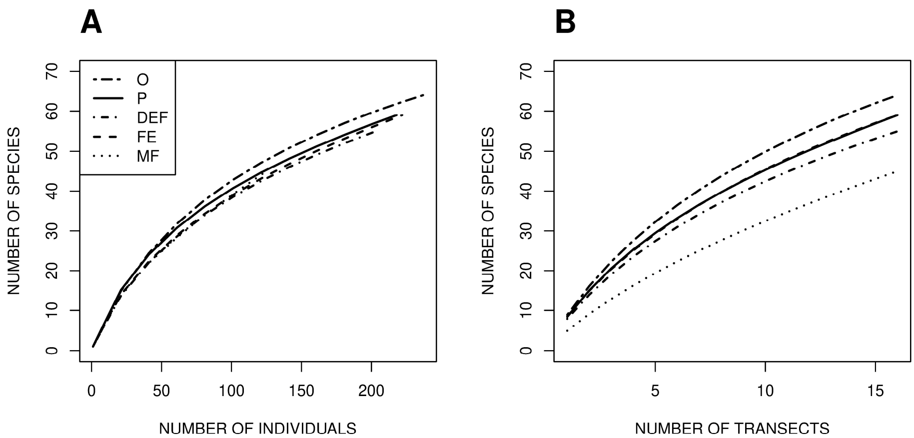

FIGURE 3. (A) Individual-based rarefaction curves of the butterfly communities of O (two-dashed line); P (solid line); DEF (dot-dashed line); FE (dashed line); and MF (dotted line). (B) Sample-based rarefaction curves of the butterfly communities of each habitat type. The rarefaction curves are plotted against the number of transects. See Fig. 2 for habitat type abbreviations.

highest species richness, followed by FE, P, DEF and MF (Fig. 3). The number of individuals and the number of species recorded in each habitat type had trends

TABLE 1. Number of species, individuals, Pielou's evenness and Shannon-Wiener's diversity index of the butterfly community in five different habitat types in Chulabhorn Dam

Habitat types	Number of species	Number of individuals	Pielou's evenness	Shannon–Wiener's diversity index
O	64	237	0.851	3.539
P	59	218	0.866	3.530
DEF	55	203	0.814	3.262
FE	59	222	0.822	3.352
MF	45	125	0.851	3.241
Total	130	1005	0.776	3.779

similar to the number of species (Table 1). P had the highest and DEF had the lowest community evenness among habitats, while the species diversity was highest in O and lowest in MF.

The dissimilarity of the species composition of the butterfly communities among the five different habitat types was rather high (Fig. 4). The dissimilarity was highest between MF and other habitat types (*J*=0.76–0.78). The lowest dissimilarity of species composition was found between O and FE (*J*=0.49). For other pairs of habitat types, the *J* value was between 0.49 and 0.58.

In the study of the distributions of butterflies in relation to the environmental data using constrained correspondence analysis, eight environmental variables were measured. Only five variables (degree of human disturbance, percentages of ground cover, percentages of canopy cover, number of vegetation layers and litter depth) were kept in the final model after model selection, as the three other variables (tree density, tree diversity and percentages of litter cover) were strongly correlated with one of the remaining variables. The degree of human disturbance (p = 0.012), percentages of ground cover (p = 0.001),

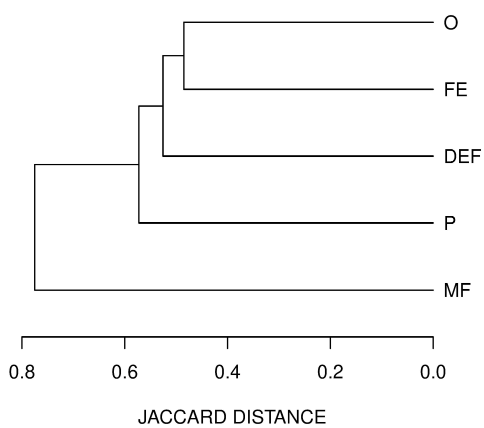

FIGURE 4. Hierarchical clustering tree based on the Jaccard distance between habitat types for butterfly communities. See Fig. 2 for habitat type abbreviations

