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continued on the back inside cover

**Cover: A bag worm with its beautiful heap of junk. Acrylics on 300 GSM paper by Dupati Poojitha based on a picture by Sanjay Molur.**

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ARTICLE

# Association analysis of *Castanopsis tungurrut* and the neighboring vegetation community in Cibodas Biosphere Reserve, Indonesia

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**Abstract:** *Castanopsis tungurrut* (Blume) A.DC. (Fagaceae) is an endangered species, specifically found in the tropical forests of Java and Sumatra. There is currently a lack of specific information regarding its interactions with other species across different life stages and natural habitats, particularly in relation to altitudine gradients. This study is aimed at investigating the relationship between *Castanopsis tungurrut* and the adjacent vegetation during different stages of its life cycle. The study also analyses the impact of this association on vegetation dynamics and propose effective strategies for *C. tungurrut* conservation strategy. The study established 41 plots across four distinct sites within the Cibodas Biosphere Reserve located in Gede Pangrango National Park. Identification of trees, poles, saplings, and wildings was carried out using the nested sampling method. A comprehensive list of 153 tree, 104 pole, 135 sapling, and 111 wilding species was documented and paired with *C. tungurrut* for association test, and a positive association was observed with the tree species *Casearia coriacea* and the wilding species *Symplocos costata* (Jaccard indices for these pairings were 0.34 and 0.33, respectively). In addition, a negative association was found for trees of *C. tungurrut* with *Castanopsis javanica* and *Macropanax dispermus*; Jaccard indices for pairings were 0.17 and 0.18, respectively. It was noted that *C. tungurrut* exhibited lower competitive ability and selectivity in less favorable habitats, and its facilitative effect on the surrounding vegetation was limited. The prevalence of negative association with neighbouring vegetation within the natural forest of Cibodas Biosphere Reserve indicates that *C. tungurrut* is isolated and facing threats such as environmental stress and competition. This condition contributes to the forest's overall diversity and promotes the sustainability of the reserve by enhancing ecosystem stability.

**Keywords:** Altitudine gradients, endangered species, Fagaceae, Gede Pangrango National Park, life stages, nested sampling method, natural habitats, plant community, tropical forests.

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**Author contributions:** DRN—proposed the objectives, methods and conducted fieldwork. He analysed data sets, wrote the paper and oversee the final drafting and publication. IEBJr—commented on the proposed objectives and methods. He actively participated in the analysis of data sets and contributed to the discussion of results, ensuring that the paper is acceptable for publication

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## INTRODUCTION

*Castanopsis tungurrut* tends to grow independently and shows selectivity in its habitat preferences. A previous study on the association of *Castanopsis* species in remnant forests found a positive association between *C. tungurrut* and *C. javanica* in the sapling stage, while wildings and mature trees were absent (Nurdiana & Buot 2021). The association and interactions among plants are primarily driven by environmental conditions (Anthony & Germino 2023; Senthilnathan & D'Andrea 2023). In extreme conditions, plant interactions are facilitated, while in milder conditions, competition arises (Díaz-Borrego et al. 2024).

Understanding the interspecific relationships between dominant species can provide insights into the structure, function, development, maintenance, and succession of natural forests. Interspecific associations reveal habitat preferences and the mutual attraction or repulsion of co-occurring species in specific environments (Song Jin et al. 2015). Limited research has been conducted on the interspecific relationships between native species in the Cibodas Biosphere Reserve forest, and there is no clear evidence of how these associations influence dynamic processes in forests. Baokun et al. (2019) indicated that a higher diameter class of a given species pair leads to a lower positive-to-negative association ratio, suggesting that these relationships occur during the successional stage of a forest rather than in its mature state.

The ecological role of the native species *C. tungurrut* in the Cibodas Biosphere Reserve forest remains poorly understood and subject to debate. Therefore, gaining a better understanding of its function can contribute to the knowledge of the forest vegetation's condition and the impact of interspecific relationships involving *C. tungurrut* on the forest's structure. This study aims to examine the interspecific relationships of *C. tungurrut*, specifically its interactions with neighboring plants and its contributions to the dynamics of the forest community. Specifically, the study investigates the following: 1) interspecific association between *C. tungurrut* and neighbouring vegetation at tree, pole, sapling, and wilding stages; 2) type of association between *C. tungurrut* with neighbouring vegetation in various life stages; 3) preferred forest type for *C. tungurrut*; 4) importance of association of *C. tungurrut* in species conservation strategies. These outcomes are expected to advance the understanding of vegetation dynamics and support the design of sustainable management strategies for *C. tungurrut* in Cibodas Biosphere Reserve.

## MATERIALS AND METHODS

A total of 41 plots, covering an area of 16,400 m$^2$ or 1.64 ha, were assessed in this study, which was conducted within the core zone in four locations: Cibodas, Bodogol, Cisarua, and Selabintana (Image 1).

