Impacts of thinning on diversity of Hymenoptera in pine plantation forest of Sukabumi, West Java, Indonesia

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Abstract. Partial cutting technique (thinning) of pine tree to improve pine growth and timber quality causes disturbances to the forest which can affect forest fauna, especially the order Hymenoptera. This study aimed to analyze how the species abundance and richness of Hymenoptera is influenced by thinning in pine plantation forest. The study compared Hymenopteran abundance before and after thinning of the pine forest. Intensity of forest thinning was at 20%. The plot used in this study was cluster plot for forest health and monitoring. The number of plots was 4 plots, which was placed systematically in the thinning area of 7.85 ha. The Hymenopterans caught using 80 pitfall traps before thinning and after thinning. Insects were identified to morphospecies level. Non parametric statistics (Mann-Whitney and Friedman test) were used to analyze the difference in abundance and species richness of Hymenoptera before thinning and after thinning at the significant level of 5%. The number of individual Hymenopterans before thinning was 2,369 individuals, consisting of 3 families, 27 genera and 44 morphospecies. After thinning, the number of individual Hymenoptera was 2,400 individuals, consisting of 4 families, 24 genera and 45 morphospecies. The abundance of Hymenopterans before thinning and after thinning was not significantly different whereas the morphospecies composition of Hymenoptera before thinning and after thinning was significantly different.

1. Introduction
Plantation forests have an important role in Indonesia's forestry sector. Indonesian plantation forests contributed 2.7% of Indonesia's gross domestic product in 2017. Besides serving as a source of log production, plantation forests also provide non-timber forest products and environmental services [1, 2], as well as improving the living standard of tree-grower communities [3]. The area of plantation forests in Indonesia covers 2.5% of Indonesia's forest area (4,660,200 ha) in 2017 [4]. Log production from plantation forests comes from clear cutting and thinning activities.
Forest thinning is a part of forest management practices, which aims to provide tree growing space by reducing stand density to increase tree growth and quality [5], and provide income for tree growers [6]. Forest thinning is a partial cutting technique, which will partially open forest canopy cover. Therefore, forest thinning may change microclimate of the forest. This change will affect forest biodiversity, both flora and fauna [7]. Differences in components and complexity of forest vegetation structure affect the diversity of forest arthropods [8]. The impact of forest thinning on insect communities is lower than clear-cutting [9, 10]. Nevertheless, some previous studies have shown that Hymenoptera and saproxylic insects are sensitive to gaps formation and forest cutting [11]. Therefore, forest insects can be considered a vital part of ecosystem complexity and their response to various environmental changes can be used as a tool to assess changes in forest habitat [12, 13].

Insects are the dominant group of invertebrates on earth. The number of insects exceeds other terrestrial reptiles, and insects can be found in various places [14]. Insects have a variety of functional roles in an ecosystem, such as predators, herbivores, and detritivores. Hymenoptera is one of the 4 largest insect orders along with Coleoptera, Diptera and Lepidoptera [15]. A number of groups of Hymenopteran insects such as ants, bees and parasitoids play an important role in the forest ecosystem. Ants and parasitoids from the order Hymenoptera functioned as forest pest controller [16]. Insects can also be used as bioindicators of forest disturbances, including forest cutting activities [17, 18].

Information on the effects of forest thinning on Hymenoptera is still limited, especially in Indonesia plantation forest. Previous studies that have been carried out related to forest thinning activities in Indonesia examine tree growth [6], thinning efficiency and productivity [19], thinning intensity [20] and utilization of thinning wood [21]. Therefore, this study measures and analyzes the impact of thinning pine plantations on the diversity of Hymenopterans.

2. Methods
This study was conducted in April-September 2018 in a 7.85 ha pine plantation forest in forest management unit of Sukabumi, West Java. Tree species planted at the area was pine (*Pinus merkusii* Jung de Vriest), which was planted in 2003. The forest was thinned at 20% intensity. The study site is located at 106°41' - 107°00' E and 6°57' - 7°20' S and located at an altitude of 700 m above sea level. The topography of the study site varied from flat to steep terrain. The type of soil at the study site was latosol. Average rainfall at the study site ranged from 4,000-6,000 mm/yr with daily temperature of 20-30 °C.

