

Diversity of insect galls associated with *Eucalyptus alba* & *E. urophylla* in altitudinal zones in Timor Island, Indonesia

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Abstract. Puspasari LT, Buchori D, Ubaidillah R, Triwidodo H, Hidayat P. 2021. Diversity of insect galls associated with *Eucalyptus alba* & *E. urophylla* in altitudinal zones in Timor Island, Indonesia. *Biodiversitas* 22: 2667-2679. We investigated the galling insects associated with two species of *Eucalyptus*, namely *E. alba* Reinw. and *E. urophylla* S.T. Blake in different altitudinal zones in Timor Island, Indonesia. This is the first report for Indonesia of the diversity patterns and community structures of galling insects in these two species of eucalyptus and the type of galls they produce. Surveys and data collection were carried out between October 2017 and June 2018 at different altitudes of secondary forest in Timor Tengah Selatan district, Timor. We visited five altitudinal zones (± 829 m asl., ± 942 m asl., $\pm 1,621$ m asl., ± 1992 m asl., and ± 2457 m asl.) and selected 25 eucalyptus plants of 3 to 5 m in height in each altitudinal zone from which to collect insect galls. The galls were observed on leaves, upper leaves (shoots), outer leaves, symptomatic twigs and stems. The galls were taken to the laboratory for rearing of the insects they contained. A total number of 12 gall types were found in *E. alba* and 15 in *E. urophylla* from which 28 insect morphospecies were identified belonging to 16 families and five orders. The order Hymenoptera was represented by ten families: Bethyliidae, Torymidae, Eulophidae, Eupelmidae, Eurytomidae, Pteromalidae, Encyrtidae, Mymaridae, Braconidae and Scelinonidae while the order Diptera was represented by three families: Fergusoninidae, Cecidomyiidae and Chaoboridae. Galling species diversity ranged from 1.71 to 2.38 on the Shannon-Wiener index and 0.75 to 0.87 on the Simpson index and showed that the galling-insect communities were species-rich and composed of galling formers and very few inquiline. In the study, communities are categorized and structured according to different types of galling insects, including those that induce galling, those that are parasitoid, and those that are inquiline. Within the category of gall-forming insects in the two species of eucalyptus, Eulophidae is found to be the dominant family. Our field data makes an important contribution to basic knowledge of insect galling patterns in eucalyptus forests and constitutes baseline data for the implementation of pest control.

Keywords: *Eucalyptus*, gall, Lesser Sunda, Myrtaceae

INTRODUCTION

Gall-forming insects are among the most interesting living arthropods, not only because of their specialist mode of life but also because there are so many species within the group. As a result, research into gall-inducing insects has received much attention in recent years and studies into species diversity patterns and composition on particular plants have been published for a number of regions. From a species richness point of view, there are estimated to be around 132,930 species of galling insects worldwide (with individual estimates ranging from 21,000 to 211,000 species) (Espírito-Santo and Fernandes 2007). Despite the region's rich biodiversity, there is limited information available on the galling insects to be found in Indonesia.

Previous research into galling insects in Indonesia was pioneered by Van Leeuwen-Reijnvaan and Van Leeuwen (1926), who reported a number of galling insects on various plants. They also described a range of causes of galls, such as nematodes, insects and mites, of which most were caused by insects from the Cecidomyiidae family that

attack the leaves of plants (Van Leeuwen-Reijnvaan and Van Leeuwen 1926). Some galling insects are important as pests in forest ecosystems and agroecosystems and recently, knowledge about galling insects in agroecosystems has been developing. In Indonesia, the pest *Asphondylia capsicum* has been reported to attack *Capsicum annuum* and *C. frutescens* chili plants in Cisarua, Bogor (West Java), Gianyar, (Bali), and Dropingi (Sumatra) (Uechi et al. 2016). In addition, some years ago *Orseolia oryzae* Wood-Mason (Diptera: Cecidomyiidae) was reported to be a major pest in rice (Roksosoesilo 1985). In the last ten years, galling insects in forest ecosystems have been studied only in industrial forests, with *Ophelimus eucalypti* (Hymenoptera: Eulophidae) having been reported to attack estimated to be around 132,930 species of galling insects worldwide (with individual estimates ranging from 21,000 to 211,000 species) (Espírito-Santo and Fernandes 2007). Despite the region's rich biodiversity, there is limited information available on the galling insects to be found in Indonesia. Industrial eucalyptus plantations in North Sumatra (Ubaidillah 2011). Research into galling insects in

a wider range of plants in Indonesia so far comprises only an inventory and descriptions of types of gall (Rachman et al. 2012, 2014) and there is almost no research as yet into insect galls on eucalyptus in natural ecosystems, in particular in eastern Indonesia.

East Lesser Sunda is particular type of dry temperate forest in eastern Indonesia that has several examples of endemic flora and fauna and may therefore support unique plant-animal interactions, including those involving gall formers. However, gall-forming interactions, specifically the species diversity of galling insects associated with *Eucalyptus* spp. in natural forests in the area, have yet to be investigated. The only study of galling insects on eucalyptus was recently carried out by Safitri (2019) and is focused on industrial eucalyptus plantations. Indonesian eucalyptus is known to grow naturally on several islands including Timor, Papua, and Sulawesi Islands (CABI 2005). In this study, eucalyptus in Timor is recorded mainly at the Forest Nature Reserve of Mount Mutis in the district of Timor Tengah Selatan, located in the altitude range of ± 800 m asl. to ± 2400 m asl.. The objective of this study was to ascertain the diversity of species and investigate the composition patterns of gall-forming insects on two species of eucalyptus, namely *E. alba* and *E. urophylla*, in the Forest Nature Reserve of Mount Mutis (NRMM) and in the buffer zone of the dry forest reserve in Timor Tengah Selatan District, Timor Island. This is the first study of gall-inducing insects in tropical dry forests of Indonesia. Its contribution in terms of galling-insect assemblage and the estimation of local species richness in eucalyptus is essential to general ecological perspectives, especially for the development of understanding of species' richness patterns and their implications.

