BIOGENESIS Jurnal Ilmiah Biologi

pISSN 2302-1616, eISSN 2580-2909
Vol 10, No. 2, December 2022, pp. 144-154
Available online http://journal.uin-alauddin.ac.id/index.php/biogenesis
DOI https://doi.org/10.24252/bio.v10i2.28578

Diversity of forest floor vegetation in Napabalano Nature Reserve and Warangga Protection Forest, Southeast Sulawesi

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ABSTRACT. Forest floor vegetation includes all plants under the forest stand, including shrubs, herbs, and ferns. The presence of a forest floor vegetation community in a landscape positively impacts the balance of the ecosystem. This study aims to identify species diversity, analyze differences in the composition and diversity of vegetation types and analyze environmental factors that influence differences in the composition and diversity of forest floor vegetation in the Napabalano Nature Reserve Area and Warangga Protection Forest. Data collection was carried out from November 2020 to March 2021 using purposive sampling according to field conditions. Vegetation data and soil samples were collected in each sample plot. Vegetation abundance was analyzed by calculating the importance value index (INP), the diversity index of vegetation types, evenness, and the similarity of vegetation types. Environmental data were analyzed using CCA with the Canoco program. This study shows that the dominant types of vegetation in the Napabalano Nature Reserve include *Leea indica* and *Ardisia saguinolenta*, while in the Warangga Protection Forest, the highest dominant species include *Chromolaena odorata* and *Oplismenus undulatifolius*. The vegetation on the forest floor of the Napabalano Nature Reserve consists of 41 species consisting of 23 species of undergrowth and 18 species, including the seedling stage. About 57 types of vegetation on the forest floor found in Warangga Protection Forest, including 35 species of undergrowth and 22 species at the seedling level. The CCA analysis showed that the environmental factors that most influenced the diversity and composition of forest floor vegetation in the Napabalano Nature Reserve and Warangga Protection Forest were temperature, light intensity, humidity, pH, and shade.

Keywords: CCA analysis; composition vegetation; environmental factors; seedling understorey; vegetation abundance

Article History: Received 20 April 2022; Received in revised form 10 May 2022; Accepted 1 December 2022; Available online 30 December 2022. Ver: Pre-Press
How to Cite This Article: Rahmawati I, Sulistijorini S, Qayim I. 2022. Diversity of forest floor vegetation in Napabalano Nature Reserve and Warangga Protection Forest, Southeast Sulawesi. *Biogenesis: Jurnal Ilmiah Biologi*. vol 10(2): 144–154. doi: https://doi.org/10.24252/bio.v10i2.28578.

INTRODUCTION

Forests are the wealthiest biological community dominated by plants interacting with their environment (Naidu *et al.*, 2016). Forest vegetation has several ecological functions, such as preventing or minimizing erosion and landslides that can cause damage and tree roots part to hold soil particles to prevent attrition (Burylo *et al.*, 2012). There is ample evidence suggesting that plant communities within a forest community can positively impact forest ecosystem function and the provision of ecosystem services for humans (Hedwall *et al.*, 2012).

The positive impact of forests cannot be separated from the role of vegetation found on the forest floor. Forest floor vegetation is vegetation that lives under tree stands in the form of shrubs, herbs, ferns, and grasses. The amount of forest floor vegetation present in a community will positively impact the balance of the ecosystem on a broader scale (Purnomo *et al.*, 2016). One of the roles of floor vegetation is that it can be used as a predictor and indicator of soil quality, including fertility and soil stability (Aertsen *et al.*, 2012). The diversity and abundance of this vegetation cannot be separated from the influence of abiotic factors in the vicinity. These abiotic factors include edaphic and climatic factors (Bellard *et al.*, 2012; Zhong-hua *et al.*, 2013).

The Napabalano Nature Reserve and the Warangga Protection Forest are lowland secondary forest areas with 10.5 ha and 18.2 ha, respectively, located at an altitude of fewer than 100 meters above sea level. Although the heights of the Napabalano Nature Reserve and Warangga Protection Forest are relatively the same, due to differences in location factors where the Napabalano Nature Reserve is located close to the beach, and the Warangga Protection Forest is adjacent to water sources, this is thought to cause differences in the composition and diversity of vegetation on the forest floor. Comprehensive research on forest floor vegetation in the Napabalano Nature Reserve and Warangga Protection Forest has never been conducted, so this research needs to be carried out as a first step to support community and government efforts in forest rehabilitation and restoration. This study aimed to identify the diversity of forest floor vegetation species in the Napabalano Nature Reserve and Warangga Protection Forest, to analyze the differences in species composition and diversity of forest floor vegetation, and to analyze environmental factors that influence the differences in the composition and diversity of forest floor vegetation species in the Napabalano Nature Reserve and the Warangga Nature Reserve Protection Forest.