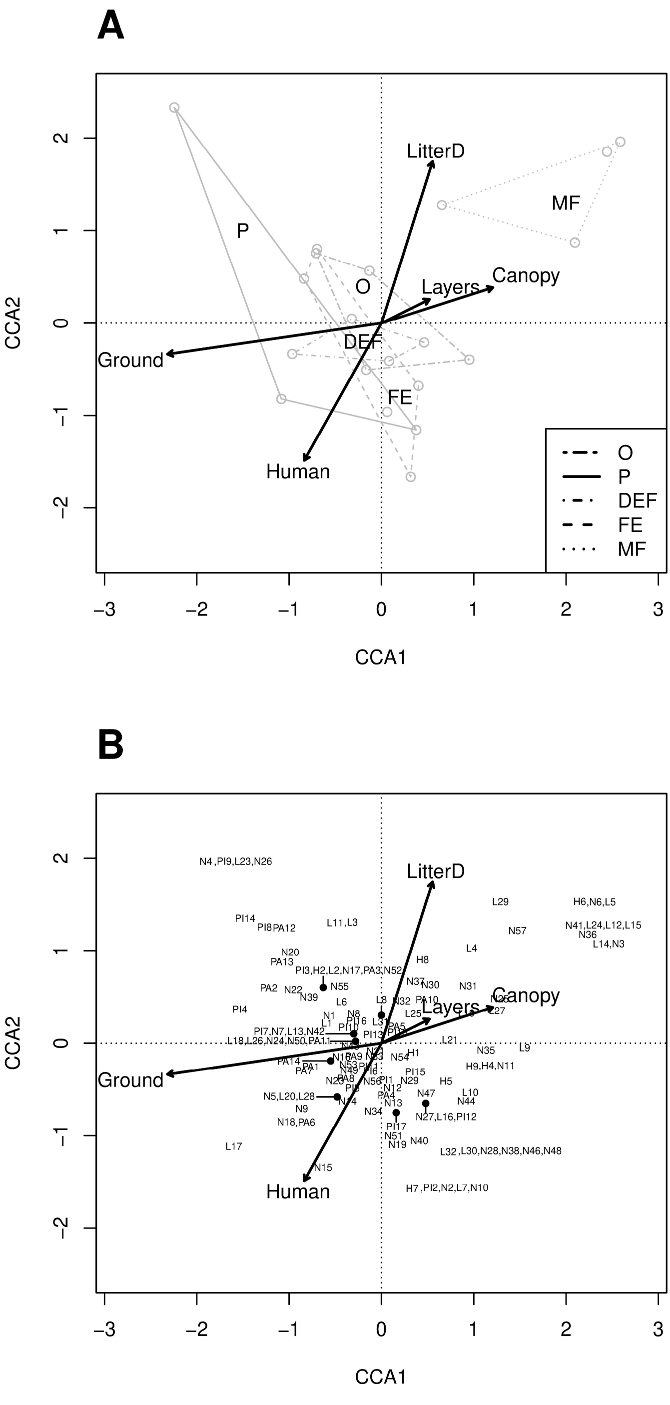

FIGURE 5. (A) Ordination diagram biplot of site scores (open points) from the constrained correspondence analysis of environmental variables (arrows), i.e., degree of human disturbance (Human), percentages of ground cover (Ground), percentages of canopy cover (Canopy), number of vegetation layers (Layers) and litter depth (LitterD). The polygons present for the convex hulls enclosing all sites in each habitat type; (B) The ordination diagram biplot of species scores with environmental variables (arrows). Arrows with circle heads indicate the actual position of species on the ordination diagram biplot. See Supplementary Table S2 for species abbreviations and Figure 2 for habitat type abbreviations.

percentages of canopy cover (p = 0.05), number of vegetation layers (p = 0.022) and litter depth (p = 0.001) significantly explained 34.8% of the species composition (*pseudo-F* = 1.491, p = 0.001 for the whole model; sum of all constrained eigenvalues = 1.153, total inertia = 3.316).