### Species sampling

A nested plot technique involving different plot sizes for different vegetation categories was employed for the study. The main plots had dimensions of 20 × 20 m and were used to measure trees. Within each main plot, smaller plots of 10 × 10 m were established for poles, 5 × 5 m for saplings, and 2 × 2 m for wildings. These plots were set up along an altitude gradient ranging 750–1,800 m, and their coordinates were recorded using a GPS Garmin e-trex 10. The number of plots established varied based on the location, elevation, and topography of the area. Specifically, there were 10 plots for Bodogol, 14 plots for Cibodas, eight plots for Cisarua (Image 2), and nine plots for Selabintana forest In each plot, the name and number of species present across different vegetation categories, including wildings, saplings, poles, and trees were recorded. Trees were defined as woody plants taller than 2 m with a stem diameter of at least 5 cm. Poles were categorized as stands with a diameter greater than 2.5 cm but less than 5 cm (Newton 1988; Fathia et al. 2019). Saplings were stands with a diameter at breast height (DBH) less than 2.5 cm and a height of at least 130 cm, while wildings referred to individuals with a height below 130 cm (Vargas-Rodriguez et al. 2005).

### Interspecific association measurement

To examine the association between species, the presence and absence of each species were recorded, following the approach used by Song jin et al. (2015). The association coefficient (AC) was then calculated using a 2 × 2 contingency table to quantify the interspecific association for each pair of species. Statistical tests, including chi-square ($x^2$) and Jaccard's association index, were performed on the data (Pielou 1972; Dogra et al. 2009). This association analysis was conducted for all recorded species across all locations.

### Data analysis

The vegetation at the research site was analyzed using the Shannon-Wiener Diversity index and evenness indices. In the analysis, a 2 × 2 contingency table, chi-square test, and Jaccard index were utilized to determine the condition of the natural forest where the *Castanopsis* species occurred.

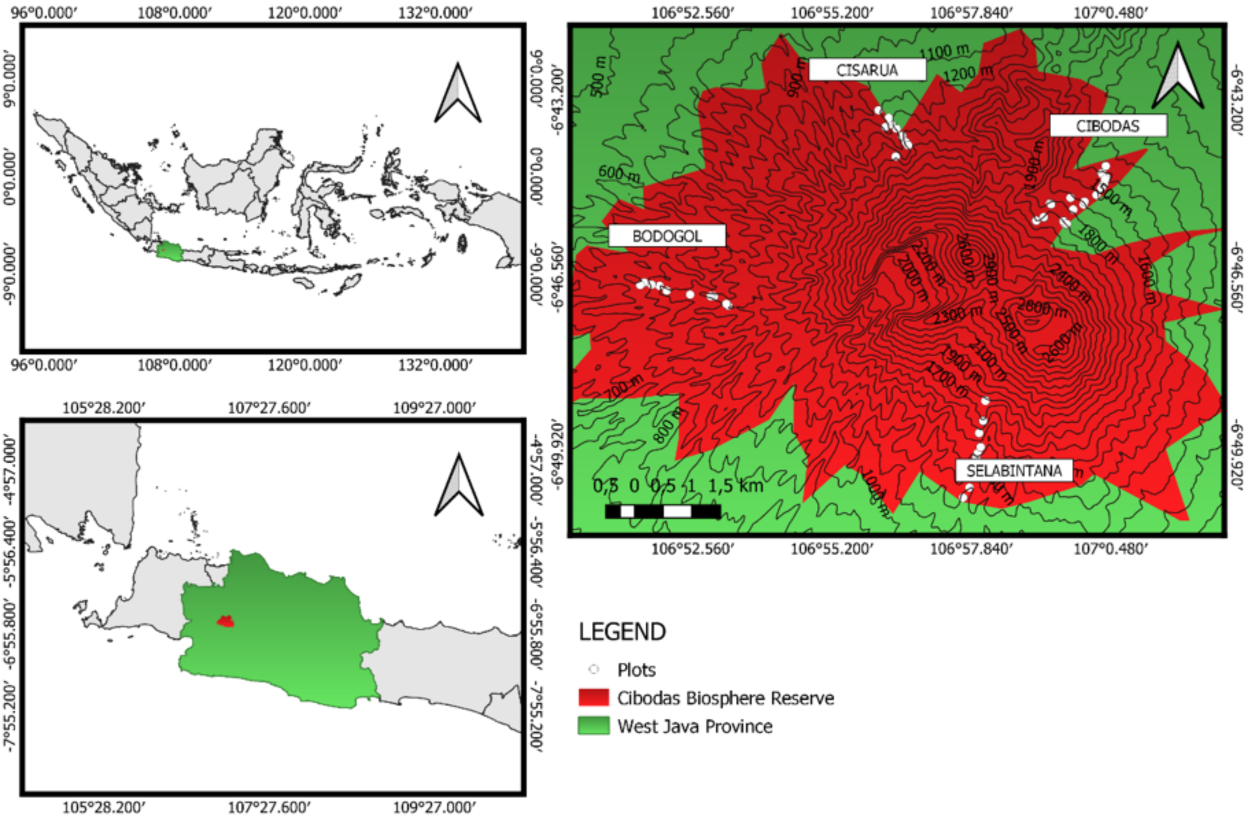

**Image 1. Map of established plot in Cibodas Biosphere Reserve (https://earth.google.com/web, https://www.gedepangrango.org). The maps were generated by QGIS version 3.16.**

### Association coefficient using 2 x 2 contingency table

| | | Species $Y$ | | |
|---|---|---|---|---|
| | | Present | Absent | |
| Species $X$ | Present | $a$ | $b$ | $a+b$ |
| | Absent | $c$ | $d$ | $c+d$ |
| | | $a+c$ | $b+d$ | |

To test the null hypothesis of independence of the 2 × 2 table, the chi-square test statistic was used.