MATERIALS AND METHODS

Study area. The study was conducted from November 2020 to March 2021. The study was conducted in the Napabalano Nature Reserve area, which administratively includes the Napabalano Village area, Napabalano District, and Warangga Protection Forest, which administratively includes the Mangga Kuning village area, Katobu District, Muna Regency, Southeast Sulawesi.

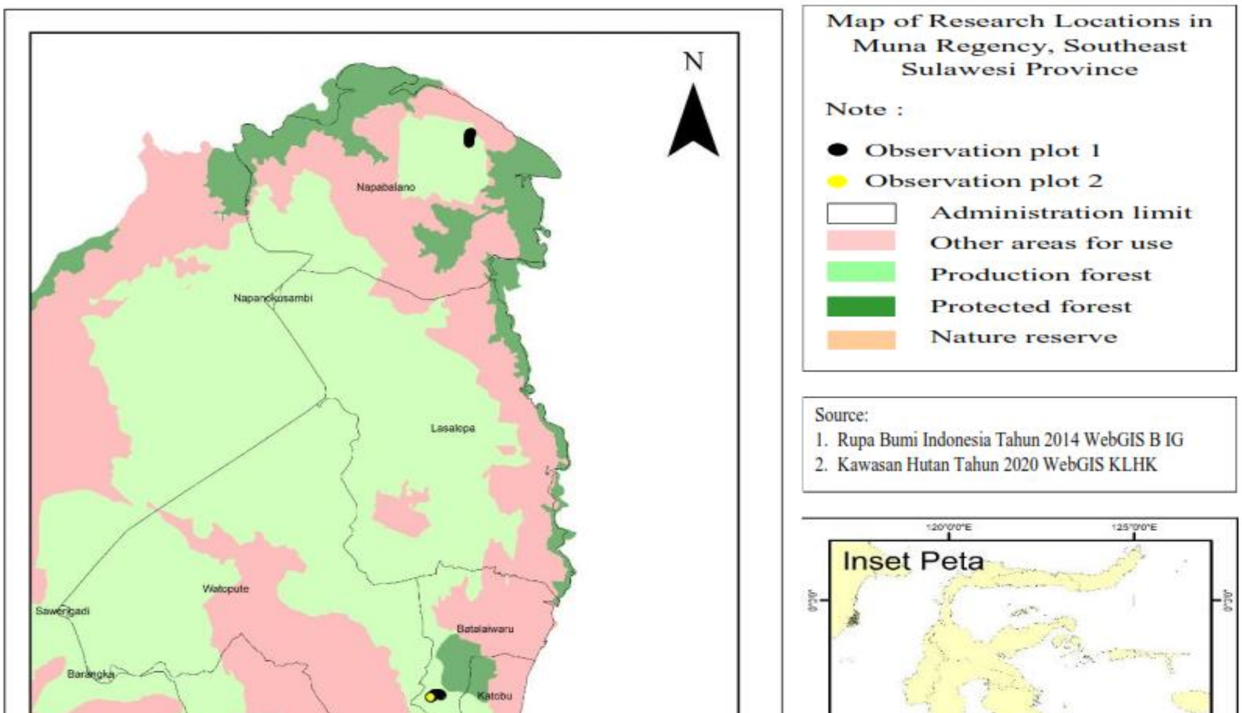

Fig. 1. Research locations for Napabalano Nature Reserves (black dots) and Warangga Protection Forest (yellow dots)

Sampling procedure. Vegetation species data collection was carried out using the stratified quadratic method (Destaranti *et al*., 2017). The sampling location was determined by purposive sampling based on field conditions. The number of observation plots at each location is 15 plots with a plot area of 20 m × 20 m. The distance between plots at each research location is 20 m. The plot area of 20 m × 20 m is the area for observing tree-level vegetation. In the 20 m × 20 m plot, there are 10 m × 10 m sub-plots for observing the pole phase, 5 m × 5 m for the sapling phase, and 2 m x 2 m for the seedling and understorey phases (Andewi *et al*., 2015). Pole and tree phase data collection was used as supporting data to observe the percentage of canopy cover.

