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# Conservation of *Diospyros* spp. in Purwodadi Botanic Garden, Indonesia with an outlook on carbon storage

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**Abstract.** Plant conservation was widely implemented to mitigate the global risk of high gas emissions with an important carbon capture ability in this industrial era. Therefore, recognizing and understanding plant species richness could contribute to various environmental problems in the future. Since 1955, Purwodadi Botanic Garden-LIPI (PBG), Indonesia, has been collecting *Diospyros* spp. (*Ebenaceae*). The purpose of this study were 1) to record the *Diospyros* spp. collection including endemic species and determine the taxonomical status of unidentified plants, and 2) discuss the carbon storage of *Diospyros* species. The study was conducted from May 2016 to February 2020. The method used in this study was morphological characterization to record plant collection, taxonomical literatures and herbarium specimens. Biomass was measured using non-destructive method. Plant reidentification resulted in 28 species with 6 new identified plant species i.e. *D. pilosanthera* var. *Polyalthioides*, *D. perfida*, *D. diepenhorstii*, *D. amboinensis*, *D. greshoffiana* and *D. pilosanthera*. Only 0.07 % of the total recorded endemic and threatened species in Indonesia are collected in PBG. *Diospyros* species showed high biomass and could be promoted in revegetation programs based on carbon storage potentials. Conserving *Diospyros* is important for climate change mitigation success by implementing plant diversity for carbon capture.

## 1. Introduction

*Diospyros* (*Ebenaceae*) is a plant group that covers important species of ebony and persimmons. It has more than 500 species worldwide with great morphological diversity across Indo-Pacific region [1][2]. It is a dioecious, medium-sized tree, rarely shrubs, mostly black and hard bole [3][4]. *Diospyros* spp. are distributed mainly in lowland tropics area with relatively wet climate to semi-dry climates, such as tropical rain forest and dipterocarp forest. In Malesian region, more than 170 species are described and revised. Most of them are distributed in Borneo with high diversity and endemism [3][4][5]. In Indonesia, *Diospyros* are widely known as Ebony or “kayu hitam” because of its high wood quality. Many pharmacological studies reported that many species of *Diospyros* shows the effects on medicinal benefits such as antioxidant [6], antimicrobial [1] and antihyperglycemic [7]. *D. kakii* and *D. discolor* has edible fruits, while *D. celebica* and *D. ebenum* are important timber commodities. Because of high demand for its wood product, the population of *D. celebica* decrease significantly in its natural habitat which leads it categorized as Vulnerable (Vu) by IUCN and listed in Appendix II CITES.

Conserving plants was widely implemented in the global risk mitigation of high gas emissions by plant species' ability in carbon capture and storage [8]. Greenhouse gas emissions could be reduced by preventing forest destruction and restoring degraded areas through tree planting and ecosystem



restoration [9]. Furthermore, recognizing and understanding plant species richness could contribute to various environmental problems in the future.

Botanic garden is one of institution which developing plant conservation, research, tourism and botanic educations. Botanic garden displays plant species as a unit of ecosystems, which serving as repositories of plant materials for species reintroduction or land revegetations [10][11]. Purwodadi Botanic Garden (PBG), known as “Hortus Botanicus Purwodadiensis,” is an ex-situ conservation institution designated to conserve plant species from lowland habitats. It was built in 1941 by a Dutch botanist, L.G.M. Baas Becking and was located in Pasuruan, East Java, at 300 meters above sea level (masl) with an area of 85 hectares.

*Diospyros* is a valuable and interesting collection in Indonesian Botanic Gardens because it is an important component of tropical lowland habitats. To increase *Diospyros* conservation's effectiveness, it is necessary to conduct a research on plant collections in botanic gardens. We conduct a study to record plant species of *Diospyros* spp. in PBG, determine the taxonomical status of unidentified plant collections and propose new collections addition.

## 2. Materials and method

### 2.1. Plant materials

Plant specimens used in this study were plant collection of *Diospyros* spp. (Ebenaceae) in Purwodadi Botanic Garden, Research Center for Plant Conservation and Botanic Gardens (Indonesian Institute of Sciences), Pasuruan, East Java, Indonesia.