### The formula for chi-square ($x^2$) test

$$x^2 = \frac{[a - E(a)]^2}{E(a)} + \frac{[b - E(b)]^2}{E(b)} + \frac{[c - E(c)]^2}{E(c)} + \frac{[d - E(d)]^2}{E(d)}$$

$$E(a) = \frac{(a+b)(a+c)}{n} \quad E(b) = \frac{(a+b)(b+d)}{n}$$

$$E(c) = \frac{(a+c)(c+d)}{n} \quad E(d) = \frac{(b+d)(c+d)}{n}$$

a >E (a) refers to positive association type,a <E (a) to negative association type, $x^2$ test >x table to associated and $x^2$ test <x table not associated, and x table 3.84.

### Jaccard index computation

$$Sj = \frac{a}{a+b+c}$$

*a* refers to the number of species in both sites; *b* refers to the number of species in the second site; *c* refers to the number of species in the first site. The data obtained were then analysed using chi-square analysis.

## RESULTS

### The diversity and occurrence of *C. tungurrut*

The nested sampling method was employed for vegetation analysis, in order to collect data on density, diversity index, evenness index, and occurrence of *C. tungurrut* across different life phases in 41 sampling plots (Table 1).

Data presented in Table 1 showed that *C. tungurrut* occurs at 750–1,500 m elevation at all four locations selected in the study. But, the occurrence of this tree species varies in its life stages at each location. Its wildings are present only at Bodogol and Selabintana locations while its mature individuals occur in all four locations indicating that each location has a dynamic

**Table 1. Diversity of vegetation and the occurrence data of *Castanopsis tungurrut* in all life stages at Cibodas Biosphere Reserve. BDL = Bodogol, CBS—Cibodas, SBL—Selabintana and CSR—Cisarua, 1—present, 0—absent.**

| | | Tree | Pole | Sapling | Wilding |
|---|---|---|---|---|---|
| **Number of species** | | 153 | 104 | 135 | 111 |
| **Diversity index** | | 4.3 | 4.2 | 4.3 | 3.9 |
| **Evenness index** | | 0.48 | 0.65 | 0.5 | 0.5 |
| **Locations** | | | | | |
| Sampling plot | Altitude (m) | | | | |
| | | | | | |
| BDL10 | 750 | 1 | 0 | 0 | 0 |
| BDL3 | 823 | 1 | 0 | 0 | 0 |
| BDL2 | 857 | 1 | 1 | 0 | 0 |
| BDL1 | 931 | 1 | 0 | 0 | 0 |
| BDL9 | 950 | 1 | 0 | 1 | 0 |
| BDL8 | 1000 | 1 | 0 | 0 | 1 |
| BDL7 | 1039 | 1 | 0 | 0 | 0 |
| BDL6 | 1050 | 1 | 0 | 0 | 0 |
| BDL5 | 1080 | 0 | 0 | 0 | 1 |
| BDL4 | 1104 | 1 | 0 | 0 | 1 |
| CSR8 | 1157 | 1 | 0 | 0 | 0 |
| SBL9 | 1163 | 0 | 1 | 1 | 0 |
| SBL8 | 1205 | 0 | 1 | 0 | 0 |
| CSR7 | 1219 | 1 | 0 | 0 | 0 |
| CSR6 | 1264 | 1 | 0 | 0 | 0 |
| SBL7 | 1300 | 0 | 0 | 1 | 1 |
| CSR1 | 1306 | 1 | 0 | 1 | 0 |
| CBS14 | 1346 | 1 | 0 | 0 | 0 |
| CSR2 | 1350 | 0 | 0 | 1 | 0 |
| CBS13 | 1373 | 1 | 0 | 0 | 0 |
| SBL1 | 1387 | 1 | 0 | 0 | 0 |
| CBS12 | 1403 | 1 | 0 | 1 | 0 |
| CSR3 | 1413 | 1 | 1 | 0 | 0 |
| SBL2 | 1459 | 1 | 0 | 0 | 1 |
| CSR4 | 1461 | 1 | 0 | 0 | 0 |
| CBS11 | 1465 | 1 | 0 | 0 | 0 |
| CBS10 | 1479 | 0 | 1 | 0 | 0 |
| CSR5 | 1500 | 1 | 0 | 1 | 0 |
| SBL6 | 1500 | 0 | 0 | 0 | 0 |
| CBS9 | 1550 | 0 | 0 | 0 | 0 |
| CBS8 | 1600 | 0 | 0 | 0 | 0 |
| SBL5 | 1600 | 0 | 0 | 0 | 0 |
| CBS7 | 1700 | 0 | 0 | 0 | 0 |
| SBL4 | 1717 | 0 | 0 | 0 | 0 |
| CBS5 | 1720 | 0 | 0 | 0 | 0 |
| CBS6 | 1739 | 0 | 0 | 0 | 0 |
| CBS3 | 1793 | 0 | 0 | 0 | 0 |
| CBS1 | 1806 | 0 | 0 | 0 | 0 |
| CBS2 | 1807 | 0 | 0 | 0 | 0 |
| SBL3 | 1829 | 0 | 0 | 0 | 0 |
| CBS4 | 1830 | 0 | 0 | 0 | 0 |

role in the regeneration of this tree species.