The ordination diagrams of the constrained correspondence analysis display the site and species scores over the ordination (Fig. 5A and 5B, respectively). A graphical overlay of the habitat types on the ordination distinguished mixed forest (MF) from other habitat types (O, P, DEF and FE), showing that the species composition in the MF differs from that in the four other habitats, while the species compositions in O, P, DEF and FE mostly overlapped. The trajectories of the arrows indicated that the litter depth, canopy cover, and vegetation layers were positively associated with each other (the angle between the arrows was narrow) and were negatively associated with ground cover and human disturbance (the angle between arrows was wide). The first axis for butterfly distribution showed a canopy cover-ground cover gradient on which the percentages of ground cover were high in open canopy and low in closed canopy. The second axis showed the human disturbance-litter depth gradient: the habitat types with low human disturbance had high litter depth.

From the species points in the ordination diagram, it can be inferred that some butterfly species, such as *Notocrypta paralysos asawa* (H6), *Tagiades japetus ravi* (H8), *Arhopala centaurus nakula* (L4), *Jamides alecto alocina* (L19), *Surendra quercetorum quercetorum* (L29), *Mycalesis intermedia* (N31), *Neptis clinia susruta* (N36), and *Ypthima savara savara* (N57), were closely associated with MF where percentages of canopy cover were high and litter was deep. Some species, such as *Hypolycaena erylus himavantus* (L17), *Cethosia biblis biblis* (N4), *Eurema laeta pseudolaeta* (PI14), and *Appias paulina adamsoni* (PI4), were closely associated with open habitat areas (low canopy cover and high ground cover). Some species, such as *Spialia galba* (H7), *Hypolycaena erylus himavantus* (L17), *Hypolimnas bolina jacintha* (N18) and *Euploea radamanthus radamanthus* (N15), were found in habitats with relatively high human disturbance.

DISCUSSION

In this study, the importance of habitat types and environmental factors of each habitat type for the diversity and composition of butterfly communities in Chulabhorn Dam was investigated. The results showed a high diversity of butterflies within the study area. One hundred thirty butterfly species were found in five habitat types of Chulabhorn Dam, which accounted for approximately 10% of all butterfly species reported in Thailand (1,287 species - Ek-Amnuay, 2012). Although the study site is not within one of national conserved forests of Thailand, it is a part of the Phu Khieo-Nam Nao forest complex and directly connects to Nam Nao National Park and Phu Khieo Wildlife Sanctuary. Chondamrongkun and Chamnankid (1998) collected butterflies in Nam Nao National Park between October 1996 and September 1997 and reported 323 butterfly species found in the national park. The previous study and our study indicate the significance of the Phu Khieo-Nam Nao forest complex as a habitat of diverse butterfly species. The large areas of primary and secondary forest within this forest complex provide diverse microhabitats, unique microclimatic conditions, specific larval host plants and support larger populations, which can enhance great diversities of butterflies (Koh and Sodhi, 2004).

The species abundance distribution curves of the butterfly communities in this study were fitted to the Zipf-Mandelbrot model. Previous studies showed that this model type can be fitted to different ecological assemblages (Spatharis and Tsirtsis, 2013). The theory underlying the model is that the abundance of each species in an assemblage depends on a number of unspecified conditions (e.g., food consumption, mortality, reproduction rate, and interspecific interactions), as well as the existence of a number of preconditions that must be satisfied by the environment (niche space) (Frontier, 1985; Barangé and Campos, 1991; Spatharis and Tsirtsis, 2013). The beta parameter of the model indicates the environmental diversity or niche diversification of the habitat. According to the results, O, DEF and FE had lower beta parameters than P and MF. This reflects the complexity of the MF structure, which has multiple vegetation layers and high litter depth and tree density. Although the structure of P differed little from the other habitat types, the transects of P were distributed widely in Chulabhorn Dam, and thus, the characteristics of the transects were diverse. The gamma parameter represents ecosystem predictability and is related to the evenness and dominance of the system. As the evenness and dominance of the system showed little variation among the habitat types, the gamma parameter did not show great differences among habitat types.

