Insect biodiversity in flowering teak (*Tectona grandis* L.f.) canopies: Comparison of wild and plantation stands

S. Tangmitcharoen [a,*], T. Takaso [b], S. Siripatanadilox [c], W. Tasen [c], J.N. Owens [d,e]

[a] *Forest Management and Forest Product Research Office, Royal Forest Department, 61 Phaholyothin Road, Bangkok 10900, Thailand*
[b] *Research Institute for Humanity and Nature, Kawaramachi nishi-iru, Kamigyo-ku, Kyoto 602-0878, Japan*
[c] *Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[d] *Centre for Forest Biology, University of Victoria, Victoria, BC, Canada V8W 3N5*
[e] *Timber West 1450 Mt. Newton Cross Roads, Saanichton, BC, Canada V0S 1M0*

Abstract

Insects were collected in the canopies of wild and plantation forests with Malaise traps and hand nets during the flowering season of teak (August–October 1998) in and near the Maegar Seed Orchard in Phayao province, Northern Thailand. A total of 10,404 individual insects were collected representing 693 morphospecies from 115 recognizable families and 11 orders. Of these 11 orders, Lepidoptera had the highest number of morphospecies (32%) followed by Hymenoptera (29%). Among 693 morphospecies, 620 (89.5%) were non-pollinators and 73 (10.5%) were potential pollinators. Canopies of wild teak had greater insect biodiversity than plantation; however, the number of potential insect pollinators in the plantation canopies was greater than the wild trees.

The total number of morphospecies was 552 in the canopies of wild trees, 340 in the plantation canopies and 199 appeared in both habitats. Mean numbers of morphospecies per individual tree for canopies of wild and plantation trees were 280 and 150, respectively. Total number of individuals collected in the canopies of wild trees was 6948 and 3456 in the plantation canopies. Mean numbers of individuals per individual tree in the canopies of wild and plantation trees were 2316 and 1152, respectively. The mean alpha diversity indices per individual tree in the canopies of wild and plantation trees were 84 and 49, respectively.

Keywords: Canopy; Insect diversity; Pollinator; *Tectona grandis*; Thailand

1. Introduction

While the demand for timber increases each year, the supply that can be extracted from remaining natural forests in Thailand and many other tropical regions is decreasing. This situation creates a serious problem (Silver et al., 2000) and one solution is to establish plantations. Plantations may provide many products and benefits including timber, non-wood forest products, carbon credits, wildlife habitats, and conservation or restoration of biodiversity. Because of these benefits many countries plan to dramatically increase plantation areas (Silver et al., 2000). Some individuals advocate the conservation benefits of biodiversity in plantations while others claim biodiversity is endangered there (Phillip, 1988).

There have been some reports on the impacts of forest plantations on the diversity and abundance of insects but most of these studies have been conducted in Africa (e.g. Nummelin and Hanski, 1989; Nummelin and Borrowiec, 1991; Nummelin and Fursch, 1992; Eggleton et al., 1995, 1996; Nummelin, 1996) with only a few recent studies being done in Asia (Holloway et al., 1992; Hill et al., 1995; Chey et al., 1997; Hamer et al., 1997; Intachat et al., 1997).

Among tropical hardwood plantation forest trees, teak is one of the most common native or introduced species (Tewari, 1992). In Thailand, teak seed orchards began to be established in 1965 in order to cope with the increased demand for teak seedlings for reforestation and afforestation. However, seed orchard trees generally have shown low fruit production (Pianhanuruk, 1995) that has often been attributed to lack of

* Corresponding author. Tel.: +66 2561 4292x429; fax: +66 2940 7396.
E-mail address: suwan@forest.go.th (S. Tangmitcharoen).

Table 1
Potential pollinator insects visiting teak flowers or inflorescences in canopies of wild (W) and plantation (P) forest trees near the Maegar Seed Orchard in Phayao province