### Interspecific association

The chi-square analysis compared *C. tungurrut* with 153 tree species, resulting in the identification of the top ten species pairs based on the highest chi-square values (Table 2). The findings revealed that out of all the pairs examined, only three pairs involving different tree life stages showed associations: *C. tungurrut* × *C. javanica*, *C. tungurrut* × *Macropanax dispermus*, and *C. tungurrut* × *Casearia coriacea*. The remaining pairs did not show any significant associations. Among these three associations, only the pair of *C. tungurrut* × *C. coriacea* displayed a positive association.

The chi-square analysis in the pole stage yielded data on 104 pole species pairs (Table 2). Surprisingly, the results indicated that *C. tungurrut* showed no associations with any species, even those belonging to the same genus. This lack of association may be attributed to intense competition for limited resources such as water, light, and nutrients within the habitat, as well as the slope factor. To cope with these challenging conditions, plants undergo morphological and physiological adjustments in response to location conditions. These adaptations enable plants to optimize their competitiveness in both above-ground and below-ground components (Xue et al. 2012).

Additionally, upon analyzing the sapling stage, the chi-square analysis of 135 sapling species pairs yielded similar results to the pole stage. Once again, *C. tungurrut* did not show any associations with other species. The prevalence of these non-associations suggests that *C. tungurrut* is a robust competitor and a key species capable of inhibiting the growth of other species due to resource limitations, similar to the effect observed in *Dactylis* at successional forest of William L. Hutcheson Memorial Forest Centre, USA as described by Myster & Pickett (1992). The behavior of *Dactylis* is very similar to that of *C. tungurrut.*

During the assessment of the wilding stage, a total of 111 wilding species pairs were examined. Interestingly, only *Symplocos costata* exhibited positive associations with *C. tungurrut*. This suggests that facilitation only occurred in specific pairs, while intense competition was observed among most tree wildings. Furthermore, the asymmetric competition resulting from canopy shading by adult trees could also have influenced the observed associations (Paine 2008).

### Co-occurence of dominant vegetation with *C. tungurrut*

Table 4 presents the preferences of *C. tungurrut* for

**Table 2. Results of association test on tree, pole, sapling and wilding life stage between *Castanopsis tungurrut* and 10 dominant co-occurrence species.**

| Co-occurring plant species | Associated/not associated (based on chi-square test) | Types of association (positive/negative) | Degree of association (Jaccard index) |
|---|---|---|---|
| **Tree stage** | | | |
| *Castanopsis javanica* (Blume) A.DC. | Associated (8.8)* | Negative | 0.17 |
| *Macropanax dispermus* (Blume) Kuntze | Associated (5.3)* | Negative | 0.18 |
| *Casearia coriacea* Thwaites | Associated (5.2)* | Positive | 0.35 |
| *Ostodes paniculata* Blume | Not Associated | - | 0.26 |
| *Villebrunea scabra* (Blume) Wedd. | Not Associated | - | 0.44 |
| *Ficus fistulosa* Reinw. Ex Blume | Not Associated | - | 0.26 |
| *Syzygium pycnanthum* Merr. & L.M.Perry | Not Associated | - | 0.23 |
| *Schima wallichii* (DC.) Korth. | Not Associated | - | 0.32 |
| *Altingia excelsa* Noronha | Not Associated | - | 0.22 |
| *Ficus ribes* Reinw. Ex Blume | Not Associated | - | 0.27 |
| **Pole stage** | | | |
| *Villebrunea scabra* (Blume) Wedd. | Not Associated | - | 0.20 |
| *Bridelia insulana* Hance | Not Associated | - | 0.20 |
| *Alangium rotundifolium* (Hassk.)Bloemb. | Not Associated | - | 0.20 |
| *Brugmansia suaveolens* (Humb.& Bonpl. Ex Willd.) Sweet | Not Associated | - | 0.20 |
| *Dysoxylum alliaceum* (G.Forst.) Seem. | Not Associated | - | 0.20 |
| *Euonymus indicus* B.Heyne ex Wall. | Not Associated | - | 0.20 |
| *Laportea Stimulans* (L.f.)Miq. | Not Associated | - | 0.20 |
| *Schefflera* J.R.Forst. & G.Forst. | Not Associated | - | 0.20 |
| *Trevesia sundaica* Miq. | Not Associated | - | 0.20 |
| *Cestrum aurantiacum* Lind. | Not Associated | - | 0.17 |
| **Sapling stage** | | | |
| *Cinchona pubescens* Vahl | Not Associated | - | 0.25 |
| *Didymocheton alliaceus* (G.Forst.) Mabb. | Not Associated | - | 0.25 |
| *Polyalthia subcordata* (Blume) Blume | Not Associated | - | 0.23 |
| *Lasianthus rigidus* Miq. | Not Associated | - | 0.14 |
| *Dinochloa scandens* (Blume ex Nees) Kuntze | Not Associated | - | 0.14 |
| *Bridelia* sp. | Not Associated | - | 0.14 |
| *Ficus heterophylla* L.f. | Not Associated | - | 0.14 |
| *Angiopteris evecta* (G.Forst.) Hoffm. | Not Associated | - | 0.14 |
| *Austroeupatorium inulifolium* (Kunth) R.M.King & H.Rob. | Not Associated | - | 0.14 |
| *Bridelia insulana* Hance | Not Associated | - | 0.14 |
| **Wilding stage** | | | |
| *Symplocos costata* (Blume) Choisy ex Zoll. | Associated (4.8) | Positive | 0.33 |
| *Smilax javensis* A.DC. | Not Associated | - | 0.29 |
| *Calamus reinwardtii* Mart. | Not Associated | - | 0.29 |
| *Piper baccatum* Blume. | Not Associated | - | 0.25 |
| *Magnolia liliifera* (L.)Baill. | Not Associated | - | 0.25 |
| *Lasianthus laevigatus* Blume | Not Associated | - | 0.22 |
| *Ficus repens* Rottler | Not Associated | - | 0.20 |
| *Gonostegia hirta* (Blume) Miq. | Not Associated | - | 0.20 |
| *Raphidophora* Hassk. | Not Associated | - | 0.20 |
| *Clerodendrum eriosiphon* Schauer | Not Associated | - | 0.20 |