MATERIALS AND METHODS

Study area

The study was conducted in the Nature Reserve of Mount Mutis (NRMM), latitude $9^{\circ}38'25''$ S longitude $124^{\circ}13'14''$ E, located about 40 km north of Timor Tengah Selatan subdistrict, East Lesser Sunda, Indonesia. Sampling was carried out over three months between June 2017 and May 2018. The sampling of galling insects was conducted according to the presence of eucalyptus trees found in NRMM and in the buffer zone. The research areas represent dry forest consisting of homogeneous vegetation with a small number of species trees, of which *E. urophylla* is the most dominant (Simbolon and Sukendar 1987), and rehabilitation forest in the buffer zone of NRMM. NRMM is situated in the Mount Mutis area in the altitude range 1500-2400 m asl.. The five sites selected as sampling locations have been widely used in previous botanical studies (Simbolon and Sukendar 1987; Pujiono et al. 2019), two sites being in the NRMM buffer zone and three others in NRMM itself: Site 1 with altitude of 829 m asl., at latitude $9^{\circ}50'59''$ S longitude $124^{\circ}16'20''$ E and Site 2, at altitude 942 m asl., latitude $9^{\circ}50'16''$ S longitude $124^{\circ}15'36''$ E are both in the buffer zone, while Site 3, altitude ± 1621 m asl., latitude: $9^{\circ}38'25''$ S longitude $124^{\circ}13'14''$ E, Site 4 at 1992 m asl., latitude $9^{\circ}34'39''$ S longitude $124^{\circ}13'59''$ E and Site 5, altitude ± 2457 m asl., latitude $9^{\circ}33'37''$ S longitude $124^{\circ}13'39''$ E, are in NRMM itself (Figure 1).

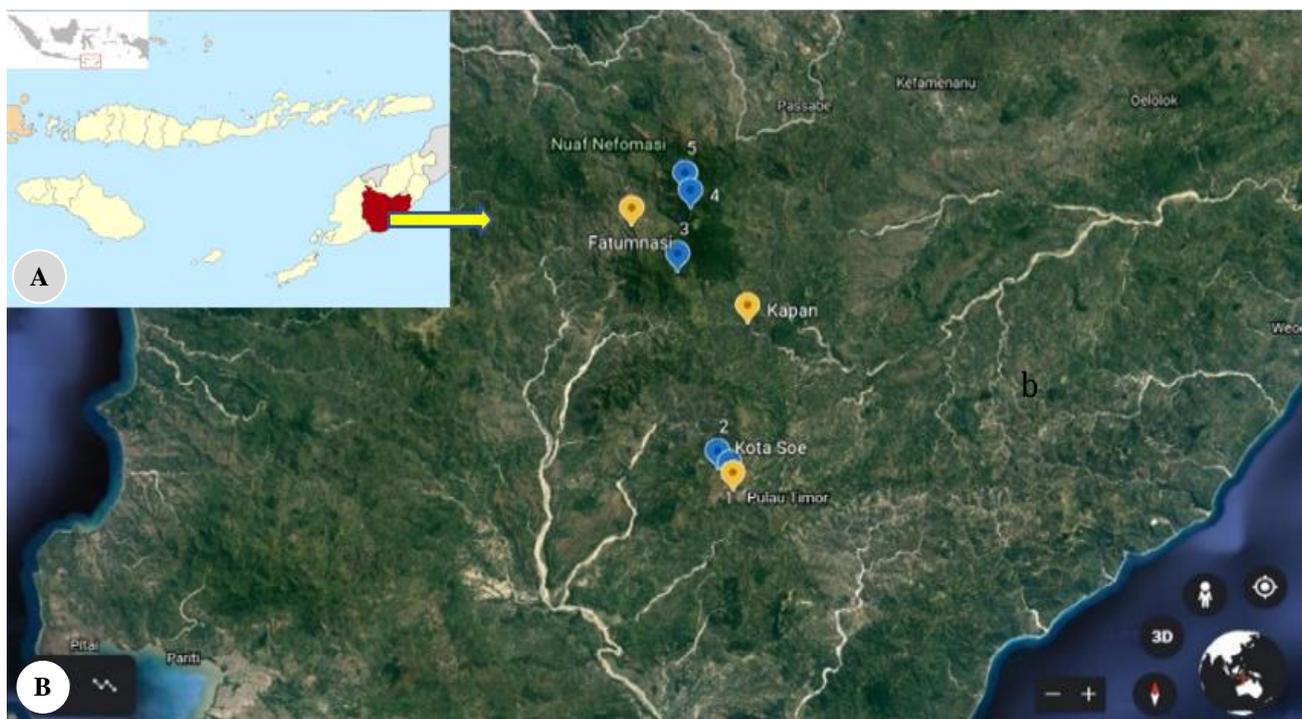


Figure 1. Map of East Nusa Tenggara Province, Indonesia: A. Location of Timor Tengah Selatan District; B. Satellite view of Mount Mutis Nature Reserve (NRMM) at an altitude of 1500-2400 m asl. and buffer zone (800-1000 m asl.) displaying the five sampling sites

Galling-insect sampling and identification

At each sample site, 25 plants for both *E. alba* and *E. urophylla* were randomly selected. The sampling of galling insects and plant organs, including branches, stems, leaves, flowers and fruits at heights of between 3 and 5 m was observed by two persons. Each insect gall found was collected and put into a separate plastic bag and transported to the laboratory for photographic registration of gall morphotype, rearing insect and gall insect identification. Samples of galls from branches, stems, leaves, flowers and fruits were identified to morphospecies. The gall morphotype was identified through external morphology characteristics including shape, color, and trichomes (Isaias et al. 2013). The relationship between galling insects and the host of each gall morphotype was considered in identifying the morphospecies of galling insects. We identified each galling insect emerging from each morphotype to species level whenever possible and recorded them for estimating the number of galling-insect morphospecies and number of morphotypes. The use of morphospecies to represent the richness of galling species is widely accepted in several studies (e.g. Santos et al. 2011a; Silva et al. 2011). All insect galls collected were deposited at IPB and Museum Zoologicum Bogoriense, Indonesian Institute of Sciences as voucher specimens.

Data analysis

The diversity and relative abundance of species are analyzed according to Shannon and Simpson's diversity index. Statistically, when all species are represented in a sample and all samples are taken at random, diversity can be reflected via the Shannon diversity index. Meanwhile, common or dominant species will be given more weight in the Simpson diversity index and the existence of species with only few representatives will not affect diversity. Our data will be measured using Shannon's index (H') as shown in Equation 1:

$$H' = \sum_{i=1}^s p_i \ln p_i$$

In which p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N). In the natural log (Equation 2), \sum is the sum of the calculations and S is the total number of insect species found in the community. Meanwhile, Shannon's equitability (E_H) can be measured by dividing H by H_{max} (here $H_{max} = \ln S$). Equitability assumes a value between 0 and 1, with 1 being complete evenness (E).

$$E = H' / \ln S$$

The vertical distribution of galling insects associated with the two eucalyptus species was analyzed using (one way) ANOVA to understand the number of galling-insect species at each site, as presented in a boxplot format using R Statistic 3.0.2 software. The species richness of galling insects and their distribution in *E. urophylla* at various elevations were also analyzed using a Venn diagram

(Oliveros 2007). Meanwhile, the Bray Curtis similarity index (Ludwig and Reynolds 1988) was used to analyze the structure and species composition of the galling insects associated with eucalyptus galls in the two species at different altitudes.