Environmental factors such as temperature, humidity, and light intensity were measured using a hygrometer and a lux meter. Data on the percentage of tree canopy cover was measured using a canopy covering free application. The climatic factor data obtained were also compared with the data available on Accuweather. In addition, forest floor vegetation, including the seedling and understorey phases, was recorded with the names and number of species.

Data analysis. Data on the abundance of forest floor vegetation types was obtained by calculating the important value index (IVI) to determine the dominant vegetation type. IVI is the cumulative relative density (KR) and relative frequency (FR) value. Several other indices to describe forest floor vegetation include the Shannon-Wiener diversity index (H'), evenness index (E), dominance index (C), and species similarity index (Is). The calculation of the values of these indices refers to Magurran (2004). Environmental data obtained from each sample plot were analyzed using Canonical Correspondence Analysis (CCA) with the CANOCO program, a multivariate analysis method to determine the effect of environmental factors on the abundance of forest floor vegetation at the study site (Adel *et al*., 2014).

RESULTS AND DISCUSSION

Forest floor vegetation composition. In the Napabalano Nature Reserve there are 41 species of forest floor vegetation from 33 families, with a total number of individuals totaling 568 individuals (Table 4.1). The total number of individuals found in this nature reserve area is 41 species, with the composition of the forest floor vegetation which includes 18 species at the seedling level and 23 species including understorey. In addition, in the Warangga Protection Forest the number of forest floor vegetation species found was relatively higher, namely as many as 57 species from 36 families with a total number of individuals of 1290 individuals (Table 4.2). The composition of the forest floor vegetation species found in the Warangga Protection Forest includes 22 species at the seedling level and 35 species belonging to the understorey category. At this location, the family with the highest number of species is the Fabaceae family, which is 6 species with 33 individuals. Local people use this Fabaceae species as building materials, food, ornamental plants, and animal feed. Examples of species that can be used are *Albizia saman* (Jacq.) Merr., *Adenanthera* sp., *Mimosa pudica* L., *Senna siamea* (Lam)., *Macroptilium atropurpureum* (Dc.) Urb., and *Caesalpinia* sp. In addition, many foreign species are also used by local people, such as *Lantana camara* L. and *Chromolaena odorata* (L.) R.M. King & H.E. Robins are included in the families Verbenaceae and Asteraceae. Both species can be used as ingredients for medicines for internal and external diseases.

One of the causes of differences in the diversity and composition of vegetation on the forest floor is the variation in environmental factors. Factors that affect the diversity of vegetation on the forest floor include soil organic matter, soil pH, temperature, light intensity, air humidity, and soil moisture (Wijana, 2014). The percentage of tree canopy cover also affects the diversity, composition, and abundance of vegetation on the forest floor. The abundance of vegetation under tree shade will be less than without shade, even though the presence of shade can reduce the negative impacts of climate change (Valladares *et al.*, 2016). In the two research locations, most of the forest floor vegetation species were found clustered in unshaded areas. Most of the forest floor vegetation found in this study is a species that requires a lot of light to support its growth and distribution. One of the causes of the distribution pattern of plants tends to be in clusters because the seeds are usually ripe and fall close to the source plants (Wijana *et al.*, 2020). Soil physical and chemical factors also affect the diversity of vegetation on the forest floor. Soil properties, which include physical properties (soil texture) and soil chemistry (nutrients), are key factors that influence the distribution of shrub and herbaceous diversity (Li *et al.*, 2018).

In addition, the low canopy cover at the two study sites led to the growth of pioneer species such as *Mallotus* sp and *Macaranga* species (Rahayu *et al.*, 2017). The percentage of canopy cover in the Napabalano Nature Reserve ranged from 23.3% to 45.5%, while in the Warangga Protection Forest, it ranged from 10.2% to 54.2%. If the average percentage of canopy cover ranges from 25%-40%, the canopy cover is included in the open category (Stephens *et al.*, 2016). The pioneers who were also present at the two research sites were *Mallotus philippinensis* Mull. Arg., *Macaranga mappa*

(L.) Muell. Arg., and *Macaranga hispida* (Blume) Müll.Arg. *Macaranga* and *Mallotus* are plants that are commonly found in secondary forests and act as indicators of disturbance in a forest area (Zixi *et al.,* 2016; Yamasaki & Sakai, 2013). This statement is in accordance with the condition of the two research sites, which are secondary forests that have previously been damaged, such as logging, fires, and conversion of land to plantation land.