*$x^2$ test >x table is associated; $x^2$ test <x table is not associated; x table.3.84 (df = 1; α = 0.05). Type of association is positive if a >E (a) and negative if a< E (a). Value of the Jaccard index (strength of association) is equal to 0 at "no association" and to 1 at "complete/maximum association".


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Image 2. The study site at Cisarua.

specific forest associations highlighting its tendency towards forests dominated by the Lauraceae family, where it exhibits high density and size. These findings further support the results obtained from the interspecific association test mentioned earlier.

## DISCUSSION

### Association of *C. tungurrut* with neighbouring vegetation

Based on Table 1, the presence of *C. tungurrut* tree phases in each location is generally observed up to 1,500 m. This shows that altitude is one of the limiting factors for the distribution of *C. tungurrut* in the Cibodas Biosphere Reserve. This is common in Javamountain forests, where the restricted diversity of adaptive species may be due to the stress that higher elevations put on environmental factors including temperature, humidity, wind, and nutrient availability as reported by Simbolon (2001) that tree species diversity decreased by 62% from 1,000 m to 1,800 m. Similar condition is depicted on pole, sapling and wilding stages. *C. tungurrut* is absent above 1,500 m and has variation in occurrence at each site. Different factors contribute to the rarity of pole, sapling and wilding in the sampling sites. This includes the restriction of altitude affect to the competition between individuals within same species and competition between different species in terms of light, groundwater, oxygen, nutrient, carbon dioxide, and space (Fathia et al. 2019), dispersal failure, high pollen limitation, and also predation on seed and wildings (Janzen 1970; Wotton & Kelly 2011; Etten et al. 2015). Furthermore, forest gap and climate change also contribute to the rarity of the pole, sapling and wilding as described by (Beckage et al. 2008; Davis et al. 2019). The forest with gaps provides more chance for the tree regeneration than the dense understorey, while the climate change may show abrupt shifts in vegetation communities.

Table 3. The total number of association species (associated & not associated) and type of association of *C. tungurrut* in various life stages based on chi-square value.

| Life stage | Associated pairs | Not associated pairs | Negative association type | Positive association type |
|---|---|---|---|---|
| Tree | 3 | 150 | 64 | 89 |
| Pole | 0 | 104 | 78 | 26 |
| Sapling | 0 | 135 | 101 | 34 |
| Wildings | 1 | 110 | 81 | 30 |

### Association of *C. tungurrut* with neighbouring vegetation

Plant-plant associations often exhibit repetition, with approximately 70% of the data from long-term observations in old-field and glasshouse settings showing similar associations within the same species (Myster & Pickett 1992). In the case of *C. tungurrut*, this pattern remains consistent across different tree life stages. Negative associations were observed between *C. javanica* and *C. argentea* pairs.

Delving deeper into the analysis of above-ground vegetation associations between *C. tungurrut* and other species, it was found that most pairs did not exhibit any associations. Out of a total of 154 tree pairs, 105 pole pairs, 135 sapling pairs, and 111 wilding pairs, only the tree and wilding stages revealed positive and negative associations. These findings agree with the hypotheses pertaining to niche differences, the Janzen-Connel effect and negative density dependence reported by Wright (2002). *C. tungurrut* may possess niche distinctions or inhabit separate microhabitats, reducing direct competition with neighboring species and enabling coexistence without being overpowered by stronger competitors. Furthermore, the presence of a herbivore that primarily feeds on seeds may result in reduced recruitment near reproductive adults compared to competitors. Competition among conspecifics may also occur. The coexistence of other species under similar conditions can be attributed to evolutionary factors, such as speciation and adaptive traits.