Order	Family	Genus or species	Common name	Forest
Diptera	Calliphoridae	*Chrysomya* sp.	Blow fly	W and P
		Rhinia sp.	Calliphorid fly	W and P
		Unknown sp. 1		W and P
	Muscidae	*Musca* sp.	House fly	W and P
	Sarcophagidae	*Parasarcophaga* sp.	Flesh fly	W and P
	Stratiomyidae	*Ptecticius australis*	Soldier fly	W and P
	Syrphidae	*Asarcina aegrota*	Syrphid fly	W and P
	Tabanidae	*Tabanus* sp.	Horse fly	W and P
	Tachinidae	*Tachina* sp.	Tachinid fly	W and P
Hymenoptera	Anthophoridae	*Xylocopa* sp.	Carpenter bee	W and P
		Braunsapis sp.	Small carpenter bee	W and P
		Ceratina spp.		W and P
		Lasioglossum sp.		W and P
		Amegilla sp.	Anthophorid	W
		Unknown sp. 2		W
	Apidae	*Apis florae*	Dwarf honey bee	W and P
		Trigona sp.	Stingless bee	W and P
		Trigona terminata		W and P
		Apis dorsata	Giant bee	P
		Trigona collina	Stingless bee	W and P
	Halictidae	*Nomia* spp.	Halictid	W and P
	Megachilidae	*Megachile* sp. 1	Leaf cutting bee	W
		Megachile sp. 2		P
	Scoliidae	*Scolia ruficeps*	Scoliid wasp	W and P
		Campsomeris sp. 1		P
		Campsomeris sp. 2		P
	Sphecidae	*Chlorion nigripes*	Sphecid wasp	W and P
		Sceliphron sp.		P
	Vespidae	*Allorhynchium* sp.	Wasp	W and P
		Polistes stigma	Paper wasp	W and P
		Vespa affinis	Wasp	W and P
		Rhynchium quinquecinctum		W and P
		Vespa velutina		W and P
		Eumenes petiolata		P
Lepidoptera	Arctiidae	*Cyana coccinea*	Tiger moth	W and P
		Asota caricae		P
	Danaidae	*Euploea core*	Common Indian crow	W and P
		Danaus genutia	Common tiger	W and P
		Euploea mulciber	Striped blue crow	W and P
	Hesperiidae	*Badamia exclamationis*	Brown awl	W and P
		Bilbasis harisa	Orange awlet	W
		Daimio sp.	Skipper	W
		Pelopidas sp.		W
		Caltoris tenuis	Common skipper	P
		Potanthus sp.	Skipper	P
		Udaspes sp.		P
	Hyblaeidae	*Hyblaea puera*	Hyblaea moth	P
	Hypsidae	*Neochera* sp.	Tiger moth	W and P
	Lycaenidae	*Anthena emolus*	Ciliate blue	W and P
		Hypolycaena erytus	Common tit	W and P
		Castalius sp.	Common pierrot	W and P
		Synturucus sp.	Moth	W
		Surendra sp.	Lycaenid	W
		Rapala sp.		W
		Poritia sp.		W
		Spindasis lohita	Long-banded silverline	P

Table 1 (*Continued*)

Order	Family	Genus or species	Common name	Forest
		Cheritra freja	Common imperial	P
	Nymphalidae	*Moduza procris*	Commander	W and P
		Athyma perius	Common sergeant	P
		Cethosia cyane	Leopard lacewing	P
		Hypolymnas bolina	Great eggfly	P
		Neptis hylas	Common sailor	P
		Phalanta phalantha	Common leopard	P
		Precis hierta	Yellow pansy	P
		Precis lemonias	Lemon pansy	P
		Yoma sabina	Lurcher	P
	Papilionidae	*Graphium doson*	Common jay	W
	Pieridae	*Catopsilia pomona*	Lemon emigrant	W and P
		Catopsilia pyranthe	Mottled emigrant	W
		Eurema sp.	Pierid	W
	Sesiidae	*Melittia* sp.	Smaller sphinx	P
	Sphingidae	*Cephonodes hylas*	Sphinx	W and P
	Syntomidae	*Amata* sp.	Moth	W
Total	26 families	71 species in 29 genera plus two unknown species		

adequate diversity or abundance of pollinating insects (Bryndum and Hedegart, 1969; Hedegart, 1973; Mathew et al., 1987; Tangmitcharoen and Owens, 1997). Also, there have been reports of insect damage to flowers and fruits of teak (Choldumrongkul and Hutacharoen, 1986; Hutacharern et al., 1988; Singh and Misra, 1990). However, there has been no report on the species richness and abundance of insects in the canopies of teak in wild and plantation forests. The objective of this study is to examine and compare the diversity and abundance of insects in the canopies of wild and plantation teak forests during the teak flowering season.