Habitat modification by humans appeared to promote butterfly diversity in the study area, as the highest butterfly diversity and species richness were found in habitats with high anthropogenic disturbance (O and P). The presence of cultivated plants in park areas, such as *Butea monosperma* (Fabaceae), *Cassia bakeriana* (Fabaceae), and *Cassia fistula* (Fabaceae), and invasive plants with nectar, such as *Chromolaena odorata* (Asteraceae), *Praxelis clematidea* (Asteraceae), and *Lantana camara* (Verbenaceae), in the parks and open areas likely attracts butterfly species such as *Appias albina darada* and *Catopsilia pomona* that are adapted to open habitats, as well as other species living in the adjacent forests. In addition, human habitat modifications in open areas provide some important resources such as mineral licks for butterflies, which attract *Catopsilia pomona*, *Appias albina darada, Libythea narina rohini*, *Phalanta alcippe alcippoides,* etc.

Butterfly community compositions among O, P, DEF and FE were quite similar (the similarity between habitats is between 42 and 51%) because the characteristics of these habitats were only slightly different. Most of these habitats were open canopy or forest gaps with low litter, a high percentage of ground cover and a moderate to high degree of human disturbance. Although MF had the lowest number of butterfly individuals and butterfly species, the butterfly community composition in this habitat was much different than that in the other habitat types because the characteristics of MF were different from those of the other habitat types, i.e., it had a high percentage of canopy cover, deep litter, a high number of vegetation layers and a low degree of human disturbance. Moreover, it had unique host plant species, such as plants in the family Fagaceae, which are host plants for diverse butterfly species, such as *Arhopala* spp. (Robinson et al., 2010).

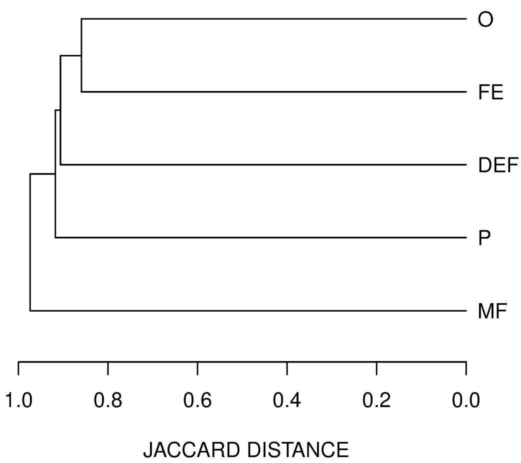

FIGURE 6. Hierarchical clustering tree based on the Jaccard distance between habitat types for plant communities. See Fig. 2 for habitat type abbreviations

The distribution of larval food plants is also an important factor determining the distribution of butterfly species in each habitat, especially for species that do not fly long distances, because adult butterflies oviposit on specific host plants, and their caterpillars feed on these hostplants. For this reason, some butterfly species were found only in specific habitats where their larval food plants were available. In this study, we observed that the differences in the species composition of the butterfly communities (Fig. 4) and the plant communities (Fig. 6) among the five habitat types followed the same trend. This suggests that the plant communities play a role in determining the species composition of butterfly communities, both as larval food plants and as nectar sources for butterflies.

The CCA results show two gradients in the ordination diagram biplot: the canopy cover-ground cover gradient and the human disturbance-litter depth gradient. Since butterflies are a very diverse group, different butterfly species responded differently to these environmental variables and thus were widely distributed on the biplot. The observed axes in this study agree with previous studies that exhibited a correlation between canopy cover and litter depth with the distribution of butterflies in tropical areas (Koh and Sodhi, 2004; Checa et al., 2014). The percentage of canopy cover and the number of vegetation layers are generally associated with the microclimate and light intensity of the area. High percentages of canopy cover result in low light, high moisture availability and high humidity, which have direct effects not only on butterfly distribution (microclimatic effects) but also on host plant quality (Hill et al., 2001). Another consequence of the closed canopy is low understory and ground cover plants, which are the main sources of nectar for butterflies. This is one important reason that closed-canopy habitats such as MF had lower butterfly diversity than other habitat types with open canopies and higher proportions of nectar-producing plants.