RESULTS AND DISCUSSION

Species diversity of galling insects

In total, 28 galling-insect morphospecies belonging to five orders and 17 families were identified from a set of 1558 individuals collected in the five different altitudinal localities. This included 28 morphospecies from four genera and eight families associated with *E. alba*, and 28 morphospecies from five genera, and 17 families associated with *E. urophylla*, from different altitudinal locations (Table 1).

We also found some interesting characteristics for this group of insects in both *E. urophylla* and *E. alba*. Comparisons of host and galling-insect richness along altitudinal gradients showed that *E. alba* occurs only in the lowlands at Site 1 and that the peak of species richness also appears at this site. *E. alba* was planted for forest regeneration about 7 to 10 years ago (Soleman Toto, pers.com 2018) and interestingly *E. urophylla* was not found in Site 1 or in low elevations. *E. alba* mainly grows between 800 and 1000 m asl. while *E. urophylla* grows between 900 and 2500 m asl.. Comparisons between low and highland habitats also showed that galling insects were most species-rich and abundant in Site 1 which was dominated by *E. alba*. The species richness of galling insects differed significantly between *E. urophylla* and *E. alba* with $\chi^2 = 1.9885$, $P = 0.000$, and $n = 25$. The species abundance of galling insects differed significantly between *E. urophylla* and *E. alba* with $\chi^2 = 35.555$, $P = 0.000$, and $n = 25$.

The species diversity indices showed values ranging from 1.71 to 2.38 (Shannon-Winner index) (Table 2). The lowest diversity was found in *E. urophylla* at an altitude of 2000 m asl., with H value of 1.71.

On the whole, the study results showed that galling-insect diversity in the two species of eucalyptus does not vary greatly from site to site, however, statistical analysis shows slightly significant difference. The Simpson index value is between 0.75 and 0.87. A low Simpson index value was obtained at Site 4 (*E. urophylla*; 1992 m asl.) whereas the highest value was obtained at Site 2 (*E. urophylla*; 942 m asl.). A statistical analysis by Tukey (Figure 4) revealed that Site 1 was significantly different from Sites 2, 4 and 5, whereas Site 3 was not significantly different. The index value of galling insects related to the two species of eucalyptus with less than one example of insect was categorized as low (Magurran 2004). Based on the dominance index (D), the values varied from 0.13 to 0.26 in *E. urophylla* at Sites 2 to 5 and 0.16 in *E. alba* at Site 1. Our findings suggest that the indices for dominant galling insects in both eucalyptus species have values of under 0.5 and range of index (D) of $0 < D \leq 0.5$. The dominance index values range from 0 to 1, being equal to

0.5 when all species have the same abundance and confirming there neither *E. alba* nor *E. urophylla* dominates. The level of species dominance and abundance would be influenced by the host and physical factors (De Araújo et al. 2013; Barbosa and Fernandes 2014) such as elevation which can directly shape species dominance in eucalyptus galling insects.

The galling insects found in the two species of eucalyptus include gall wasps (Hymenoptera), gall midges (Diptera: Cecidomyiidae), psyllids (Hemiptera: Psyllidae), leaf moths (Lepidoptera: Tortricidae) and thrips (Thysanoptera: Phlaeothripidae). Among these species of galling insects, 20 are Hymenoptera, four Diptera, two Hemiptera, one Thysanoptera and one Lepidoptera (Table 6). Hymenoptera gall wasps are the most dominant galling insect in both eucalyptus species, at 64% in *E. urophylla* and 50% in *E. alba* (Figures 2 and 3). In *E. urophylla* this

is followed by gall midges at 29% and psyllids at 7%, meanwhile, in *E. alba* the dominance of gall wasps is followed by gall midges at 25%, Lepidoptera at 13% and Thysanoptera at 12% (Figure 3).

Relative abundance of galling insects in both eucalyptus types was also calculated, and Table 2 showed the most dominant species in the NRMM. The relative abundance of gall species might be related to the compatibility of host plants and suitable habitat conditions. Here we attempt to discuss each of the two eucalyptus species and their galling insects in each vertical distribution. Species richness and distribution patterns along altitudinal gradients have shown that the peak number of species occurs in *E. alba* between 800 and 1000 m asl. in areas covered not only by *E. alba* but also by other vegetation (*Chromolaena odorata*, and *Erechtites valerianifolia*).

Table 1. Number of galling-insect species associated with each eucalypt species in Mount Mutis Nature Reserve, Timor Tengah Selatan District, Timor Island, Indonesia

Sampling site/altitude (m asl.)	<i>Eucalyptus</i> species	∑ morphospecies	∑ families	∑ orders
829	<i>Eucalyptus alba</i>	17	8	4
942	<i>E. urophylla</i>	16	9	3
1621	<i>E. urophylla</i>	16	10	3
1992	<i>E. urophylla</i>	12	7	3
2457	<i>E. urophylla</i>	12	8	3
Total		28	17	5

Table 2. Species richness and diversity indices for galling insects on *E. alaba* and *E. urophylla* in Mount Mutis Nature Reserve, Timor Tengah Selatan District, Timor Island, Indonesia

Elevation m asl.	S	N	H	E	1-D (Simpson)
828 (<i>E. alba</i>)	17	359	2.147237	0.75788	0.837377
942 (<i>E. urophylla</i>)	16	517	2.379262	0.858138	0.868108
1621 (<i>E. urophylla</i>)	16	701	1.789869	0.645559	0.770593
1992 (<i>E. urophylla</i>)	12	212	1.711849	0.688899	0.746663
2457 (<i>E. urophylla</i>)	12	129	2.149063	0.864847	0.864491

Note: S: Species number, N: Individual number, H: Shannon-Wiener Index, E: Evenness Index