2. Materials and methods

2.1. Study trees

The studies were carried out in and near the Maegar Seed Orchard (19°10′N, 99°55′E), which is located at about 200 m elevation in Phayao province in Northern Thailand. Six trees were used for the study. Three trees (P6, P8, P10) were selected from 30-year-old trees within the clonal seed orchard in which teak trees were growing at 12 m × 12 m spacing. The three trees were growing in similar environments and, were located approximately 100 m from one another. Tree P6 had wider spacing than the other two trees because of the death of nearby trees. Three teak trees (N1, N6, N15), of similar size and age as those in the seed orchard, were selected from a nearby deciduous forest in which there was abundant teak trees located approximately 3 km from the seed orchard. These trees were about 200 m away from one another. Abundance of flowers on each of the six trees was similar.

2.2. Insect collection

During the teak flowering season (August–October, 1998), canopy insects were collected using Malaise traps and hand net. The Malaise traps were set up once the sample trees started to flower. The traps consisted of sheets of fine black net, sizes of 90 cm × 110 cm × 170 cm that were suspended vertically and kept tight by several ropes. There was a central vertical sheet and a roof sheet forming an open-sided tent with an upward sloping roof that funneled into an uppermost cone in which a collecting bottle was located containing 70% ethanol. Flying insects that encountered the tent generally flew upwards after hitting the central sheet and were directed towards the top of the cone and into the aperture of the collecting bottle. The trap was supported by a wooden frame and was lifted into the canopy of each flowering tree (1 trap per tree) using a simple bamboo elevating system. Specimens were collected weekly from the bottles.

Hand netting was done from scaffolds erected (typically 8–12 m high) into the canopy. Insects were collected from 08:00 to 14:00 h each day, coinciding with the most receptive period of teak flowers (Tangmitcharoen and Owens, 1997). Collected insects were killed in a glass container containing cotton saturated with ethyl acetate ($CH_3COOC_2H_5$). All collected specimens were preserved in 70% ethanol for later sorting.

2.3. Insect sorting and identification

Insects collected from the six trees were sorted into broad categories then were identified by comparison with the specimens preserved at the Division of Entomology and Zoology, Department of Agriculture, Ministry of Agriculture and Cooperatives, and Faculty of Agriculture, Kasetsart University in Thailand. Many insects could not be identified and were sorted as morphospecies, as recommended by Oliver and Beattie (1993). Based on their feeding habit and behavior, insects were divided into two broad groups: potential pollinators and non-pollinators. Insects that visited teak flowers or inflorescences and possibly fed on pollen and nectar were considered to be potential pollinators. Insects that did not visit

flowers or inflorescences and did not feed on pollen or nectar but were collected near the canopies were considered non-pollinators.

2.4. Data analysis

Insect species diversity and abundance in the canopies of the six trees were analyzed using Fisher's alpha diversity index, following the recommendations of Southwood and Henderson (2000). Means were calculated for all measurements. The variation between wild and plantation trees in Fisher's alpha index were assessed by analysis of variance (ANOVA).

3. Results and discussion

Canopies of wild teak had greater insect biodiversity than their plantation counterparts; however, the number of potential insect pollinators in the plantation canopies was greater than the wild trees. Consequently, plantations may produce more seed.

The six sample trees in the wild and plantation forests generally produced high numbers of inflorescences (80–100). In the dense canopy of the plantation, the trees had higher numbers of inflorescences per unit area due to the relatively close spacing (12 m × 12 m). In the mixed deciduous forest where teak trees had a scattered distribution, the number of inflorescences per unit area was lower.

The numbers of flowers in a canopy may influence the visits of insect pollinators. Linhart (1973) reported that the humming bird-pollinated species (*Haliconia*) attracted territorial humming birds when the trees produced more flowers in inflorescences or in the whole plant. In accordance with this result, we found that, the number of potential pollinators in the plantation canopies was higher than that in the canopies in the wild. In the plantation, teak trees were planted at 12 m × 12 m spacing, producing a dense canopy with a high number of flowers and inflorescences in close proximity. In the wild, teak had a more scattered distribution resulting in less dense canopies and a medium amount of flowers and inflorescences in close proximity. It appears that in teak, abundant flowers attract more flower visitors to approach the blossoms.