Important value index. The Important Value Index (IVI) is an index that describes the dominant vegetation type or species that has the highest control of species in a forest community. Table 1 shows several types of forest floor vegetation found at the two research sites. There were two species with the highest INP values at each study site. Species dominate Napabalano Nature Reserve with seedling habitus, such as *Ardisia sanguinolenta* species, with the highest IVI value of 40.93%, and *Leea indica* at 22.38%. In comparison, the Warangga Protection Forest is dominated by *Oplismenus undulatifolius* species with the highest IVI value of 54.71% and *Chromoalena odorata* with the second-highest INP value, which is 13.33% (Table 1). The high value of IVI in *O. undulatifolius* and *C. odorata* is because these two species dominate more than the other species. When viewed from the generative organs, what causes these two species to dominate is the size and shape of the seeds, which are very small and light, making it easier for these two species to spread quickly, for example, through the help of the wind (Rathnayake & Wijetung, 2016; Kepner & Beauchamp, 2020). *O. undulatifolius* can quickly invade forests via stolons, and animals can also mediate its spread by attaching to the outside of the animal's body (Novac *et al.,* 2020). In the *C. odorata*, the seeds have a hairy structure so that the seeds can easily stick to clothing and skin, thus helping the spread of this species. *C. odorata* flowers have a greater amount of nectar than other flowers, so they attract many insects, and the shape of the stigmas creates a good landing process for many insects so that the movement of insects from flower to flower is easier and more efficient (Rathnayake & Wijetung, 2016).

Table 1. Important value index of dominant species of forest floor vegetation in Napabalano Nature Reserve and Warangga Protection Forest

Species Name	Family	RD (%)	RF (%)	RDom (%)	IVI (%)
Napabalano Nature Reserve					
Ardisia sanguinolenta Roxb.	Primulaceae	34.70	7.14	-	40.93
Leea indica (Burm.f.) Merr.	Vitaceae	13.77	8.03	-	22.38
Leea aequata L.	Vitaceae	6.51	5.93	-	12.44
Gaultheria procumbens L.	Ericaceae	5.63	5.93	-	11.56
Warangga Protection Forest					
Oplismenus undulatifolius (Ard.) Roem. & Schult.	Poaceae	47.87	6.94	-	54.71
Chromolaena odorata (L.) R.M. King & H.E. Robins	Asteraceae	7.20	6.25	-	13.33
Lantana camara L.	Verbenaceae	4.81	5.44	-	10.25
Dioscorea hispida Dennst.	Discoreaceae	1.94	6.12	-	8.06

Note: RD = relative density, RF = relative frequency, RDom = relative dominance, IVI = important value index

The dominance of *Ardisia sangunolenta* (Primulaceae) and *Leea indica* (Vitaceae) species in the Napabalano Nature Reserve is due to forest conditions with low canopy cover (Fig. 2). Species *A. sanguinolenta* and *L. indica* are mostly found in disturbed and open forests (Mishra *et al.,* 2016; Tokuoka *et al.,* 2015). *Ardisia* has a more dominant habitat control than other species, with an IVI value of 40.93%. This is presumably because this species has a relatively faster growth. Forest conditions with leaf litter, abundant sunlight, and windy conditions are very favorable for the growth of Ardisia roots (Kai *et al.,* 2013). Another factor that plays a role in the dominance of these two species is the edible fruit, which helps in seed dispersal. In one *Ardisia* and *Leea* individual, there are lots of small fruits. Because the fruit is small and edible, it can provide food for seed-dispersing birds and other wildlife (Zeng *et al.,* 2012; Manchester *et al.,* 2012). As seed dispersers, fruit-eating birds or herbivorous animals can expand the scope of biotic spread in a plant species (Hu *et al.,* 2022).