Comparing with other *Castanopsis* species, various studies have indicated that *Castanopsis* species, including *C. kawakamii*, *C. eyrei*, and *C. chinensis*,

**Table 4. *Castanopsis tungurrut* vegetation associations at four locations within Cibodas Biosphere Reserve.**

| Locality | Vegetation association | Plots characteristics |
|---|---|---|
| **Bodogol**<br>(Humid forest with slope and long ridge) | Lauraceae is dominant – 10 species (*Cinnamomum rhynchophyllum, Cryptocarya ferrea, C. laevigata, Endiandra rubescens, Lindera polyantha, Litsea* sp. *L. garciae, Neolitsea javanica, Persea excelsa* and *Phoebe excelsa*). | Uneven canopy, reaching to a height of 28 m, dominated by several species based on IVI, *Schima wallichii, Castanopsis tungurrut, Syzygium rostratum, Lithocarpus pseudomoluccus, Maesopsis eminii, Casearia coriacea* and *Prunus arborea.* |
| **Cibodas**<br>(Humid forest with less slope and some open area) | Lauraceae is dominant – 8 species (*Cryptocarya ferrea, Litsea resinosa, Neolitsea cassiifolia, N. javanica, N. triplinervia, Persea rimosa, Phoebe excelsa* and *P. grandis*). | Even canopy, reaching to a height of 20–30 m, dominated by several species based on IVI, *Schima wallichii, Macropanax concinnus,Dacrycarpus imbricatus,Castanopsis javanica,Villebrunea scabra, Macropanax dispermus.* |
| **Cisarua**<br>(Near to *Cinchona* plantation; relatively humid forest with slope and small portion of opened forest) | Fagaceae is dominant – 6 species (*Castanopsis argentea, C. javanica, C. tungurrut, C. acuminatissima, Lithocarpus indutus, L. pseudomoluccus*). | Uneven canopy, the upper canopy reaching to a height of 38 m, dominated by several species based on IVI, *Castanopsis tungurrut,C. javanica, Villebrunea scabra, Cinchona pubescens, Schima wallichii, Casearia coriacea.* |
| **Selabintana**<br>(Humid forest with steepy slope) | Rubiaceae is dominant – 5 species (*Cinchona pubescens, Coffea* sp., *Lasianthus stercorarius, Neonauclea lanceolata, Wenlandia* sp.). | Relatively even canopy, reaching to a height of 10–30 m. The dominant species based on IVI include *Schima wallichii, Macropanax dispermus,Villebrunea scabra, Neolitsea javanica, Acronychia pedunculata, Macropanax concinnus.* |

exhibit diverse levels of inter-specific associations. *C. kawakamii* shows a weak association with dominant *Castanopsis* forests (Jinfu et al. 2001), while *C. eyrei* demonstrates a decrease in positive associations between species pairs with increasing diameter classes, leading to heightened inter-specific competition within the plot (Etten et al. 2015; Baokun et al. 2019). Also, the intensity of association in *C. chinensis* decreases as life stages progress (Li et al. 2008). Additionally, *C. argentea* showed a positive association with *Pinus merkusii* which is known as the producer of allelopathic substances (Hendrayana et al. 2022).

Moreover, it is worth noting that *C. tungurrut* only exhibits positive associations with *Casearia coriacea* and *Symplocos costata* in the tree and wilding stages, while negative or no associations were observed with other species. These intriguing findings suggest that *C. tungurrut* is a selective species and offers less facilitation to other species within the same habitat. It appears that competition outweighs facilitation when it comes to neighboring species.

It is probable that *C. tungurrut* and *Casearia coriacea* have complementary biological characteristics and nutrition requirements. *C. coriacea* provides protection from insects, while *C. tungurrut* provides nutrients and protection for *C. coriacea.* Therefore *C. tungurrut* and *C coriacea* can be successfully mixed with each other as they have complementary requirements. Similarly, *Symplocos costata* and *Castanopsis tungurrut* have a positive association because there is complementary interaction between them. Wihermanto (2004) reported that *Symplocos costata* has scattered clumped distribution at 1,000–1,421 m elevation and is positively associated with *Castanopsis javanica*. Further, this species lacks allelopathy substances that promote the development of *Rhizobium* and mycorrhiza in the roots of other plants. Therefore, in the wilding phase, *C. tungurrut* is facilitated by *S. costata* and vice-versa, especially in terms of providing nutrients to each other.

## TYPES OF ASSOCIATION

### a. Positive association between *C. tungurrut* and other species

The positive association observed between *C. tungurrut* and *Casearia coriacea* likely indicates a facilitation mechanism or mutualism between these species. Several factors may contribute to positive associations between neighboring plants, including mutual protection from harsh environmental conditions. One organism creates a more favorable local environment for another through direct means such as shading and wind reduction, or indirect means such as removing competitors and deterring predators. Ecologically, positive associations play a crucial role in shaping community structure and dynamics by reducing physical and biotic stress in habitats and creating new habitats for dependent species (Callaway 1995; Hacker & Bertness 1996; Stachowicz 2001). Different authors (Wihermanto 2004; Li et al. 2008, 2010; Song Jin et al. 2015; Hendrayana et al. 2022) reported that *Castanopsis* has positive association with several species such as *Pinus merkusii*, *P. taiwanensis, Nauclea* sp., *Schima superba, Saurauia bracteosa*, *S. cauliflora*, *Symplocos costata*, *Altingia chinensis* and *Engelharditia roxburghiana*). It is noteworthy that *Castanopsis* species are mostly associated positively with dominant species

**Image 3. Plant forms of *Castanopsis tungurrut*: a—wilding | b—sapling | c—pole | d—tree. © Authors.**

in particular forest because *Castanopsis* species occupy a specific ecological niche within their habitat and flourish in the understory or with other dominant plants as forests mature since they are frequently early- to mid-successional species (Yang et al. 2003; Wang et al. 2012).