A total of 693 morphospecies were collected in wild and plantation tree canopies that were potential pollinators and non-pollinators. They belonged to 115 recognizable families and 11 orders. The pollinators were from Diptera, Hymenoptera, and Lepidoptera were identified to 73 species; 31 could only be identified to the level of genus; and two could only be identified to the level of family (Table 1). The non-pollinators consisted of 620 morphospecies from 11 orders. Of the 620 morphospecies, 49 were identified to level of species from 20 families within five orders: Coleoptera, Diptera, Hemiptera, Homoptera, and Hymenoptera (Table 2). Another 57 were identified to level of genus. These belonged to 46 genera and 27 different families in five orders: Coleoptera, Diptera, Hemiptera, Homoptera, and Hymenoptera (Table 3). There were 514 morphospecies that could only be identified to the level of family. These belonged to 84 families in 11 orders (Table 4).

Table 2
Non-pollinator insects collected from the teak canopies of wild (W) and plantation (P) forest trees near the Maegar Seed Orchard in Phayao province and identified at the level of species

Order	Family (common name)	Scientific name	Forest
Coleoptera	Buprestidae	*Chrysobothris indica*	W and P
		Belionota prasina	W
		Lampestis affinis	W
	Cerambycidae	*Perissus laetus*	W and P
		Perissus dilatus	W
		Mesosa undata	W
		Niphona cylindracea	W
		Coptops polyspila	W
		Xylotrechus buqueti	P
		Moechotypa suffusa	P
	Cleridae	*Rhytidoclerus rufoventris*	W and P
		Tenerus signaticollis	W
	Coccinellidae	*Cryptolaemus montruzieri*	W and P
		Harmonia octomaculata	W
		Micraspis discolor	W
		Menochilus sexmaculatus	W
	Meloidae	*Zonabris cichorii*	P
		Mylabris phalerata	P
Diptera	Tabanidae	*Tabanus rubidus*	W and P
Hemiptera	Tingidae	*Belenus ravana*	W
		Dulinius conchatus	W
Homoptera	Cicadellidae	*Erythroneura suzukii*	W
	Deltocephalidae	*Scaphoideus albovittatus*	W and P
	Dictyopharidae	*Orthopagus lunulifer*	W
	Flatidae	*Neosalurnis reticulatus*	W
	Machaerotidae	*Machaerota noctua*	W and P
	Membracidae	*Emphusis malleus*	W
	Plataspidae	*Coptosoma japonicum*	W
	Ricaniidae	*Pochazia fuscata*	W and P
		Pochazia mamyona	W
		Pochazia pipera	W
		Ricania marginlis	W
Hymenoptera	Formicidae	*Tapinoma melanocephalum*	W and P
		Tetraponera ruflonigra	W
		Dolichoderus thoracicus	W
		Tetraponera attenuata	W
		Gnamptogenys bicolor	W
		Camponotus rufoglaucus	P
	Vespidae	*Provespa barthelemyi*	W
	Lymantriidae	*Orgyia turbata*	P
	Noctuidae	*Calesia stillifera*	W
		Platyia umminia	W
		Hamodes propitia	W
		Plecoptera reflexa	P
		Pararellia areuata	P
		Entomogramma fautrix	P
		Ericeia freterna	P
		Pericyma eruegeri	P
	Pyralidae	*Sylepta derogata*	W
Total	20 families	49 species	

Table 3
Non-pollinator morphospecies collected at the teak canopies of wild (W) and plantation (P) forests near the Maegar Seed Orchard in Phayao province and identified to the level of genus

Order	Family	Genus	Number of morphospecies	Number in forest types		
				W	P	W and P
Coleoptera	Cerambycidae	*Pterolophia*	2	1		1
Diptera	Calliphoridae	*Chrysomya*	1		1	
	Cecidomyiidae	*Orseolia*	1			1
	Celyphidae	*Celyphus*	1		1	
	Culicidae	*Culex*	1			1
	Pipunculidae	*Pipunculus*	1			1
	Stratiomyidae	*Ptecticus*	1	1		
		Hermetia	1	1		
	Syrphidae	*Asarcina*	1		1	
	Tabanidae	*Tabanus*	1			1
Hemiptera	Tingidae	*Monanthia*	1	1		
Homoptera	Fulgoridae	*Ancyra*	1	1		
	Membracidae	*Emphusis*	1			1
Hymenoptera	Bethylidae	*Tiphia*	1		1	
	Braconidae	*Phanerotoma*	1	1		
	Chalcididae	*Brachymeria*	1		1	
	Crabronidae	*Ectemnius*	1	1		
	Eurytomidae	*Eurytoma*	1			1
	Formicidae	*Crematogaster*	2	1	1	
		Monomorium	1			1
		Polyrhachis (*Myrma*)	1	1		
		Philidris sp.	1	1		
		Tetramorium	2	2		
		Camponotus	3	2	1	
		Tetraponera	1	1		
	Ichneumonidae	*Xanthopimpha*	1	1		
	Pempredonidae	*Psenulus*	1	1		
	Pompilidae	*Episylon*	1		1	
	Sphecidae	*Pison*	1			1
		Trypoxylon	4	3	1	
		Larra	1		1	
	Trichogrammatidae	*Trichogramma*	1	1		
	Vespidae	*Polistes*	1		1	
	Geometridae	*Semiothisa*	1	1		
		Pingasa	2	2		
	Noctuidae	*Ercheia*	1			1
		Episparis	1			1
		Nagia	1			1
		Elydra	1	1		
		Ericeia	2	2		
		Fodina	1	1		
		Stictoptera	2	2		
		Parallelia	1	1		
		Eublemma	1		1	
		Mythimna	1		1	
	Chrysopidae	*Chrysopa*	1			1
Total	27 families	46 genus	57	31	13	13