### 2.2. Method

**2.2.1. Plant identification.** This study was conducted from May 2016 to February 2020. Plant collection catalog of PBG from 1955 to 2019 was used to record the species identity, origin of plant collections and the number of specimens. Species identifications were conducted by describing the morphological characters, including plant habit, stems, branches, leaves, inflorescences, male and female flowers, fruits and fruit calyx, using the descriptions by Bakhuizen [3][4], Soepadmo *et al.* [12] and herbarium collection in BO (Herbarium Bogoriense). To record the endemic species among plant collections, the literature study was conducted based on Bakhuizen [3][4].

**2.2.2. Biomass measurements.** Biomass was measured using an allometric method estimated from stem diameter at breast height of adult trees so-called DBH and trees height. Three replications were used in the measurement for *D. discolor*. Biomass was obtained by calculating using the formula of biomass [13] as follows:

$$\text{Biomass (kg)} = 0.122 (\text{rD}^2\text{H})^{0.916} \quad (1)$$

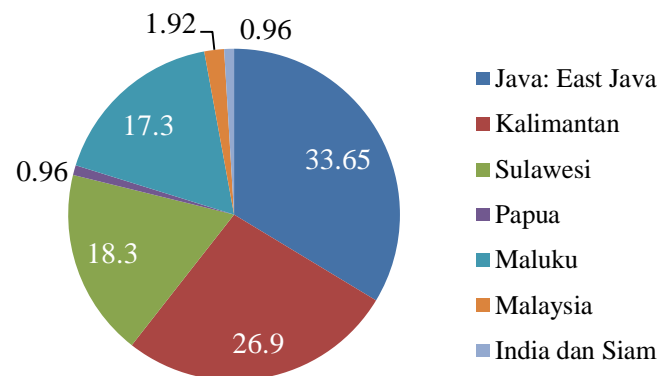
Where  $r$  = wood density;  $D$  = diameter (cm), and;  $H$  = plant height (m)

Comparison of biomass between *Diospyros* species and other plant species was conducted through literature study with similar measurements method and plant size (stem mass, in Kg/ha).

## 3. Result and discussion

### 3.1. Collection of *diospyros* spp.

Plant collection of *Diospyros* spp. consisted of 28 species, mostly collected from Java, with 33.65% (Figure 1). The specimens that originated from Kalimantan were in second place, with percentage of 26.9%. While the specimens from Maluku and Sulawesi were 17.3% and 18.3%, respectively. Less than 1% of specimens were collected from Papua. Only 2.88% of plant collections were obtained from other countries (Malaysia 1.92%, India and Siam 0.96%).