*Casearia coriacea* is a species that can survive under changing environmental conditions and adapt to extreme conditions. It produces various bioactive compounds, including clerodane-type diterpenoids that serve as insect antifeedants (Ledoux et al. 2023). On the other hand, *C. tungurrut* prefers to grow on slopes and exhibits buttress morphological characteristics, which can provide nutrients to surrounding plants and reduce the impact of wind exposure (Tang et al. 2010). These factors may explain the positive association between *C. tungurrut* and *Casearia coriacea*. The facilitative relationships are also similar to other *Castanopsis* species, just like *Castanopsis chinensis* and *Schima superba* providing shelter to small trees (Li et al. 2008).

Positive association occurs between *C. tungurrut* and *Symplocos costata* in the wilding phase but the associations between these species are different during the tree phase. Differences in associations during different life phases are common and influenced by dynamic conditions, including variations in life history and seasons (Osawa et al. 2014). *S. costata* exhibits random dispersion patterns, acts as a pioneer plant, and produces numerous seeds, making it easily found in the mountainous regions of West Java (Wihermanto 2004; Zuhri et al. 2020). In contrast, *C. tungurrut* shows habitat selection and faces significant threats from seed predation. Similar condition with *Castanopsis chinensis* that are eaten either by rodent and people contribute to the poor regeneration. The positive association observed in the wilding phase may be attributed to similar habitat requirements for the germination phase of both plants, facilitating wilding establishment.

It is noteworthy that the dynamic association within the life stages is correlated with the environmental heterogeneity or patchiness, where positive association in early stages is different from mature stage as depicted of different association type of *C. tungurrut* with *S. costata* in wilding and mature stages. The presence of positive associations between these two species can significantly impact vegetation structure and dynamics. The associations observed between them are dynamic and may change during a plant's life. From an ecosystem perspective, maintaining positive associations with other species can help preserve endangered species diversity such as *C. tungurrut* by providing favorable conditions. In addition, the different numbers of positive and negative association of *Castanopsis* will reflect the successional stage of the species. Yang et al. (2003) revealed that high number of insignificant association reflected a stable late successional stage of species community. More positive association with dominant species will reflect an unstable succession. The negative associations between later life stages and early life stages usually indicate the suppression of early stages by later stages. Helmanto et al. (2020) reported that negative association Indicates a tendency for exclusion or different responses in the same environment.

The study shows that the small number of positive associations of *C. tungurrut* is correlated with the facilitation relationship among the neighbouring vegetation and regeneration capacity of species. The mature tree cannot produce the wilding due to predation and hunting of seed, while the wilding cannot grow to the later stages due to suppression of dominant species in habitat. In the end, *C. tungurrut* is aggregated and had been less facilitative to neighbouring vegetation during tree and pole phase.

### b. *Negative associations between C. tungurrut and other species*

Negative associations are commonly observed in perennial plants, including *C. tungurrut*. The negative association of *C. tungurrut* were observed only with *Castanopsis javanica* and *Macropanax dispermus* on the tree stage. There is no observed negative association between pole, sapling, and wilding. The negative association within the same genus was also described by Helmanto et al. (2020) where *Saurauia microphylla* was paired with *S. pendula* indicating that they have a tendency to exclude one another or respond differently to a similar environment. The negative association is not observed in the pole, sapling, and wilding stages. This dynamic condition suggests that *C. tungurrut* is a species that tends to compete within its habitat with minimal interaction between surrounding plant species. Intraspecific associations within the genus *Castanopsis* reveal that the patterns exhibited by *C. tungurrut* vary depending on the species' life phase. Similar observations have been found by Rejmánek & Leps (1996), Yang et al. (2003), and Cheng et al. (2014) in *Arctostaphylos patula* and *Cirsium vulgare* as well as *Quercus liaotungensi* and *Castanopsis chinensis*. The early stages association changed in the later stages due to competition for resources (light, nutrients, and water) and facilitation among the species. Competition for limited resources like water, nutrients, and light significantly impacts plant growth, community composition, and ecosystem function. Plants compete for these resources, with those capturing more light, such as those growing above others, gaining an advantage. This competition shapes plant evolution, favoring traits that enhance survival in the early stages, even if detrimental later. Additionally, environmental factors like slope influence species interactions, with negative associations decreasing in drier environments, suggesting adaptations to specific microclimates and resource utilization.