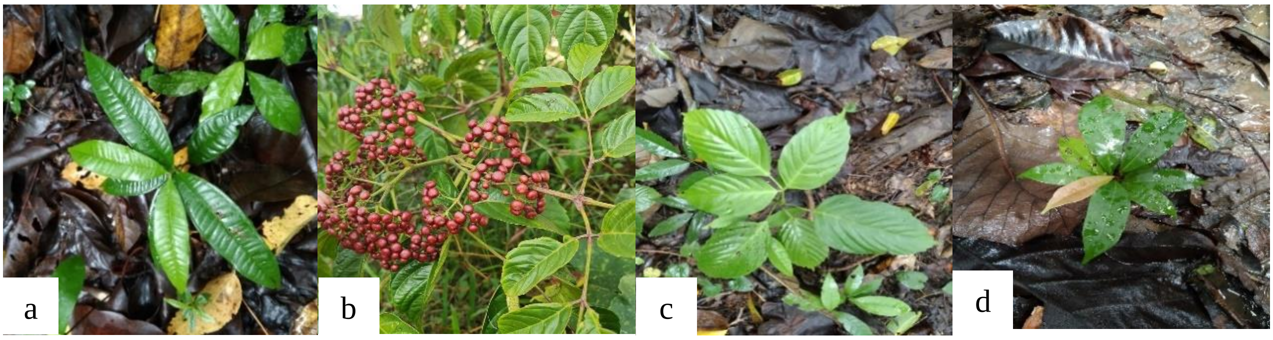

Fig.2. The species of vegetation on the forest floor in Napabalano Nature Reserve with the highest IVI value: a. *Ardisia sanguinolenta,* b. *Leea indica,* c. *Leea aequata,* d. *Gaultheria procumbens*.

In addition, in the Warangga Protection Forest, many *O. undulatifolius* and *C. odorata* species (Fig. 3) were found with IVI values of 54.71% and 13.33% (Table 1). These species are invasive species that can spread rapidly (Bowen *et al.,* 2020; Omokhua *et al.*, 2016). The mechanism for spreading several invasive species, such as *C. odorata* and *L. camara*, in the Warangga Protected Forest, in general, is with the help of wind, animals, and humans. However, spreading by wind is relatively more accessible because it spreads in all directions, from the highest to the lowest. The distribution of *L. camara*, besides being assisted by the wind, water, is also assisted by animals, especially birds and mammals. It has fertile seeds, so it can grow fast and is multiplicative (Ramaswami *et al.,* 2014). For other invasive species, such as *O. undulatifolius,* the mechanism of its spread is not only through the help of the wind but also by using stolons. Stolons and rhizomes are means of asexual reproduction, enabling plants to effectively produce large numbers of clones (Guo *et al.,* 2019). The presence of invasive species can reduce the abundance of vegetation. According to Kepner & Beauchamp (2020), areas invaded by *O. undulatifolius* and other invasive species usually have low species richness. Although the abundance of individual forest floor vegetation types in the Warangga Forest is low, the number of vegetation types in this area tends to be higher. In the Warangga Protection Forest, there are tree canopies that can filter light so that it does not fall directly onto the forest floor. Most of the species *O. undulatifolius* and *C. odorata* did not invade observation plots with a dense canopy and low light intensity (Beauchamp *et al.*, 2013; Nath *et al.*, 2019). This condition is in accordance with where this species is found in large numbers in the research location of the Warangga Protection Forest, with shading conditions varying between 10.2% to 54.2% (classified as low). Another factor that causes the number of species in the Warangga Protection Forest Area to be more diverse is its location close to springs. The soil around water sources is usually always moist due to the presence of *Ficus* species, whose roots are thought to have the ability to absorb and store large amounts of water at night and spread to the soil surface the next day so that the soil becomes moist and fertile (Ridwan & Pamungkas, 2015; Ulfah *et al.*, 2015). *Ficus* found in the Warangga Protection Forest include *Ficus Sumatrana* Miq., *Ficus simplicissima* Lour., *Ficus hispida* Linn., and *Ficus racemose* Linn.

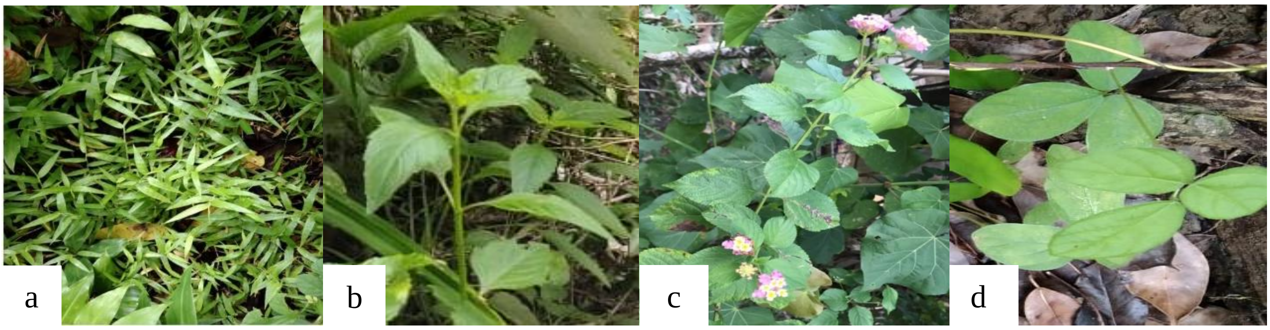

Fig. 3. The species of vegetation on the forest floor in Warangga Protection Forest with the highest IVI value: a. *Oplismenus undulatifolius*, b. *Chromolaena odorata*, c. *Lantana camara*, d. *Dioscorea hispida*