Our results support the previous study indicating that leaf litter depth can be an indicator of the degree of habitat disturbance in tropical forests (Koh and Sodhi, 2004), as shown by the human disturbance-litter depth gradient in the ordination diagram biplot. The areas with greater litter depth might attract species that are sensitive to human disturbance. In addition, leaf litter is important for the cryptic coloration of different butterfly stages in which butterflies are able to hide from their predators by resembling dry leaves (Bonebrake et al., 2010; Mayekar and Kodandaramaiah, 2017). Butterflies with brown colors, such as *Mycalesis intermedia*, *Mycalesis mineus mineus*, and *Ypthima savara savara,* were often found in the forest areas with deep leaf litter.

CONCLUSION

This study emphasizes the importance of the maintenance of environmental heterogeneity and habitat diversity for the conservation of butterfly diversity. Habitat modification and disturbance by humans (such as parks or open habitats in this study) does not always lead to a reduction in butterfly numbers and butterfly diversity, but it changes butterfly community compositions from those of pristine habitats. Deforestation and land-use changes lead to increases in the proportion of open habitats within an area, which support and promote butterfly species adapted to open canopy or highly disturbed areas, whereas forest areas that are suitable for forest butterfly species are reduced. However, the impacts of land-use change on the butterfly community and the community-level responses to habitat disturbance remain relatively poorly understood, especially in the Southeast Asian region (Koh, 2007). Over the past 30 years, tropical forest areas in this region have rapidly declined and have been converted to other land uses, such as agricultural or urban land uses (Food and Agriculture Organization of the United Nations, 2016). Further empirical studies of the effects of land-use change on butterfly communities, especially forest butterfly communities, should be urgently conducted to determine the threats and status of various butterfly groups and to provide recommendations for conservation decisions.

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Supplementary material

SUPPLEMENTARY TABLE S1. A human disturbance score system for each transect used in this study

Disturbance score	Definition	Number of pedestrians and vehicles observed during the survey	Traces of human activities	Trail, road, or other constructions within 50 m around a transect
1	No human disturbance	0	Absence	Absence
2	Low human disturbance	0	Presence (such as footprint or garbage), No regular activities	Only trails
3	Intermediate human disturbance	0	Presence of regular human activities such as weed control or watering	Only trails
4	Intermediate-high human disturbance	Less than 5	Presence of regular human activities such as weed control or watering	Only trails
5	High human disturbance	Less than 5	Presence of regular human activities such as weed control or watering	Presence of trails or roads
6	Very high human disturbance	More than 5 but less than 20	Presence of regular human activities such as weed control or watering	Presence of trails or roads and other permanent construction
7	Highest human disturbance	More than 20	Presence of regular human activities such as weed control or watering	Presence of trails or roads and other permanent construction

SUPPLEMENTARY TABLE S2. Summary information of butterfly species recorded in Chulabhorn Dam, including species abbreviation (Code), family, abundance in each habitat type and total abundance. See *Materials and methods* for habitat type abbreviations.