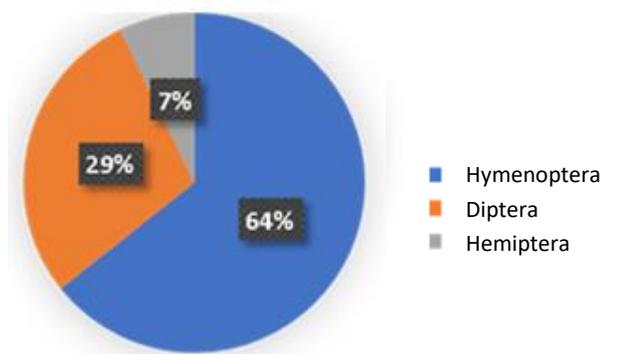


Figure 2. Proportion of galling insects on *Eucalyptus urophylla*

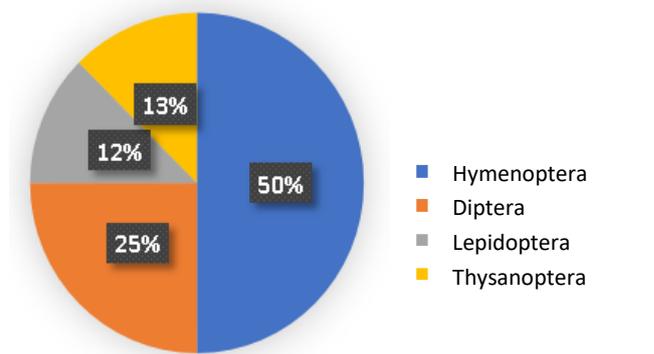


Figure 3. Proportion of galling insects on *Eucalyptus alba*

Our hypotheses have been proposed to explain variation in species richness and diversity of galling species in two species of eucalyptus in NRMM. Richness of host-plant species can be a potential factor (e.g. De Araújo 2011), a negative relationship between altitude and gall species richness might be dependent on differential proportion of xeric versus mesic habitats, nutrient availability, variable top-down control of gall populations, and/or plant resistance traits among others (Quintero et al. 2014). Our research in NRMM shows greatest species richness revealed in the lowland of Site 1 (in *E. alba*). Based on this hypothesis, the forest regenerated with eucalyptus has higher richness than highland areas. Our results are incongruent with this hypothesis because the regenerated forest was richer in species of galling insects than other areas of wild eucalyptus forest; this finding requires further study.

Although the purpose of this study was not to compare the richness of galling insects among the sample areas, it is important to emphasize that the galling insects in eucalyptus forest showed approximately half (27 morphotypes) of all the species found in this survey. This pattern could be produced by the atypical vegetation of this forest, revealed as having a pattern of plant species different from those of the NRMM lowland and highland, with part of its flora representing the geographical distribution covering highland vegetation formations.

The species richness of galling insects associated with the two species of eucalyptus is closely related to insect behaviors themselves. Analysis of the number of individuals and species as well as the distribution of insects associated with eucalyptus galls is presented in the form of boxplot diagrams (Figures 4 and 5).

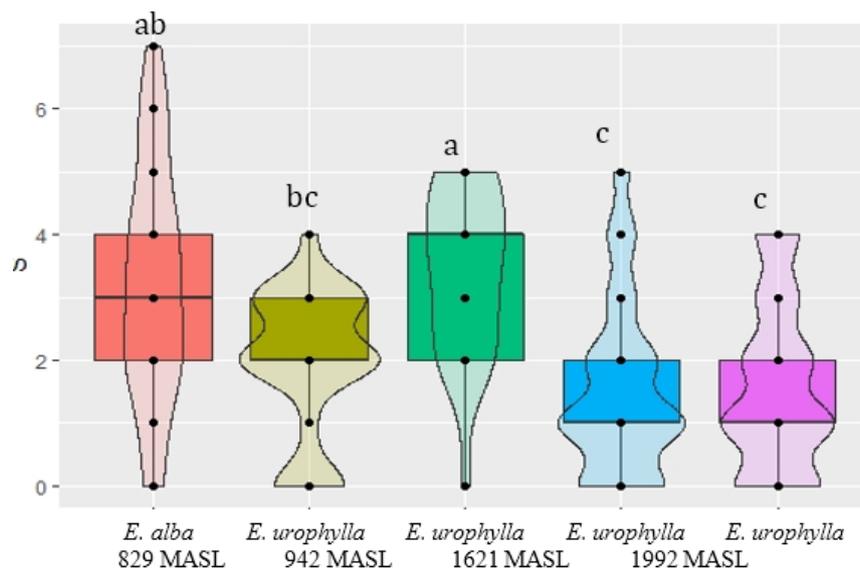


Figure 4. Species richness of galling insects in both *Eucalyptus alba* and *E. urophylla* in Mount Mutis Nature Reserve, Indonesia

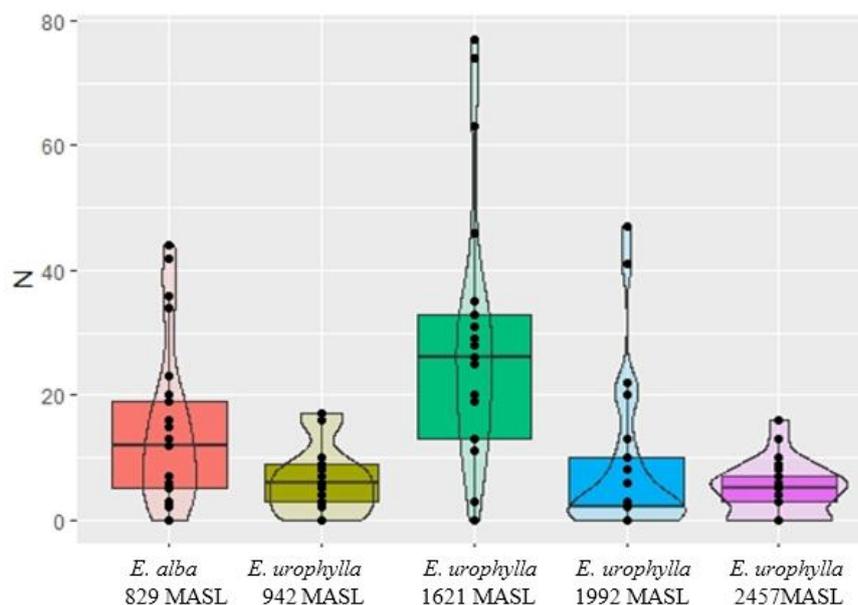


Figure 5. Abundance of species of galling insect in both *Eucalyptus alba* and *E. urophylla* in Mount Mutis Nature Reserve, Indonesia

Species richness at several altitudes based on ANOVA analysis followed by Tukey's range test) showed that ($P=0.0003 < 0.05$) were significantly different in the two eucalyptus plant species at different altitudes. While the abundance of individuals at several altitudes did not show a significant difference based on the results of Anova ($P=0.0843 > 0.05$). Variations in the number of individuals and insect species associated with eucalyptus galls were higher in *E. urophylla* at an altitude of 1621 m asl.. The results of this analysis confirm that differences in eucalyptus species and altitude do affect the number of individuals and the number of species of galling insects associated with them. The eucalyptus may be a particularly important host for species of galling insects such as gall wasps (Hymenoptera), gall midges (Diptera Cecidomyiidae) and psyllids (Hemiptera: Psyllidae) which are generally weak fliers.