Diversity Index (H'), Evenness Index (E) and Dominance (C). In general, the diversity and evenness index of forest floor vegetation types at the two research sites is low, with the diversity index value ranging between 1.63 and 1.48, while the evenness index at the two research sites is included in the high category, ranging between 0.82 and 0.66. In addition, the species dominance index at both locations was included in the low category, namely 0.27 and 0.35 (Fig. 4 and 5).

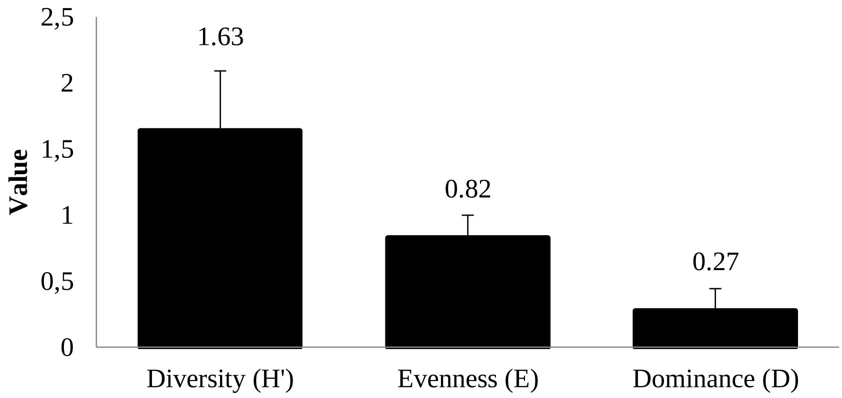

Fig. 4. Average index of diversity, evenness and dominance of forest floor vegetation in Napabalano Nature Reserve (± SE = standard error)

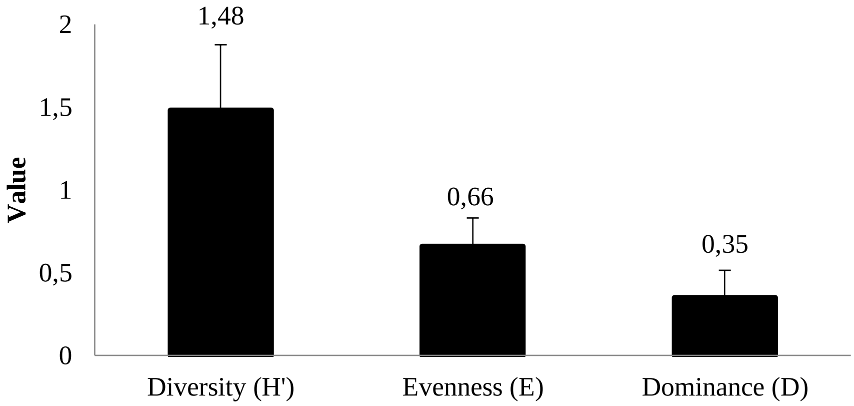

Fig. 5. Average index of diversity, evenness and dominance of forest floor vegetation in the Warangga Protection Forest (± SE = standard error)

The diversity index is an index that functions to calculate the level of diversity of vegetation types to illustrate the stability of a forest community. The diversity index of forest floor vegetation types at the two research sites was low, with a diversity index value of < 2 (Magurran, 2004). Mathematically, the diversity index value in the Warangga Protected Forest is lower than the Napabalano Nature Reserve even though the number of plant species in the Warangga Protection Forest is more. The low diversity index value is caused by the dominance of a species with a disproportionate number of individuals (Morris *et al.*, 2014). Species with an unbalanced or excessive number of individuals will reduce the value of the diversity and evenness index of vegetation types.

Based on the evenness value data obtained, it can be seen that the evenness value in the Napabalano Nature Reserve is classified as high or even, namely 0.82 or close to 1. This is due to the proportional distribution of the number of individuals of all species in each observation plot. Based on Krebs (1972), if the evenness index value is close to 1, then the distribution of the plant community is more even, whereas if the index value is close to 0 (zero), then the distribution of the plant community can be said to be more uneven.