Code	Family	Scientific name	Abundance					
			O	P	DEF	FE	MF	TOTAL
H1	Hesperiidae	*Astictopterus jama olivascens*	0	0	4	0	1	5
H2	Hesperiidae	*Ampittia dioscorides camertes*	1	0	0	0	0	1
H3	Hesperiidae	*Baoris farri farri*	0	0	1	1	0	2
H4	Hesperiidae	*Celaenorrhinus asmara consertus*	0	0	0	1	0	1
H5	Hesperiidae	*Iambrix salsala salsala*	0	0	1	1	0	2
H6	Hesperiidae	*Notocrypta paralysos asawa*	0	0	0	0	1	1
H7	Hesperiidae	*Spialia galba*	1	0	0	0	0	1
H8	Hesperiidae	*Tagiades japetus ravi*	0	0	1	1	1	3
H9	Hesperiidae	*Taractrocera maevius sagara*	0	0	0	1	0	1
L1	Lycaenidae	*Allotinus unicolor rekkia*	1	0	1	0	0	2
L2	Lycaenidae	*Anthene emolus emolus*	1	0	0	0	0	1
L3	Lycaenidae	*Arhopala arvina aboe*	0	0	0	1	0	1
L4	Lycaenidae	*Arhopala centaurus nakula*	0	0	0	1	1	2
L5	Lycaenidae	*Arhopala paramuta paramuta*	0	0	0	0	1	1
L6	Lycaenidae	*Castalius rosimon rosimon*	5	1	3	9	0	18
L7	Lycaenidae	*Catochrysops panormus exiguus*	1	0	0	0	0	1
L8	Lycaenidae	*Catochrysops strabo strabo*	2	1	2	2	1	8
L9	Lycaenidae	*Cheritra freja evansi*	0	1	0	0	1	2
L10	Lycaenidae	*Cigaritis syama peguanus*	1	1	0	0	1	3
L11	Lycaenidae	*Cigaritis vulcanus tavoyanus*	0	0	0	1	0	1
L12	Lycaenidae	*Curetis bulis bulis*	0	0	0	0	1	1
L13	Lycaenidae	*Discolampa ethion ethion*	0	0	1	0	0	1
L14	Lycaenidae	*Dodona deodata deodata*	0	0	0	0	1	1
L15	Lycaenidae	*Drupadia ravindra boisduvalii*	0	0	0	0	1	1
L16	Lycaenidae	*Euchrysops cnejus cnejus*	1	0	0	0	0	1
L17	Lycaenidae	*Hypolycaena erylus himavantus*	0	1	0	0	0	1
L18	Lycaenidae	*Ionolyce helicone merguiana*	0	0	0	1	0	1
L19	Lycaenidae	*Jamides alecto alocina*	1	3	0	2	7	13
L20	Lycaenidae	*Jamides bochus bochus*	0	0	1	0	0	1
L21	Lycaenidae	*Jamides celeno aelianus*	7	4	4	4	10	29
L22	Lycaenidae	*Jamides pura pura*	3	0	3	1	0	7
L23	Lycaenidae	*Lampides boeticus*	0	1	0	0	0	1
L24	Lycaenidae	*Loxura atymnus continentalis*	0	0	0	0	1	1
L25	Lycaenidae	*Nacaduba kurava euplea*	0	0	0	3	1	4
L26	Lycaenidae	*Neopithecops zalmora zalmora*	0	0	0	1	0	1
L27	Lycaenidae	*Pithecops corvus corvus*	0	0	1	0	1	2
L28	Lycaenidae	*Rapala pheretima petosiris*	0	0	1	0	0	1
L29	Lycaenidae	*Surendra quercetorum quercetorum*	0	0	0	0	2	2
L30	Lycaenidae	*Udara dilecta dilecta*	0	1	0	0	0	1
L31	Lycaenidae	*Zizina otis sangra*	5	0	0	4	0	9
L32	Lycaenidae	*Zizula hylax hylax*	0	2	0	0	0	2
N1	Nymphalidae	*Ariadne merione tapestrina*	2	0	1	0	0	3