Based on the analysis of the Venn diagram (Figure 6) it can be seen that species richness at several altitudes in *E. urophylla* is almost the same. However, there are some species that are only found at certain elevations. Three species are only found at an altitude of 942 m asl., namely *Bethylidae* sp.1, *Eulophidae* sp.2, and *Eupelmidae* sp.1. Likewise, three species were found at an altitude of 1621 m asl., namely *Scelionidae* sp.1, *Chaoboridae* sp.1, and *Psyllidae* sp.2, and one species was only found at an altitude of 1992 m asl., namely *Braconidae* sp. 2.

The structure and species composition of the galling insects associated with the two species of eucalyptus at different vertical elevations were analyzed using the Bray Curtis similarity index. Similarity of species at various altitudes shows differences ranging from 0.19 to 0.49. The closest similarity of insect species was seen in *E. urophylla* at an altitude of 2457 m asl. and at an altitude of 1992 m asl. (Table 3).

This shows that the forest habitat of *E. urophylla* at an altitude of 2457 m asl. has the same host source and

microclimate conditions as 1992. This is in line with the opinion of several previous researchers (Koneri 2010; Cleland 2011) who state that the structure of vegetation, microclimate conditions and human interference can influence the structure of insect communities.

Types of gall forms in *E. urophylla* and *E. alba*

In this study, various gall morphologies were found, from simple galls, such as folded, rolled and swollen leaves, to complex gall types, such as increases in the size and volume of cells, tissues or certain organs in different parts of the plant. The most influencing factor for the diversity of gall morphology is the insects that interact with the gall, either directly or indirectly. According to Espírito-Santo and Fernandes (2007), the diversity of insects related to galls in the tropics is higher than in subtropical and temperate regions such as North America. Fernandes and Price (1992) state that there is a positive relationship between insects associated with galls and plant wealth in tropical regions such as Indonesia.

Our study shows there are 27 morphologically distinct types of insect galls in both species of eucalyptus. For *E. alba* there are those in Figure 7.A, B, C, D, G, H, I, K, L (leaves), buds (Figure 7.J), twigs (Figure 7.E), and trunks (Figure 7.F) while in *E. urophylla* there are those in leaves (Figure 8.M, N, O, P, Q, U, V, W, X, Y, Z, AA), buds (Figure 8.R), twigs (Figure 8.S), and axillae (Figure 8.T).

Table 3. Bray Curtis similarity index for galling insects associated with *Eucalyptus alba* and *E. urophylla*

Elevation (m asl.)	829	942	1621	1992	2457
829	1				
942	0.41	1			
1621	0.27	0.27	1		
1992	0.23	0.44	0.26	1	
2457	0.25	0.37	0.19	0.49	1

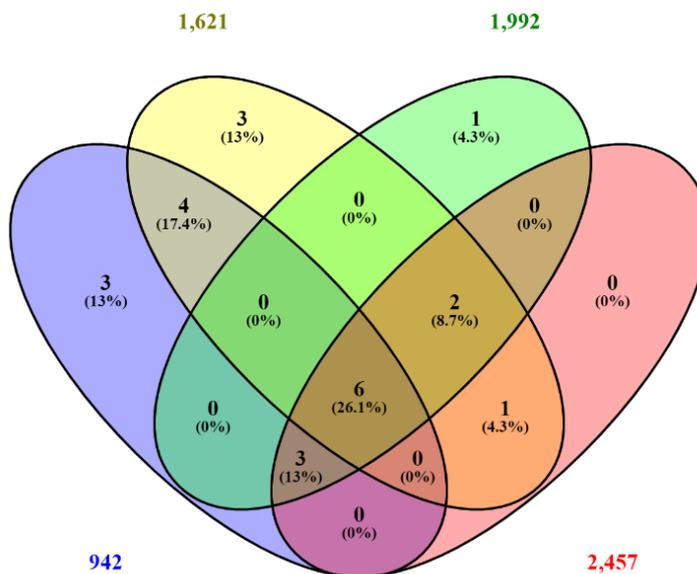


Figure 6. Species richness and distribution of insect galls in *Eucalyptus urophylla* at various elevations using Venn diagram analysis

Our results showed that leaves have a higher percentage of galls than other plant organs, at 75% of those found in *E. alba* and 80% in *E. urophylla* (Figure 9). The galls found in axillae are categorized as galls on twigs. The results of this study agree with previous studies by Rachman et al. (2014). Rachman et al. (2012) confirmed that 98% of galls were found in leaves and a similar finding was reported by, Toma and Mendonça-Junior (2013) who stated that the preference for galls to be formed in leaves was a general pattern that occurred worldwide. Miller and Raman (2019) suggest that leaves are the most susceptible organs for gall development. Leaves are usually the most available plant organs and therefore the most susceptible to gall induction. These organs are also more abundant and easily observed, in contrast to the other plant organs; they are more plastic (Formiga et al. 2013), and have a larger potential to respond to galling stimuli.

The galls found in *E. alba* and *E. urophylla* vary in terms of their shape and the parts of the plants on which they are located. The differences in the types and forms of

gall in *E. alba* and *E. urophylla* are thought to be due to the different characteristics of the two types of eucalyptus. The galls formed in the two eucalyptus species were grouped into 13 gall types based on their similarity in shape and their inducing insect (Table 4). In *E. alba* there are eight types of gall while in *E. urophylla* there are ten types. The gall species GT 7, GT 10 and GT 12 were only found in *E. alba* while GT 8, GT 9, GT11 and GT 13 were only found in *E. urophylla*.

Our results indicated that the types of galls found at various elevations in the two eucalyptus species in NRMM differ. In *E. alba* there were eight types of gall while in *E. urophylla* there are 11, at different elevations. Gall types GT 7, GT 10 and GT 12 were only found in *E. alba* while gall types GT 8, 9, 11 and 13 were only found in *E. urophylla* at an altitude of 1500 m asl.. The results shown in Table 5 and Table 6 have strengthened our opinion that gall species diversity decreases at higher elevations. There are different types of gall found in *E. alba* and *E. urophylla* at different heights, namely GT1, 2, and 3.