The dominance values in both research locations are relatively the same and are included in the low category. However, mathematically, the dominance value in the Warangga Protected Forest is higher than the Napabalano Nature Reserve. This condition indicates that the dominance tends to be concentrated in one or fewer species (Nuraina, 2018). The species that dominate the area is the species *Oplismenus undulatifolius*. A low level of dominance indicates that no species as a whole dominates an area (Febriana *et al.*, 2020).

The species similarity index is needed to determine the similarity of plant species in the two forest communities being compared. Therefore, the size of the similarity index value can describe the level of similarity of vegetation species in two different forest communities. The index value of the similarity of forest floor vegetation species at the two research locations was 22.45%. This value can explain that the species composition at the two locations is not the same (different). This difference is caused by variations in environmental factors, both climatic factors and physical and chemical soil factors along the observed gradient.

The effect of environmental factors on the abundance of forest floor vegetation. The results of the CCA analysis show that each environmental parameter influences the abundance and distribution of forest floor vegetation (Fig. 6 and 7). The biplot analysis of the Napabalano Nature Reserve CCA shows that axis 1 explains 14% of the diversity. In comparison, axis 2 explains 24.3% of the diversity, so the CCA biplot analysis demonstrates 38.3% of the overall diversity of environmental factors. In addition, the results of the CCA analysis in the Warangga Protection Forest on axis 1 explain 16.8% of diversity. In comparison, axis 2 explains 26.4% of diversity, so the overall value of the diversity of environmental factors through CCA biplot analysis is 43.2%. The results of the CCA biplot analysis in the Warangga Protection Forest were higher than the Napabalano Nature Reserve with a value of 43.2% diversity, so from this, it can be explained that the biplot model in the Warangga Protection Forest is excellent or able to represent the conditions being modelled.

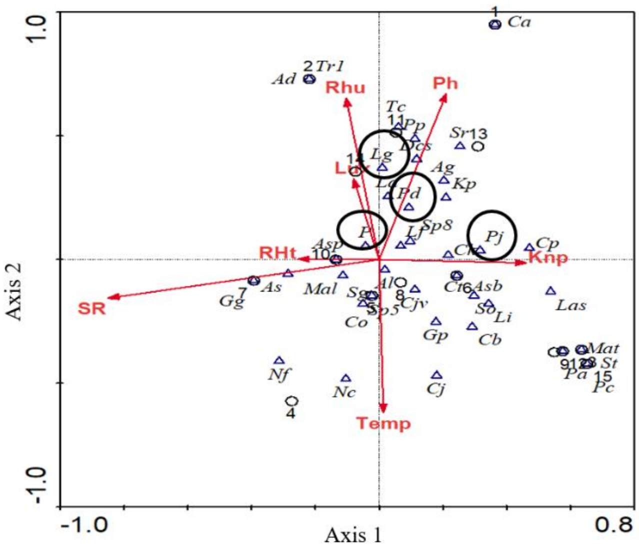

Fig. 6. Results of CCA analysis in the Napabalano Nature Reserve. Lg: *Lapotherum gracile*, Pj: *Pterospermum javanicum*, Pd: *Pterospermum diversifolium*, P: Piperaceae, SR: Litter, Rhu: Humidity, RHt: Soil Moisture, Lux: Light Intensity, Temp: Temperature, Knp: Canopy, pH: Soil pH

Although the two research locations are in the same relatively high altitude range, these results illustrate differences in variations in environmental factors at the two locations. Environmental factors can affect the diversity, composition, abundance, and distribution of forest floor vegetation. Results of the CCA analysis in the Napabalano Nature Reserve show that the vectors representing vegetation are mostly clustered close to environmental factors, which include light intensity (Lux), humidity (RHU), pH, and canopy (Fig. 6). This indicates that these factors are the most influential in the abundance of forest floor vegetation. Several types of forest floor vegetation influenced by these factors are *Lapotherum gracile* Brong. (Lg), whose presence is affected by air humidity. The specific characteristic of the Poaceae family is its need for high sunlight and low humidity to support its growth. According to Zhou *et al.*, (2016), *L. gracile* grows in groups under tree crowns with large gaps with low humidity. There is also *Pterospermum diversifolium* Blume. (Pd) species that are influenced by soil pH and *Pterospermum javanicum* Jungh. (Pj) is influenced by the presence or absence of a canopy (shade). Soil pH in the Napabalano Nature Reserve tends to be neutral, with a pH value of 7.43, making it ideal for forest floor vegetation growth. In their research, Xu *et al.*, (2014) stated that the pH range between 6 and 7.5 is optimum for producing good phosphorus (P) for plant growth. In addition, the development and reproduction of *P. javanicum* (Pj) species are faster in open forest areas with a low percentage of canopy cover (Hidayat, 2014). Other species, such as species belonging to the Piperaceae family, are affected by light intensity. The growth of the *Piper aduncum* L. species was fast.