The plot used in this study was a cluster plot for forest health monitoring (FHM). Four FHM plots were systematically located in the forest thinning area with a distance between plots of 200 meters. Pitfall trap was used to collect the insects. A total of 5 pitfall traps were installed in a 1 m x 1 m square sub plot, which was placed at the center of each microplot of FHM plot. Insects collection was carried out before and after forest thinning. Collected insects were identified to morphospecies level based on identification keys by Borror [6] and Goulet [22, 23]. Abundance, Shannon-Wiener species diversity index, Margalef species richness index, and species evenness index were calculated for insect community parameters.

Environmental factors, such as air temperature, humidity, litter thickness, number of understorey plants, and canopy cover were measured in the square sub plot of 1x1 m. A digital thermohygrometer was used to measure temperature and humidity. Measurements of canopy cover were done using a spherical densiometer. Environmental factors were measured before and after forest thinning.

Non parametric statistics were used to analyze differences in abundance and species richness before thinning and after thinning, because the variables did not follow normal distribution. The Mann-Whitney test was used to compare the differences of Hymenopteran insect abundance before and after forest thinning. The Friedman test was used to compare the differences in species richness of Hymenoptera before and after forest thinning. Pearson correlation test was used to test the relationship between the abundance of Hymenopterans and environmental factors (α = 0.05).
3. Results and discussion

The number of families of the order Hymenoptera after thinning was higher than before thinning. We found 3 families before thinning, which are Formicidae, Diapriidae, and Trigonalidae. Meanwhile, after thinning, there were 4 families, which are Formicidae, Diapriidae, Ceraphronidae and Ichneumonidae. The number of genera of the order Hymenoptera before thinning was 34, whereas after thinning it was 23. The number of morphospecies of the order Hymenoptera before thinning was 49 morphospecies and after thinning it was 39 morphospecies (Fig. 1). The number of individuals of the order Hymenoptera before thinning was smaller than after thinning, but there was no difference in abundance before thinning and after thinning (P>0.05). Total individual of Hymenopterans before thinning was 2,369 individuals, which consisted of Formicidae family 98.22%, Diapriidae 1.71%, and Trigonalidae 0.04%. Meanwhile, the number of individuals after thinning was 2400 individuals, consisted of Formicidae 99.41%, Diapriidae 0.47%, Ichneumonidae 0.08%, and Ceraphronidae 0.04%. The genera of the order Hymenoptera before and after thinning are presented in Table 1 and the names of morphospecies are presented in Table 2.

Index of the Hymenopteran community tends to decrease after forest thinning. The diversity index of Hymenoptera before thinning was 2.12 and after thinning it was 1.32. The richness index of Hymenoptera before thinning was 6.22 and after thinning it was 4.85. Meanwhile, the evenness index of Hymenoptera before thinning was 0.54 and after thinning it was 0.36 (Fig. 2). The morphospecies composition of Hymenoptera before and after thinning was significantly different.

Thinning forests decreases canopy cover, the density of understory plants, and humidity, while daily temperature and litter thickness are increased. The average daily temperature before thinning was 23.2°C, whereas after thinning it was 25.7 °C. The average air humidity before thinning was 86.9%, while after forest thinning it was 75.7%. After thinning, the percentage of canopy cover decreased by 4.1%, and litter thickness increased by 1% (Table 3). Results of Pearson correlation test showed that the abundance of Hymenopteran insects did not correlate significantly with air temperature, humidity, canopy cover, litter thickness and the density of understorey plants (Table 4).
Thinning pine forests with an intensity of 20% affected forest environmental factors such as temperature, humidity, canopy cover, litter thickness, and the number of understorey plants. The study results showed that thinning pine forests increased the abundance of Hymenopteran insects by 1.31%. Although the abundance of Hymenopteran insects is greater than before thinning, there was no significant difference in abundance between before thinning and after thinning. The result of this study contradicts the research result of Hammond [24], which found that the abundance of insects in thinned forests was different with un-thinned forests.