Hymenoptera, Lepidoptera, and Diptera have been reported as major orders of insects visiting teak flowers in Nigeria, India, and Thailand. In Thailand, the numbers of species in each of these three orders were 7, 17, and 35, respectively (Egenti, 1981; Mathew et al., 1987; Tangmitcharoen and Owens, 1997). Results from the present study in Thailand demonstrated that 75% of the species, genera and morphospecies collected in the canopies of teak trees were from these three orders. However, in the canopies there was much variety of potential pollinating and non-pollinating insects. We found that the major components

Table 4
Non-pollinator morphospecies collected in the teak canopies of wild (W) and plantation (P) forests near the Maegar Seed Orchard in Phayao province and identified to the level of family

Order	Family	Number of morphospecies	Number in forest types		
			W	P	W and P
Coleoptera	Alleculidae	1	1		
	Anthicidae	2		1	1
	Anthribidae	5	4		1
	Bostrichidae	1		1	
	Bruchidae	1			1
	Carabidae	4	2	2	
	Cerambycidae	4	2	1	1
	Chrysomelidae	9	4	1	4
	Cleridae	9	7	1	1
	Curculionidae	5	5		
	Dermestidae	2	1		1
	Elateridae	1		1	
	Helodidae	1		1	
	Lycidae	1			1
	Melandryidae	1	1		
	Mordellidae	3	2		1
	Nitidulidae	1		1	
	Passalidae	1	1		
	Platypodidae	3	2	1	
	Rhipiphoridae	1		1	
	Scaphidiidae	1	1		
	Scarabaeidae	2	1	1	
	Scolytidae	2	2		
	Staphylinidae	2	2		
	Unknown beetle	2		2	
Dermaptera	Unknown earwigs	2	1	1	
Dictyoptera	Blattellidae	3		2	1
Diptera	Agromyzidae	3	1		2
	Asilidae	3	1	1	1
	Bibionidae	2		1	1
	Bombyliidae	1	1		
	Calliphoridae	1			1
	Cecidomyiidae	1			1
	Culicidae	6	1	2	3
	Dolichopodidae	1			1
	Drosophilidae	4	2	1	1
	Empididae	1			1
	Eptogastidae	1	1		
	Lauxaniidae	1		1	
	Lonchaeidae	1	1		
	Muscidae	10	3	4	3
	Mycetophilidae	2	1		1
	Neriidae	1	1		
	Sarcophagidae	1			1
	Stratiomyidae	4	3		1
	Syrphidae	2	2		
	Tabanidae	2	1	1	
	Tachinidae	6	3	1	2
	Tephritidae	7	5	2	
	Tipulidae	2		1	1
	Unknown fly	14	3	5	6
Hemiptera	Berytidae	1	1		
	Cydnidae	1	1		
	Lygaeidae	4	3	1	
	Miridae	5	3	2	
	Pantatomidae	4	2		2
	Reduviidae	2	2		
	Scutelleridae	1	1		
Homoptera	Cercopidae	21	9	1	11

Table 4 (*Continued*)