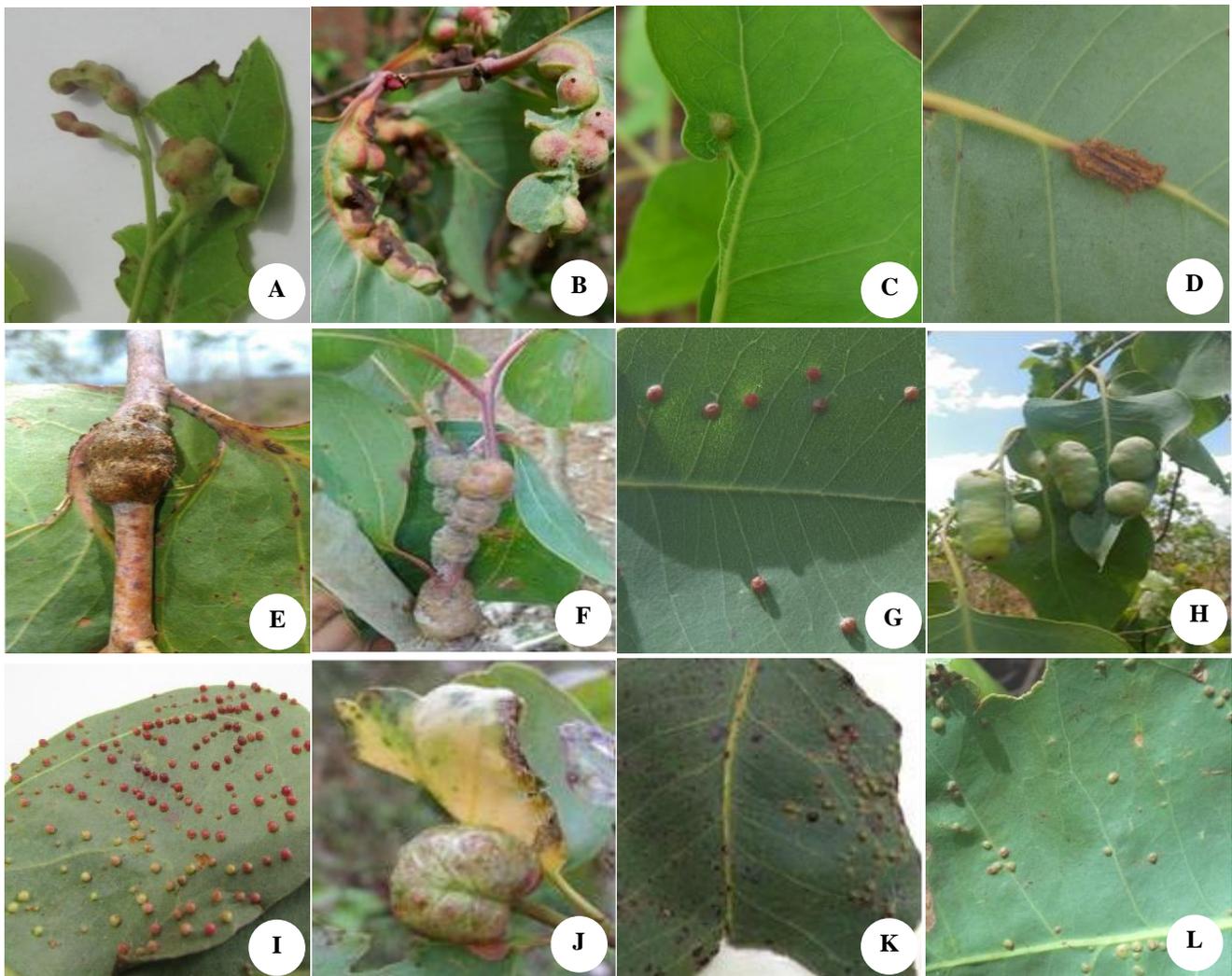


Figure 7. Types of gall forms in *Eucalyptus alba*: leaves (A, B, C, D, G, H, I, K, L); bud (J); twig (E), and trunk (F)

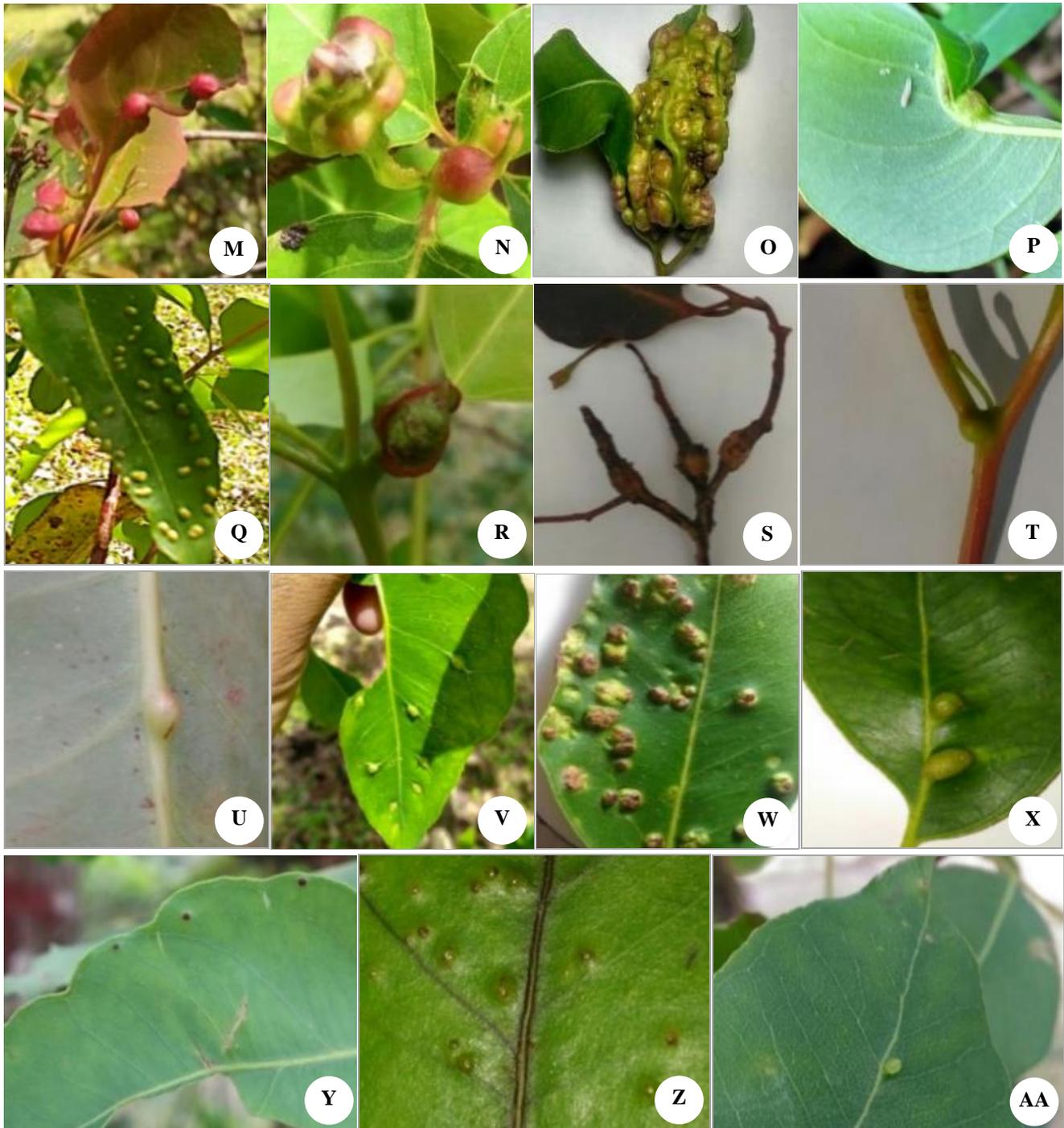


Figure 8. Types of gall forms in *Eucalyptus urophylla*: leaves (M, N, O, P, Q, U, V, W, X, Y, Z, AA); bud (R); twig (S); and axilla (T)