The study proved that some Hymenopteran insects responded rapidly to changes in forest microclimate, especially temperature. There were 19 Hymenoptera morphospecies, which were not found after forest thinning. The morphospecies of this group which have an abundance more than 1 individual were *Myrmicaria* sp. 4, *Basalys* sp. 2, *Odontoponera* sp. 4, *Aenictus* sp., *Chrysapace* sp. 1, *Nylanderia* sp. 4, *Ectomomyrmex* sp. 2, *Myrmicinae* sp., *Ophion* sp., and *Polyrhachis* sp. 1. While the others only have an abundance of 1 individual. These insects prefer low temperatures and more open forest canopy. Meanwhile, there were 9 new morphospecies of Hymenoptera found only after thinning. These Hymenopteran morphospecies preferred a slightly exposed canopy cover and disturbed forest habitat. The morphospecies of this group, which have an abundance more than 1 individual were *Ectomomyrmex* sp. 4, *Diacamma* sp. 4, *Strumigenys* sp. 4, *Aphaenogaster* sp. 4, and *Leptogenys* sp. 7 (Table 2). The results of the study supported the results of previous studies, which reported that Hymenopterans have a narrow tolerance level, rapid response to changes in microclimate, especially temperature [25], and prefer low temperatures [26].

The result of the study indicates that the diversity index, species richness index and evenness index of Hymenopteran insect before forest thinning were greater than after forest thinning (Fig. 2). It was suspected that the reduction of canopy closure due to forest thinning affects the diversity index, species richness and species evenness index. Thinning pine forests with an intensity of 20% caused a reduction of canopy cover by 15.73%. Forest thinning can reduce the number of natural prey or host of Hymenopterans. Most of the Hymenopteran insects functioned as natural enemies of insect pests. Reduction of natural prey and host of Hymenopterans decreased the morphospecies composition and diversity of Hymenopterans. Friedman test results showed that the morphospecies composition of the Hymenopteran insects before and after thinning was significantly different (p<0.05). Thinning pine forests with an intensity of 20% changed the morphospecies composition of the Hymenopteran insect. The result of the study is in line with the study result of Chung and Maryati [27], which reported that the diversity of Hymenopterans in anthropogenically disturbed habitats was lower than in

**Figure 2.** Diversity, species richness, and evenness index of Hymenoptera before and after thinning of pine forest in Sukabumi, West Java.
Undisturbed habitats. Febrita et al. [28] reported that changes in vegetation composition in an ecosystem greatly affected the abundance of insects.