Order	Family	Number of morphospecies	Number in forest types		
			W	P	W and P
	Cicadellidae	17	9	2	6
	Dictyopharidae	1	1		
	Kerridae	1	1		
Hymenoptera	Bethylidae	4	3	1	
	Braconidae	40	30	7	3
	Chalcididae	10	8	2	
	Chrysididae	4	2	1	1
	Crabronidae	3	3		
	Eupelmidae	1	1		
	Eurytomidae	5	3	1	1
	Evaniidae	4	3	1	
	Formicidae	14	10	2	2
	Ichneumonidae	15	12	2	1
	Scoliidae	1	1		
	Sphecidae	5	1	2	2
	Tenthredinidae	1	1		
	Trichogrammatidae	8	7	1	
	Vespidae	6	4	2	
	Unknown	21	17	3	1
Lepidoptera	Geometridae	9	4	2	3
	Limacodidae	2	2		
	Noctuidae	43	16	8	19
	Notodontidae	2	1		1
	Pyralidae	6	2	1	3
	Unknown moth	97	42	14	41
Neuroptera	Chrysopidae	2	2		
Orthoptera	Acrididae	1			1
	Gryllidae	2	1		1
	Mantidae	1		1	
	Tetrigidae	1			1
Thysanoptera	Thripidae	1	1		
Total	84 families	514	279	95	140

(89.47%) of collected insects were non-pollinators, and only 10.53% were potential pollinators. Of the 73 morphospecies of potential pollinators, Lepidoptera had the highest number (39), followed by Hymenoptera (25) and Diptera (9) (Table 5).

A total of 10,404 individual insects were collected from the six tree canopies. The numbers of morphospecies belonging to potential pollinators and non-pollinators from the two habitats varied considerably from one to another (Table 5). Lepidoptera

Table 5
Number of morphospecies of insects collected from teak canopies of wild and plantation forest

Order	Grand total			Percentage			Wild forest			Plantation forest			Wild and plantation forests		
	Total	Po	Non	Total	Po	Non	Total	Po	Non	Total	Po	Non	Total	Po	Non
Lepidoptera	223	39	184	32.18	5.63	26.55	174	11	81	131	16	33	82	12	70
Hymenoptera	201	25	176	29.0	3.61	25.40	161	3	127	71	6	34	31	16	15
Diptera	96	9	87	13.85	1.30	12.55	73	0	32	64	0	23	41	9	32
Coleoptera	85	0	85	12.27	0	12.27	66	0	49	36	0	19	17	0	17
Homoptera	53	0	53	7.50	0	7.65	50	0	29	24	0	3	21	0	21
Hemiptera	21	0	21	3.17	0	3.03	18	0	16	5	0	3	2	0	2
Orthoptera	5	0	5	0.72	0	0.72	4	0	1	4	0	1	3	0	3
Dictyoptera	3	0	3	0.43	0	0.43	1	0	0	3	0	2	1	0	1
Neuroptera	3	0	3	0.43	0	0.43	3	0	2	1	0	0	1	0	1
Dermaptera	2	0	2	0.29	0	0.29	1	0	1	1	0	1	0	0	0
Thysanoptera	1	0	1	0.14	0	0.14	1	0	1	0	0	0	0	0	0
Total	693	73	620	100	10.5	89.5	552	14	339	340	22	119	199	37	162

Po, potential pollinators; Non, non-pollinators.

Table 6
Insects collected from teak canopies of wild (W) and plantation (P) forests and their number of morphospecies, number of individuals and Fisher′s alpha index

Tree	Number of morphospecies	Number of individuals	Fisher′s alpha index
N1	268	2058	82.26
N6	261	1942	81.18
N15	311	2948	87.80
Mean	280.0 ± 15.63	2316 ± 15.63	83.75 ± 2.05
Total morphospecies/ individuals	552	6948	
P6	226	2168	63.52
P8	105	795	32.42
P10	119	493	49.82
Mean	150 ± 38.21	1152 ± 515.43	48.59 ± 9.0
Total morphospecies/ individuals	340	3456	

had the highest number (32.18%), followed by Hymenoptera (29.0%), and the smallest number was recorded in Thysanoptera, in which only one morphospecies (0.14%) was collected. In most orders, the numbers of morphospecies in the wild tree canopies were higher than those in the plantation canopies.

In general, means and total number of morphospecies, number of individuals, and Fisher's alpha index in the wild canopies were higher than those in the plantation. (Table 6). The Fisher's alpha index between wild trees and plantation trees differed significantly (F-value = 14.512, P-value = 0.019). The numbers in the plantation canopies were more variable than those in the wild canopies. The P6 canopy, which had wider spacing, had a much higher number of morphospecies, number of individuals, and Fisher's alpha index than the canopies of the other two plantation trees.