Gall-forming organisms can achieve greater success than herbivores, living freely in more stressful environments. Modifications to galls in terms of size, shape or other defense systems will increase the protection of the gall-inducing insect from predators and parasitoids. The gall-causing insects must be able to manipulate the host plant as needed to protect against natural enemies and thus increase their survival. The more various the gall shapes and sizes, the more insects interact with them. Classical

studies as those of Fernandes and Price (1992) suggest that gall abundance usually decreases with altitude due to the sensitivity of gall-inducing insects to changes in humidity and temperature associated to increased altitude. More recent studies such as Carneiro et al. (2014) have suggested, however, that altitude might influence gall abundance only in xeric habitats, as the morphological structure created by the gall actually protects the growing larvae against climatic harsh and natural enemies.

Discussion

There has been little research into galling insects on eucalyptus in Indonesia, either in natural forests or in the eucalyptus tree industry, and only a few publications have just appeared in the last two years (Safitri et al. 2019; Syawalludin et al. 2019). This study represents the first contribution to the understanding of species richness of galling insects and the types of galls they produce in mixed natural forests in which eucalyptus is the dominant tree. As height increases towards the top of Mount Mutis, the domination of *E. urophylla* decreases while other plants such as *P. imbricatus* and *Casuarina junghuniana* become increasingly prominent, but *E. urophylla* still remains the

main tree species to the summit (Simbolon and Sukendar 1987). The presence of insects associated with gall on *E. urophylla* at an altitude of 1621 m asl. was higher than other lands because at an altitude of 1621 m asl. there was more canopy than at an altitude of 1992 m asl. which was dominated by grasslands. The more diverse the canopy in an area, the more host insects or natural enemies will interact (Horstmann et al. 2005). This indicates that there are differences in eucalyptus species and the height of the number of insect morphospecies associated with eucalyptus clumps. Differences in insect diversity between elevations and between different eucalyptus species are possible if there are differences in landscape structure.

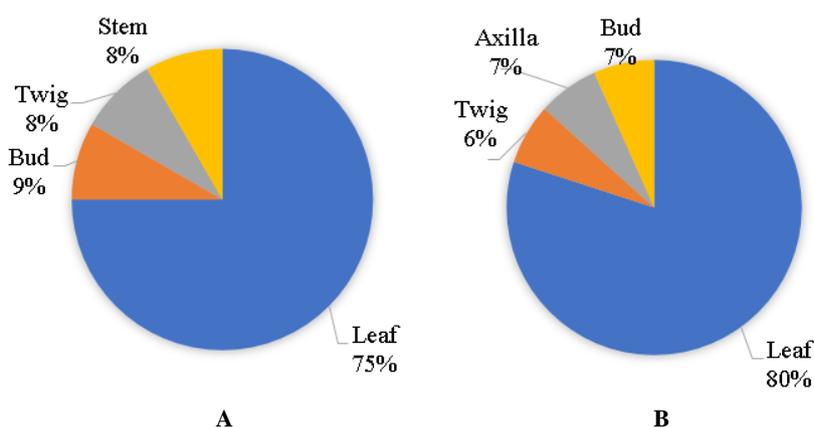


Figure 9. Proportion of plant organs with galls: A. *Eucalyptus alba*, B. *E. urophylla*

Table 4. The types of gall and gall forms found in *Eucalyptus alba* and *E. urophylla*

Type of gall	Plant organ	Position	Form of gall	<i>E. alba</i>	<i>E. urophylla</i>
GT1	Leaf	Concealed	Globoid	A, B, C	M, N, O, P
GT2	Leaf	Concealed	Ovoid	H, K	Q
GT3	Twigs, stems, leaves, axillae	Concealed	Fusiform	E, F	S, T
GT4	Leaf	Concealed	Ovoid	G	U, V
GT5	Leaf	Open	Amorphous	-	W
GT6	Leaf	Open	Ovoid	-	X
GT7	Leaf	Open	Globoid	I	-
GT8	Leaf	Open	Conical	-	AA
GT9	Leaf	Open	Globoid	-	Y
GT10	Leaf	Open	Fusiform	D	-
GT11	Leaf	Open	Lenticular	L	Z
GT12	Bud	Open	Globoid	J	-
GT13	Bud	Open	Folded	-	R

Table 5. Type of gall found in the two species of eucalyptus at different elevations

Elevation (m asl.)	Type of gall												
	GT 1	GT 2	GT 3	GT 4	GT 5	GT 6	GT 7	GT 8	GT 9	GT 10	GT 11	GT 12	GT 13
829*	+	+	+	+	-	-	+	-	-	+	+	+	-
942**	+	+	+	+	+	-	-	-	-	-	+	-	-
1621**	+	+	+	+	+	+	-	+	+	-	+	-	+
1992**	+	+	+	+	+	+	-	-	-	-	-	-	-
2457**	+	+	+	-	+	-	-	-	-	-	-	-	-

Notes: + : Found; - : No galls; * : *E. alba*; ** : *E. urophylla*

Table 6. Insects associated with galls in two species of eucalyptus, and their roles