**Table 1.** The genera of Hymenoptera found before and after thinning of pine forest in Sukabumi, West Java.

| No. | Family       | Genera        | Abundance (Individu) |
|-----|--------------|---------------|----------------------|
|     |              |               | Before thinning | After thinning |
| A.  | Found before and after thinning |               |                     |
| 1   | Formicidae   | *Pheidole*    | 1530           | 1917           |
| 2   | Formicidae   | *Myrmicaria*  | 414            | 92             |
| 3   | Formicidae   | *Leptogenys*  | 90             | 146            |
| 4   | Formicidae   | *Ectomomyrmex* | 74          | 74             |
| 5   | Formicidae   | *Odontoponera* | 52           | 25             |
| 6   | Formicidae   | *Anoplolepis* | 2             | 1              |
| 7   | Formicidae   | *Anochetus*   | 31            | 34             |
| 8   | Formicidae   | *Aphaenogaster* | 24          | 23             |
| 9   | Formicidae   | *Nylanderia*  | 24            | 3              |
| 10  | Formicidae   | *Strumigenys* | 17            | 28             |
| 11  | Formicidae   | *Diacamma*    | 16            | 11             |
| 12  | Formicidae   | *Brachyponera* | 9            | 12             |
| 13  | Formicidae   | *Crematogaster* | 6           | 4              |
| 14  | Formicidae   | *Harpegnathos* | 6           | 4              |
| 15  | Formicidae   | *Tetraponera* | 5             | 6              |
| 16  | Formicidae   | *Prenolepsis* | 4             | 7              |
| 17  | Formicidae   | *Proceratium* | 3             | 1              |
| 18  | Diapriidae   | *Basalys*     | 40            | 8              |
| B.  | Found only before thinning |               |                     |
| 1   | Formicidae   | *Aenictus*    | 4             | 0              |
| 2   | Formicidae   | *Chrysapace*  | 4             | 0              |
| 3   | Formicidae   | *Polyrhachis* | 3             | 0              |
| 4   | Formicidae   | *Amblyopone*  | 2             | 0              |
| 5   | Formicidae   | *Myrmicinae*  | 2             | 0              |
| 6   | Formicidae   | *Technomyrmex* | 1           | 0              |
| 7   | Formicidae   | *Aretidris*   | 1             | 0              |
| 8   | Formicidae   | *Pyramica*    | 1             | 0              |
| 9   | Trigonalidae | *Lycogaster*  | 1             | 0              |
| 10  | Ichneumonidae| *Ophion*      | 2             | 0              |
| C.  | Found only after thinning |               |                     |
| 1   | Formicidae   | *Cardiocondyla* | 0          | 1              |
| 2   | Formicidae   | *Myrcidris*   | 0             | 1              |
| 3   | Ceraphronidae| *Ceraphron*   | 0             | 1              |
| 4   | Diapriidae   | *Camptopsilus* | 0           | 1              |
| No. | Family       | Morphospecies         | Abundance (Individu) |
|-----|--------------|-----------------------|----------------------|
|     |              |                       | Before thinning | After thinning |
| A.  | Found before and after thinning | | | |
| 1   | Formicidae   | Pheidole sp. 1        | 767 | 149 |
| 2   | Formicidae   | Pheidole sp. 2        | 737 | 10 |
| 3   | Formicidae   | Myrmicaria sp. 1      | 297 | 88 |
| 4   | Formicidae   | Ectomomyrmex sp. 1    | 72 | 33 |
| 5   | Formicidae   | Odontoponera sp. 1    | 46 | 25 |
| 6   | Formicidae   | Leptogenys sp. 6      | 35 | 13 |
| 7   | Formicidae   | Leptogenys sp. 1      | 30 | 15 |
| 8   | Formicidae   | Anochetus sp. 1       | 29 | 33 |
| 9   | Formicidae   | Aphaenogaster sp. 1   | 24 | 19 |
| 10  | Formicidae   | Proceratium sp.       | 21 | 4 |
| 11  | Formicidae   | Nylanderia sp. 1      | 21 | 3 |
| 12  | Formicidae   | Strumigenys sp. 1     | 17 | 23 |
| 13  | Formicidae   | Diacamma sp. 1        | 16 | 6 |
| 14  | Formicidae   | Pheidole sp. 3        | 14 | 13 |
| 15  | Formicidae   | Pheidole sp. 4        | 11 | 1745 |
| 16  | Formicidae   | Leptogenys sp. 3      | 10 | 9 |
| 17  | Formicidae   | Brachyponera sp. 1    | 9 | 12 |
| 18  | Formicidae   | Myrmicaria sp. 2      | 7 | 4 |
| 19  | Formicidae   | Anochetus sp. 2       | 2 | 1 |
| 20  | Formicidae   | Crematogaster sp.     | 6 | 4 |
| 21  | Formicidae   | Harpegnathos sp. 1    | 6 | 4 |
| 22  | Formicidae   | Leptogenys sp. 2      | 5 | 4 |
| 23  | Formicidae   | Leptogenys sp. 4      | 5 | 84 |
| 24  | Formicidae   | Leptogenys sp. 5      | 5 | 18 |
| 25  | Formicidae   | Tetraponera sp.       | 5 | 6 |
| 26  | Formicidae   | Prenolepsis sp.       | 4 | 7 |
| 27  | Formicidae   | Anoplolepis sp.       | 2 | 1 |
| 28  | Diapriidae   | Basalys sp. 1         | 21 | 4 |
| 29  | Diapriidae   | Basalys sp. 4         | 6 | 3 |
| 30  | Diapriidae   | Basalys sp. 3         | 4 | 1 |
| B.  | Found only before thinning | | | |
| 1   | Formicidae   | Myrmicaria sp. 4      | 110 | 0 |
| 2   | Formicidae   | Polyrhachis sp. 2     | 1 | 0 |
| 3   | Formicidae   | Odontoponera sp. 4    | 6 | 0 |
| 4   | Formicidae   | Aenictus sp.          | 4 | 0 |
| 5   | Formicidae   | Chrysapace sp. 1      | 4 | 0 |
| 6   | Formicidae   | Nylanderia sp. 4      | 3 | 0 |
| 7   | Formicidae   | Ectomomyrmex sp. 2    | 2 | 0 |
| 8   | Formicidae   | Myrmicinae sp.        | 2 | 0 |
| 9   | Formicidae   | Technomyrmex sp.      | 2 | 0 |
| 10  | Formicidae   | Polyrhachis sp. 1     | 2 | 0 |
Table 2. (continued)

| No. | Family      | Species          | Before thinning | After thinning |
|-----|-------------|------------------|-----------------|---------------|
| 11  | Formicidae  | Amblyopone sp. 1 | 1               | 0             |
| 12  | Formicidae  | Amblyopone sp. 2 | 1               | 0             |
| 13  | Formicidae  | Arendtis sp.     | 1               | 0             |
| 14  | Formicidae  | Pyramica sp.     | 1               | 0             |
| 15  | Formicidae  | Pheidole sp. 5   | 1               | 0             |
| 16  | Diapriidae  | Basalys sp. 2    | 9               | 0             |
| 17  | Trigonalidae| Lycogaster sp.   | 1               | 0             |
| 18  | Ichneumonidae| Ophion sp.     | 1               | 0             |