Variations occur in species diversity and abundance of insects depending on habitat characteristics. In Sabah, Malaysia, Chey et al. (1997) reported that the diversity of moths in *Eucalyptus deglupta* forest plantations is as high as that in the natural forest. Toft et al. (2001) reported the richness of beetles was high where there was high variety of plants in lowland broadleaf forest fragments in New Zealand. We found that the species richness, abundance and alpha diversity indices of insects in the wild teak canopies were higher than those in the plantation teak canopies.

In plantations and seed orchards, spacing could play a significant role in insect diversity and abundance. Hamphrey et al. (1999) reported that diversity of syrphids (hoverflies) in open canopy stands, which are characterized by high levels of understory, is greater than in dense closed canopy stands. They suggested that the open stands with diverse understory provide a greater source of adult food and suitable breeding sites for syrphids. In addition, Fermon et al. (2000) reported that the species richness and diversity indices of butterflies in liberation thinning (broader spacing) are higher than those in monodominant tree plantations. We believe that our results from this study of teak are in agreement with results from these other teak studies. We found higher species diversity and abundance of morphospecies in one of the plantation trees that grows at broader spacing compared with the other plantation trees. A possible explanation for these characteristics is that broader spacing contributes to the increase of understory vegetation that provides a source of food and habitat for insects.

The role played in pollination by different pollinators may vary with insect species. Bohart et al. (1970) gave a list of all pollinators observed on onion (*Allium cepa* L.) and classified them with regard to efficiency in pollination and abundance. Out of 255 pollinators visiting onion flowers, only eight were efficient and/or abundant, thus important as pollinators, and 164 were both rare and inefficient pollinators. In teak, Tangmitcharoen and Owens (1997) reported that *Ceratina* sp. was the main pollinator, although 36 other species were observed to visit flowers in a plantation in central Thailand. The numerous potential pollinators (73) reported in the present study could have different roles in the pollination of teak flowers depending on behavior of the insects. An examination of all of the pollinators and their behavior in this plantation is needed to further evaluate their different roles and relative importance in the pollination of teak.

Acknowledgements

This work was supported by TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT 140008, Thailand and also a Ronpaku Program of Japan Society for the Promotion of Science (JSPS), Japan. We thank Mr. Robert Cunningham for statistical analyses and Mr. P. Pianhanuruk, station chief at Maegar Seed Orchard, Phayao for providing the field facility. We are grateful to Ms. M. Takeaw who assisted with data collection during field work and processing of insect specimens and to Dr. A. Lewvanich and the staff of Entomology and Zoology Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand for insect identification.

References

Bohart, G.E., Nye, W.P., Hawthorn, L.R., 1970. Onion pollination as affected by different levels of pollinator activity. Utah Agric. Exp. Stn. Utah State. Bull. 482, 57.

Bryndum, K., Hedegart, T., 1969. Pollination of teak (*Tectona grandis* Linn. f.) Silv. Genet. 18, 77–80.

Chey, V., Holloway, J., Speight, M., 1997. Diversity of moths in forest plantations in Sabah. Bull. Ent. Res. 87, 371–385.

Choldumrongkul, S., Hutacharoen, C., 1986. The relationship between the flower development of teak and its associated. J. Natl. Res. Council Thailand 18 (2), 45–51.

Egenti, L.C., 1981. Aspects of pollination ecology of teak (*Tectona grandis* L.f.) in Nigeria: flowering and insect dynamics. In: Krugman, S.L., Katsuta, M. (Eds.), Flowering Physiology, Proceeding of IUFRO XVII World Congress, Kyoto, Japan, pp. 17–20.

Eggleton, P., Bignell, D., Sands, W., Mawdsley, N., Lawton, J., Wood, T., Bignell, N., 1996. The diversity, abundance and biomass of termites under differing levels of disturbance in Mbalmayo forest reserve, southern Cameroon. Philos. Trans. R. Soc. London, Ser. B Biol. Sci. 351, 51–68.

Eggleton, P., Bignell, D., Sands, W., Waite, B., Wood, T., Lawton, J., 1995. The species richness of termites (Isoptera) under differing levels of forest

disturbance in the Mbalmayo forest reserve, southern Cameroon. J. Trop. Ecol. 11, 85–98.