N2	Nymphalidae	*Athyma pravara indosinica*	1	0	0	0	0	1
N3	Nymphalidae	*Athyma selenophora amharina*	0	0	0	0	1	1
N4	Nymphalidae	*Cethosia biblis biblis*	0	2	0	0	0	2
N5	Nymphalidae	*Cethosia cyane euanthes*	0	0	1	0	0	1
N6	Nymphalidae	*Chersonesia intermedia intermedia*	0	0	0	0	1	1
N7	Nymphalidae	*Cupha erymanthis erymanthis*	0	0	1	0	0	1
N8	Nymphalidae	*Danaus genuita genuita*	4	0	0	2	0	6
N9	Nymphalidae	*Elymnias hypermnestra tinctoria*	0	1	1	0	0	2
N10	Nymphalidae	*Euploea algea menetriesii*	1	0	0	0	0	1
N11	Nymphalidae	*Euploea camaralzeman camaralzeman*	0	0	0	1	0	1
N12	Nymphalidae	*Euploea core godartii*	2	1	0	1	0	4
N13	Nymphalidae	*Euploea modesta modesta*	12	7	4	11	2	36
N14	Nymphalidae	*Euploea mulciber mulciber*	2	2	0	1	0	5
N15	Nymphalidae	*Euploea radamanthus radamanthus*	1	1	0	0	0	2
N16	Nymphalidae	*Euploea sylvester harrisii*	6	8	1	4	1	20
N17	Nymphalidae	*Euripus nyctelius nyctelius*	1	0	0	0	0	1
N18	Nymphalidae	*Hypolimnas bolina jacintha*	0	1	1	0	0	2
N19	Nymphalidae	*Ideopsis vulgaris contigau*	0	1	0	0	0	1
N20	Nymphalidae	*Junonia almana almana*	2	2	0	0	0	4
N21	Nymphalidae	*Junonia atlites atlites*	5	2	5	0	1	13
N22	Nymphalidae	*Junonia iphita iphita*	1	5	2	2	0	10
N23	Nymphalidae	*Junonia lemonias lemonias*	3	6	1	2	0	12
N24	Nymphalidae	*Kallima inachus siamensis*	0	0	0	1	0	1
N25	Nymphalidae	*Lethe confusa confusa*	0	0	1	0	1	2
N26	Nymphalidae	*Lethe europa niladana*	0	1	0	0	0	1
N27	Nymphalidae	*Libythea geoffroy alompra*	1	0	0	0	0	1
N28	Nymphalidae	*Libythea myrrha sanguinalis*	0	1	0	0	0	1
N29	Nymphalidae	*Libythea narina rohini*	3	0	0	1	0	4
N30	Nymphalidae	*Melanitis leda leda*	0	1	0	0	2	3
N31	Nymphalidae	*Mycalesis intermedia*	1	1	7	6	17	32
N32	Nymphalidae	*Mycalesis mineus mineus*	2	3	2	4	8	19
N33	Nymphalidae	*Mycalesis perseoides*	1	3	2	1	1	8
N34	Nymphalidae	*Mycalesis perseus tabitha*	0	3	0	1	0	4
N35	Nymphalidae	*Mycalesis sangaica tunicula*	1	0	0	4	1	6
N36	Nymphalidae	*Neptis clinia susruta*	0	0	0	0	2	2
N37	Nymphalidae	*Neptis hylas kamarupa*	7	4	4	4	8	27
N38	Nymphalidae	*Neptis nata adipala*	0	1	0	0	0	1
N39	Nymphalidae	*Orsotriaena medus medus*	4	1	0	3	0	8
N40	Nymphalidae	*Pantoporia hordonia hordonia*	2	0	0	0	0	2
N41	Nymphalidae	*Pantoporia paraka paraka*	0	0	0	0	1	1
N42	Nymphalidae	*Pantoporia sandaka davidsoni*	0	0	1	0	0	1
N43	Nymphalidae	*Parantica aglea melanoides*	0	5	1	0	2	8
N44	Nymphalidae	*Parantica aspasia aspasia*	2	0	0	0	1	3
N45	Nymphalidae	*Parantica melaneus plataniston*	5	0	1	1	0	7
N46	Nymphalidae	*Parthenos sylvia apicalis*	0	1	0	0	0	1
N47	Nymphalidae	*Phalanta alcippe alcippoides*	2	0	0	0	0	2
N48	Nymphalidae	*Phalanta phalanta phalanta*	0	1	0	0	0	1
N49	Nymphalidae	*Rohana parisatis pseudosiamensis*	0	0	1	1	0	2
N50	Nymphalidae	*Rohana tonkiniana siamensis*	0	0	0	1	0	1