The negative associations of *C. tungurrut* with surrounding plants have significant impacts on the distribution and abundance of other species, especially those with high morphological plasticity and adaptability, which struggle to grow and develop. The present study found the prevalence of negative associations between *C. tungurrut* and other species. In interspecific competition, the availability of nutrients and light plays a primary role. Plant competition shapes community structure, influences nutrient cycling, and even affects the evolution of plant species (Goldberg & Barton 1992; Fréville & Silvertown 2005). The negative association among *Fagus lucida*, *Quercus variabilis, Castanopsis lamontii,* and *Litsea cubeba* is brought about by the differences of environmental requirements due to long-term adaptation of micro-environment, resources spaces and niche separation (Song jin et al. 2015). *C. tungurrut* tends to grow in isolation and restricts its associations with neighboring vegetation, hence, there were not many associated species. The association was driven mainly by environmental factors such as light availability, water, nutrient, and temperature. The association could be positive or negative depend on the resource utilization patters, level of competition, and habitat preferences (Maihaiti & Zhang 2014).

**Forest Association Preference**

*C. tungurrut* is commonly found and thrives in forests dominated by the Lauraceae family. Yamada (1975) reported similar situation in Mount Pangrango montane forest. In this forest, Lauraceae, Fagaceae and Theaceae have been found to be dominant families. But, *C. tungurrut* tends to have a negative association with the members of all these three families. This species is negatively associated with Theaceae member, *Schima wallichii* suggesting that *C. tungurrut* does not facilitate the growth of other trees, which is most likely due to intense competition among them for resources. Soepadmo & van Steenis (1972) described that when Fagaceae litter decomposes, it releases compounds (allelopathic) that, combined with specific fungi, may hinder or limit the growth of other forest trees. This phenomenon could contribute to *C. tungurrut*'s less facilitative nature. Matsuoka et al. (2019) and Wang (2011) reported that the association of ectomycorrhizal (ECM) fungi is closely related to the dispersal and distribution pattern of *Castanopsis*. Latitude and longitude also play a significant role in influencing the diversity and community structure of ECM fungi. Moreover, these biogeographic shifts in the ECM community are strongly linked with *Castanopsis* as the host tree. Hendrayana et al. (2022) revealed the positive association of *C. argentea* with dominant species *Pinus merkusii* and *Nauclea* sp. in Mount Ciremai National Park while Li et al. (2008) revealed the dynamic association in different life stages of species pair, *Castanopsis eyrei* and *Schima superba*. Nurdiana & Buot (2021) found a positive association of *C. tungurrut* and *C. javanica* in a remnant forest of the Cibodas Botanical Garden.

In general, *C. tungurrut* is capable of growing alongside major dominant families in the montane forest. It prefers to grow independently. Its density decreases when the dominant vegetation does not belong to the dominant families of Fagaceae, and Lauraceae, as observed in the case of the Selabintana forest, where Rubiaceae is dominant The lower density of *C. tungurrut* can possibly be attributed to its limited morphological adaptability and reduced competition with neighboring species. Further, favorable conditions, as commonly found in Fagaceae according to Soepadmo & van Steenis (1972), are necessary for the growth of *C. tungurrut*.

**Importance of association of *C. tungurrut* and its conservation strategy**

*C. tungurrut* plays a vital role as a keystone species in supporting the existence of other species within their habitats, thereby contributing to conservation efforts and promoting sustainability. This indicates that unfavorable interactions within the same species can create opportunities for the regeneration of different species, thus preserving biodiversity and preventing the dominance of monocultures. Different authors (Dolezal et al. 2020; Loreau & de Mazancourt 2013; Rozdilsky & Stone 2001) reported that intense interspecific competition, species asynchrony to environmental fluctuation, connectance, the strength of competition, speed of species in responding the perturbation and diverse plant communities are significant factors in shaping the ecosystem stability. The present study highlights how these effects differ depending on the age of the wildings: younger wildings are more affected by interactions with their conspecific neighbors, whereas older wildings are influenced to a greater extent by neighboring trees of the same species. These findings can provide valuable insights for conservation initiatives aimed at sustaining biodiversity in forests and similar environments where similar processes occur. It is important to note that even though intraspecific interactions weaken as the wildings age, they still impact overall survival rates in later stages of development (Zhao et al. 2021). It is worth mentioning that the study was limited to observations of above-ground vegetation and did not investigate subterranean associations, such as the involvement of microorganisms in the growth of *C. tungurrut*. To mitigate biases in observations and assess interactions in underground associations, it is recommended to conduct repeated observations using consistent patterns.

## CONCLUSION

The association of *C. tungurrut* with other species in the community is dynamic and influenced by competition, facilitation, and succession. Overall, *C. tungurrut* is not associated with neighbouring species indicating that the co-occurrence of *C. tungurrut* and the paired species is independent. It is a selective species that does not rely on the presence of other species for its growth. Instead, it tends to grow independently up to 1500 m in Lauraceae and Fagaceae forests, reducing its density in unfavorable habitats. Furthermore, *C. tungurrut* prefers not to be associated with the dominant species in its habitat. This behavior provides important insights for reserve management, specifically in the development of sustainable management frameworks for the Cibodas Biosphere Reserve. Factors such as favorable location, including soil conditions, environmental parameters, and vegetation types, should be considered while crafting these management strategies. *C. tungurrut* can be planted with *Casearia coriacea* and *Symplocos costata* since both exhibit complementary ecological characteristics and facilitation mechanisms.

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