Order	Family	Morphospecies	Elevation					Role		
			829	942	1 621	1 992	2 457	Gall-inducing	Parasitoid	Inquiline
Hymenoptera	Bethylidae	Bethylidae sp.1		+						+
	Torymidae	<i>Megastigmus specularis</i>	+	+	+					+
		<i>Megastigmus zebrinus</i>	+	+		+	+			+
	Eulophidae	<i>Leptocybe invasa</i>	+	+	+		+		+	
		<i>Ophelimus eucalypti</i>	+	+	+	+	+	+		
		<i>Ophelimus maskelli</i>	+	+	+		+	+		
		<i>Cirrospilus</i> sp.1	+		+	+	+			+
		<i>Cirrospilus</i> sp.2	+	+	+	+				+
		<i>Eulophidae</i> sp.1	+	+	+					+
		<i>Eulophidae</i> sp.2	+	+						+
		<i>Eulophidae</i> sp.3	+							+
		Pteromalidae	<i>Pteromalidae</i> sp.1		+	+	+	+		
	<i>Pteromalidae</i> sp.2			+		+	+			+
	Eupelmidae	<i>Eupelmidae</i> sp.1		+						+
	Encyrtidae	<i>Encyrtidae</i> sp.1	+							+
	Eurytomidae	<i>Eurytomidae</i> sp.1	+	+	+					+
	Braconidae	<i>Braconidae</i> sp.1			+		+			+
		<i>Braconidae</i> sp.2				+				+
	Scelionidae	<i>Scelionidae</i> sp.1			+					+
Mymaridae	<i>Stethyinum</i> sp.1			+		+			+	
Diptera	Cecidomyiidae	<i>Lasioptera</i> sp.1	+					+		
		<i>Cecidomyiidae</i> sp.1	+	+		+	+			+
	Fergusoninidae	<i>Fergusonina</i> sp.1	+	+	+	+	+	+		
	Chaoboridae	<i>Chaoboridae</i> sp.1			+					+
Thysanoptera; Tubulifera	Phlaeothripidae	<i>Phlaeothripidae</i> sp.1	+						+	
Lepidoptera	Tortricidae	<i>Tortricidae</i> sp.1	+						+	
Hemiptera	Psyllidae	<i>Psyllidae</i> sp.1		+	+	+	+	+		
		<i>Psyllidae</i> sp.2			+			+		

This is possible because close to the top of Mount Mutis plant diversity is decreasing (Simbolon and Sukendar 1987) and at an altitude of 2000 is covered by grasslands which affect the insect composition (Miller and Raman 2019). Heterogeneous vegetation generally has more insect diversity than homogeneous vegetation (Pimenta and Marco 2015). The galling-insect diversity value in the two types of eucalyptus and at different altitudes is classified as moderate, with index value of between one and three. Galling-insect diversity in the Mutis forest seems to be relatively high, and the condition of the ecosystem tends to be stable. However, we need more studies to understand what exactly the mechanisms of galling-insect diversity relationship to ecosystem stability. Our study showed that ecophysiological constraints have played an important role in gall diversity. The decline in gall diversity is most likely influenced by physical and biological conditions (Hortal et al. 2013; Cirimwami et al. 2019). In contrast, Carneiro et al. (2014) argue that there is a negative correlation between the species diversity of gall-forming insects and altitude, reflecting more stressful environmental conditions in the lowlands.

Based on our present results, the species diversity of galling insects and their types of gall in both *E. alba* and *E. urophylla* tend to show relative richness compared to the results of previous research (Safitri et al. 2019). Recent studies have shown that interspecific competition be an important phenomenon capable of shaping the community structure of sedentary organisms, such as gall-inducing insects (e.g., Cornelissen et al. 2013; Fagundes et al. 2018). Some characteristics of the interaction between galling insects and their host plants make this system suitable for better understanding the processes that structure natural communities. Galls are an emphatic marker of species-specific relationships, since about 90% of all gall-forming species are monophagous (Raman 2010), so they can be applied to understand the relationship between gall-making species richness and plant species diversity in an area (Butterill and Novotný 2015), with the potential to use galls as bioindicators (Santana and Isaias 2014). Differences in the diversity of galling insects between altitudes and between eucalyptus species are possible if there are differences in the landscape structure (Lawton 1983; Miller and Raman 2019). Increase in species richness and abundance of insects depends on the complexity of plant structure. This is confirmed by our finding that near the summit of Mount Mutis the dominance of eucalyptus decreases followed by a decrease in species richness of galling insects. However, eucalyptus trees are still more visible in the landscape and are more likely to be targeted by galling insects.

The set of colors observed in gall structures is a consequence of changes in the accumulation of plant pigments, and may change during gall development, especially from green to red (Inbar et al. 2010). Even though it is an easy trait to be registered, the color of 28.7% of the gall morphotypes was not reported in the inventories (Maia and Oliveira 2010; Santos et al. 2011b; Malves and Friero-Costa 2012). The plant families with the largest number of species in a given area are usually those which

also host a higher richness of galls. The Myrtaceae (*E. urophylla* and *E. alba*) at Timor Tengah Selatan subdistrict were also the main hosts of galls, which confirm the pattern presented in the inventories in the areas. The green color in the galls eucalyptus indicates the presence of photosynthetic cells which can be beneficial to the host plant, because it increases the photosynthetic surface due to hyperplasia and hypertrophy of plant cells. These green balls may be a good model for the study of photosynthesis and cytological responses to painful stress. What's more, several studies in the tropics have shown that photosynthesis in galls is insufficient for maintenance of their structure, and is used as an accessory for host plant machinery, as (Oliveira et al. 2011; Castro et al. 2012). The age of the galls can affect the color variation. During senescence, chlorophyll is degraded and carotenoids and anthocyanins are no longer disguised (Dias et al. 2013). Sometimes, the color of the same gall morphotype may be same varies from dark to yellowish-green, reaching the red and even the brown colors depending on the stimuli from the galling insect and from environmental conditions such as light exposure.

In conclusion, information on the association between gall-forming insects and eucalyptus in natural and industrial forests in Indonesia is still very limited. However, the results presented in this paper indicate that Indonesian native eucalyptus has a large diversity of gall-forming insects and gall-type forms associated with them, and that internal and external gall morphology varies structurally. More studies on the diversity of gall-inducing insects and gall morphology are needed to understand the adaptive significance of gall induction in eucalyptus in tropical forests in regions such as Indonesia. In addition, eucalyptus species in industrial plantations that use hybrid plants have the potential to become new adaptive zones for the diversification of species of gall insects on eucalyptus. This being one of the main factors explaining the prominent species richness of eucalyptus in industrial forests in Indonesia, many gall-forming insects are also predicted to have co-evolved. A more comprehensive study of the relationships between galling insects and Indonesian eucalyptus plants needs to be carried out, and in particular, work should be directed at comparing endemic species with limited distribution with species with wider distributions of latitude and altitude. It is hoped that this study will contribute to our understanding of the dynamics of these interactions at different spatial scales. The gall-forming insects associated with eucalyptus native to Indonesia may represent a greater species richness than those found among eucalyptus species themselves. Therefore, this information should be considered as an important component of biodiversity, which has its own specific conservation requirements in the eucalyptus forests of the mountains of eastern Indonesia and their very specific climate conditions.

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