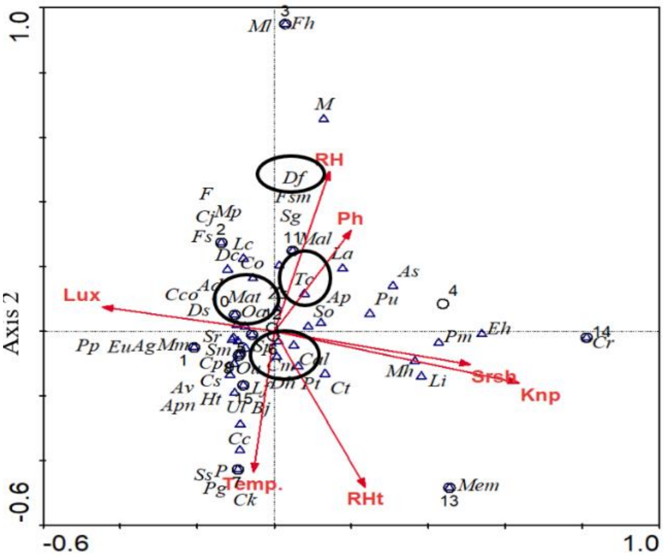

Fig. 7. The results of the CCA analysis of the Warangga Protection Forest. Tc: *Tetracera* sp, Mat*: Macroptilium atropurpureum*, Cm: *Caryota mitis*, Df: *Dropteris filix*, SR: Litter, Rhu: Humidity, RHt: Soil moisture, Lux: Light intensity, Temp: Temperature, Knp: canopy, pH: pH soil

The results of CCA analysis in Warangga Protection Forest show that the factors of temperature, light intensity, humidity, and pH tend to strongly influence the abundance of forest floor vegetation. This can be seen clearly from the number of plant species clustered close to the factoring line (Fig.7). Several species are affected by these environmental factors, including *Caryota mitis* Lour., which is affected by temperature. *C. mitis* was mostly found in shady stations because it was protected by tree canopy (Chairunnisa *et al.*, 2018). The air temperature under the tree canopy located in the forest of the Osaka Prefectural University Campus during the day decreased by about 1ºC more than in a sunny open space. This is because the decrease in air temperature correlates with the leaf area index, which is related to the reduction in the intensity of sunlight falling on the forest floor surface (Yoshida *et al.*, 2015). *Dryopteris filix* L. species are also affected by air humidity (RH). Based on direct observations of Brunet *et al.*, (2021), in the forests of Skbersjo and Torup, the genus Dryopteris is mostly found in plots with low humidity. In addition, there is a species of *Tetracera* sp. correlated or affected by soil pH. In forest ecosystems, soil pH is very influential on the biogeochemical process of the soil, which is a process that determines soil fertility and will affect the abundance of vegetation types (Neina, 2019). Another species that correlate with environmental factors is *Macroptilium atropurpureum* siratro (Dc.) Urb. which is a species that is affected by light intensity. Research by Costa *et al.*, (2020) showed that 70% shade is ideal for the growth of this species compared to full sun. However, in Warangga Forest, this species is also widely distributed in areas exposed to direct sunlight, but in relatively small numbers.

CONCLUSION

The dominant species that make up the vegetation in Napabalano Nature Reserve include *Ardisia sanguinolenta* and *Leea indica*, while the highest dominant species in Warangga Protection Forest include *Chromolaena odorata* and *Oplismenus undulatifolius*. The forest floor vegetation in the Napabalano Nature Reserve consists of 41 species, with 23 species including understorey and 18 species belonging to the seedling level, while in Warangga Forest, about 57 species including 35 species understorey, and 22 species of the seedling growth stage. According to CCA analysis, light intensity, humidity, soil pH, and canopy cover (shade) are the environmental factors that have the most impact on the diversity and composition of forest floor vegetation in Napabalano Nature Reserve, while light intensity, humidity, soil pH, and temperature have the most influence in Warangga Protection Forest.

ACKNOWLEDGEMENTS

We thank the Napabalano Nature Reserve, Warangga Protection Forest, IPB University for the research supporting and the cooperation.

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