N51	Nymphalidae	*Tirumala septentrionis septentrionis*	5	0	2	1	0	8
N52	Nymphalidae	*Vagrans sinha sinha*	1	0	0	0	0	1
N53	Nymphalidae	*Vindula erota erota*	0	0	2	0	0	2
N54	Nymphalidae	*Ypthima baldus baldus*	9	13	12	17	6	57
N55	Nymphalidae	*Ypthima huebneri*	2	7	1	9	3	22
N56	Nymphalidae	*Ypthima nebulosa*	0	0	4	0	0	4
N57	Nymphalidae	*Ypthima savara savara*	1	0	0	0	4	5
PA1	Papilionidae	*Graphium agamemnon agamemnon*	0	1	2	1	0	4
PA2	Papilionidae	*Graphium aristeus hermocrates*	4	2	0	0	0	6
PA3	Papilionidae	*Graphium doson axion*	1	0	0	0	0	1
PA4	Papilionidae	*Graphium macareus indochinensis*	3	3	4	4	0	14
PA5	Papilionidae	*Graphium megarus megapenthes*	1	0	0	1	0	2
PA6	Papilionidae	*Graphium sarpedon sarpedon*	0	1	1	0	0	2
PA7	Papilionidae	*Lamproptera meges annamiticus*	1	3	0	1	0	5
PA8	Papilionidae	*Pachliopta aristolochiae geniopeltis*	0	4	2	0	0	6
PA9	Papilionidae	*Papilio castor mahadeva*	0	0	1	1	0	2
PA10	Papilionidae	*Papilio helenus helenus*	2	2	2	0	2	8
PA11	Papilionidae	*Papilio memnon agenor*	0	0	0	1	0	1
PA12	Papilionidae	*Papilio nephelus annulus*	0	1	0	1	0	2
PA13	Papilionidae	*Papilio paris paris*	0	7	5	3	0	15
PA14	Papilionidae	*Papilio polytes romulus*	3	4	4	3	1	15
PI1	Pieridae	*Appias albina darada*	25	24	21	24	1	95
PI2	Pieridae	*Appias indra indra*	1	0	0	0	0	1
PI3	Pieridae	*Appias lyncida vasava*	2	0	0	0	0	2
PI4	Pieridae	*Appias paulina adamsoni*	0	6	0	1	0	7
PI5	Pieridae	*Catopsilia pomona*	5	10	7	4	1	27
PI6	Pieridae	*Cepora iudith lea*	0	0	1	0	0	1
PI7	Pieridae	*Cepora nerissa dapha*	0	0	1	0	0	1
PI8	Pieridae	*Delias descombesi descombesi*	1	1	0	0	0	2
PI9	Pieridae	*Delias pasithoe pasithoe*	0	1	0	0	0	1
PI10	Pieridae	*Eurema amdersoni sanadobui*	2	2	4	3	1	12
PI11	Pieridae	*Eurema blanda silhetana*	7	13	10	2	5	37
PI12	Pieridae	*Eurema brigitta hainana*	1	0	0	0	0	1
PI13	Pieridae	*Eurema hecabe hecabe*	42	26	48	43	16	175
PI14	Pieridae	*Eurema laeta pseudolaeta*	1	1	0	0	0	2
PI15	Pieridae	*Eurema simulatrix sarinoides*	4	1	4	3	1	13
PI16	Pieridae	*Gandaca harina burmana*	0	0	2	3	0	5
PI17	Pieridae	*Leptosia nina nina*	5	4	1	8	0	18
PI18	Pieridae	*Pareronia anais anais*	4	0	0	1	1	6
		Total individuals	237	218	203	222	125	1005
		Total species	64	59	55	59	45	130