C. Found only after thinning

| No. | Family      | Species          | Before thinning | After thinning |
|-----|-------------|------------------|-----------------|---------------|
| 1   | Formicidae  | Ectomomyrmex sp. 4 | 0               | 41            |
| 2   | Formicidae  | Diacamma sp. 4   | 0               | 5             |
| 3   | Formicidae  | Strumigenys sp. 4 | 0               | 5             |
| 4   | Formicidae  | Aphaenogaster sp. 4 | 0             | 4             |
| 5   | Formicidae  | Leptogenys sp. 7 | 0               | 3             |
| 6   | Formicidae  | Myrceidris sp.   | 0               | 1             |
| 7   | Formicidae  | Cardiocondyla sp. | 0               | 1             |
| 8   | Ceraphronidae| Ceraphron sp.    | 0               | 1             |
| 9   | Diapriidae  | Camptopsilus sp. | 0               | 1             |

Table 3. Average of temperature, humidity, canopy cover, litter thickness, and number of understorey plants before thinning and after thinning of pine forest.

| No. | Variable                          | Before thinning | After thinning |
|-----|-----------------------------------|-----------------|----------------|
| 1   | Temperature (˚C)                   | 23.2 ± 0.60     | 25.7 ± 0.34    |
| 2   | Humidity (%)                       | 86.9 ± 1.19     | 75.7 ± 0.69    |
| 3   | Canopy cover (%)                   | 64.2 ± 4.20     | 54.1 ± 4.46    |
| 4   | Litter thickness (cm)              | 3.13 ± 1.48     | 3.16 ± 1.47    |
| 5   | Number of understorey plants (Ind.)| 14.9 ± 9.98     | 14.3 ± 10.00   |

Table 4. Correlation coefficient between morphospecies composition of Hymenoptera and environmental factors.

| Abundance | Temperature | Humidity | Canopy cover | Litter thickness | Understorey plants |
|-----------|-------------|----------|--------------|------------------|--------------------|
| r^a       | -0.112      | 0.090    | 0.114        | 0.024            | 0.209              |
| p         | 0.167^ns    | 0.256^ns | 0.153^ns     | 0.764^ns         | 0.080^ns           |

*a* r = coefficient correlation, P = probability, ns = not significant at α: 5%.

Pearson correlation test results showed that the abundance of Hymenoptera insects did not have a strong correlation with environmental factors such as air temperature, humidity, canopy cover, litter thickness, and the number of understorey plants (P > 0.05). The results of the study indicated that the abundance of Hymenoptera insects after thinning was higher than before forest thinning. Forest thinning produced forest litter from thinned trees. As a result, litter thickness after thinning was greater than before thinning. Increasing litter thickness in the forest floor affected total abundance of Hymenoptera insects. Besides playing an important role as predator, Hymenoptera functioned as a decomposer of organic materials. In forest ecosystems, the majority of organic material comes from forest litter. In addition, thicker litter creates suitable microclimate for Hymenoptera insect [29]. Yuniar and Haneda [30] reported that
Hymenopteran presence with high abundance is mostly found in secondary forest ecosystems that have thick litter.

4. Conclusion

Thinning pine forest did not significantly affect the abundance of Hymenopterans. The morphospecies composition of Hymenopterans before thinning was significantly different compared to after thinning. Forest thinning created a new habitat for some Hymenopteran insects, which prefer open and disturbed forest. Forest thinning also disturbed the habitat of some Hymenopterans, which are sensitive to reduction of forest canopy cover. The abundance of Hymenopteran insects did not correlate significantly with air temperature, humidity, canopy cover, leaf thickness and amount of vegetation. Although the morphospecies composition of Hymenopterans before thinning was different compared to after thinning, understanding how thinning intensity affects diversity of Hymenopterans requires additional investigation.

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