Fermon, H., Waltert, M., Larsen, T.B., Dall, U., Muhlenberg, M., 2000. Effect of forest management on diversity and abundance of fruit-feeding nymphalid butterflies in south eastern Cote d'lvoire. J. Insect Conserv. 4, 173–189.

Hamer, K., Hill, J., Lace, L., Langan, A., 1997. Ecological and biogeographic effects of forest disturbance on tropical butterfies of Sumba. Indonesian J. Biogeogr. 24, 67–75.

Hedegart, T., 1973. Pollination of teak (*Tectona grandis* L. f.) Silv. Genet. 22 (4), 124–128.

Hill, J., Hamer, K., Lace, L., Banham, W., 1995. Effects of selective logging on tropical forest butterflies on Buru. Indonesian J. Appl. Ecol. 32, 754–760.

Holloway, J., Kirk-Spriggs, A., Khen, C., Marshall, A., Swaine, M., 1992. The response of some rain forest insect groups to logging and conversion to plantation. Philos. Trans. R. Soc. London, Ser. B, Biol. Sci. 325, 425–436.

Hamphrey, J.W., Hawes, C., Peace, A.J., Ferris-Kaan, R., Jukes, M.R., 1999. Relationships between insect diversity and habitat characteristics in plantation forests. Forest Ecol. Manage. 113 (1), 11–21.

Hutacharern, C., Choldumrongkul, C., Eungwijarnpanya, S., Choldumrongkul, A., 1988. Check List of Forest Insects in Thailand. Office of Environmental Policy and Planning, Bangkok, Thailand.

Intachat, J., Holloway, J., Speight, M., 1997. The effects of different forest management practices on geometrid moth populations and their diversity in peninsular Malaysia. J. Trop. Forest Sci. 9, 411–430.

Linhart, Y.B., 1973. Ecological and behavioural determinants of pollen dispersal in humming bird-pollinated *Heliconia*. Am. Nat. 107, 511–523.

Mathew, G., Koshy, M.P., Mohanadas, K., 1987. Preliminary study on insect visitors to teak (*Tectona grandis* Linn.f.) inflorescence in Kerela, India. Indian Forest 113, 61–64.

Nummelin, M., 1996. Community structure of arthropods in virgin and managed sites in the Kibale forest Western Uganda. Trop. Ecol. 23, 201–213.

Nummelin, M., Borrowiec, L., 1991. Cassidinae beetles of the Kibale forest Western Uganda: comparison between virgin and managed forests. Afr. J. Ecol. 30, 10–17.

Nummelin, M., Fursch, H., 1992. Coccinellids of the Kibale forest Western Uganda a comparison between virgin and managed sites. Trop. Zool. 5, 155–166.

Nummelin, M., Hanski, H., 1989. Dung beetles of Kibale forest Uganda: comparison between virgin and managed forest. J. Trop. Biol. 5, 349–352.

Oliver, I., Beattie, A., 1993. A possible method for rapid assessment of biodiversity. Conserv. Biol. 7, 562–568.

Pianhanuruk, P., 1995. Assessment of teak (*Tectona grandis* Linn. f.) seed orchard in Thailand. M.Sc. Thesis, Kasetsart University, Thailand (in Thai).

Phillip, P., 1988. Down to Earth. Collins, London, United Kingdom.

Singh, P., Misra, R.M., 1990. External motphology, binomics and natural enemy complex of Pagyda salvalis Walker Lepidoptera: Pyralidae) the inflorescence feeder and fruit borer of teak. Indian Forest 116 (9), 742–747.

Silver, S., Dunning, G., Ashton, M., Binko, H., 2000. Tropical Forest Plantations and Biodiversity. Yale Forest Forum Series Publication, Yale University, Connecticut, USA.

Southwood, T., Henderson, P., 2000. Ecological Methods, third ed. Blackwell Publishing, Massachusetts, USA.

Tangmitcharoen, S., Owens, J.N., 1997. Floral biology, pollination, pistil receptivity, and pollen tube growth of teak (*Tectona grandis* L. f.) Ann. Bot. 79, 227–241.

Tewari, D.N., 1992. A monograph on teak (*Tectona grandis* L. f.) International Book Distributors, Dehradun, India.

Toft, R.J., Harris, R.J., Williams, P.A., 2001. Impact of the weed *Tradescantia fluminensis* on insect communities in fragmented forests in New Zealand. Biol. Conserv. 102, 31–46.