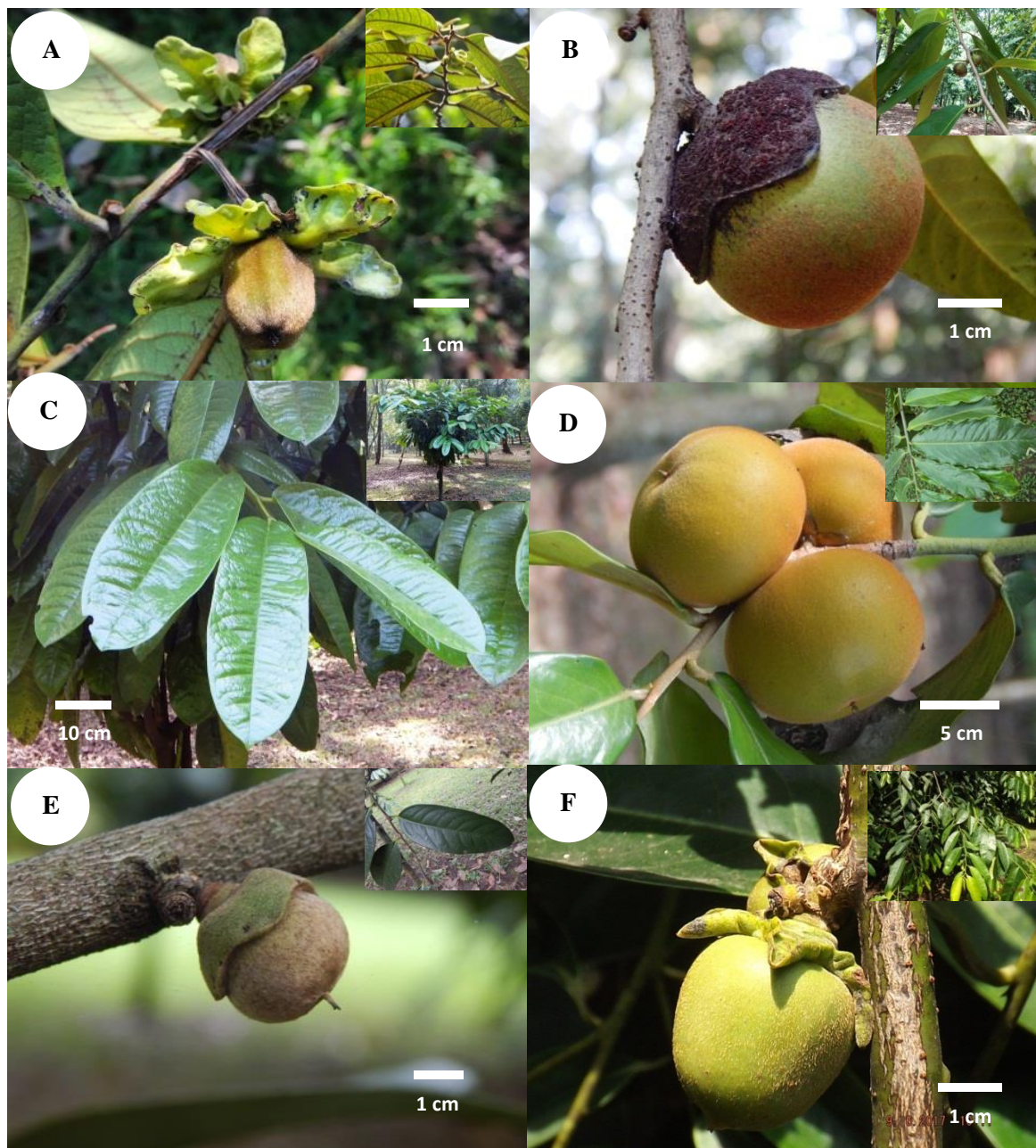
**Figure 1.** Percentage (%) of *Diospyros* spp. based on the specimen origin.

### 3.2. Plant collection identification

**3.2.1. *Diospyros pilosanthera*.** Local name is “Kayu arang.” Synonym is *D. polyalthioides*, *D. plicata* Merr. and *D. cubica* Bakh. Tree to 35 m tall. Twigs slender, reddish-brown pubescent when young, drying greyish or blackish. Leaves chartaceous to coriaceous, bullate between veins, velvety yellow; oblong, elliptic, oblong-elliptic or oblong obovate, 7-25x2-9 cm, base cuneate, subcordate to slightly attenuate, margin entire, apex acute to acuminate, midrib sunken above, midrib prominent below with reddish densely pubescent, 10-17 pairs, inarching to form multiple anastomosing loops near leaf margin, intercostal venation prominent below and reticulate; petiole 0.5-1 cm long. Male inflorescence 1 cm long, each bearing 1-5. Female flowers with calyx divided into 4 valvate lobes, which large and plicate, wavy, yellow, much enlarge until 4 cm diam. Fruits 1-3, subsessile on 0.1-0.5 cm long stalks, green, globose to ovoid 2-2.5 cm diam, faintly vertically grooved, densely velvet when young, maturing velvety, apex blunt depressed with tips. Fruit calyx greatly accrescent; green, leafy, margin wavy, 4-5 lobes, lobes spreading and erect, 2 cm long, 1.5 wide, 2-3.5 cm diam., greatly enlarged until 4-6 cm diameter, veins faint. Distributions are in Peninsula Malaya, Sumatra, Java, Borneo to Philippines. Ecology is Hill's primary lowland forest under 1000 masl. It is valuable ebony. The fruits are edible. Variant of *polyalthioides* has larger fruit calyx than *D. pilosanthera* (enlarge until 6 cm in diameter with very wavy calyx lobes).

**3.2.2. *Diospyros perfida*.** Local name is “toeba api” (fish poison). Tree is tall to 25 meters. Twigs blackish and lenticellate. Leaves membranaceous, glabrous, oblong-elliptic, (7.5-)12-25x(2-)4.5-10 cm, base cuneate to slightly attenuate, margin entire, apex acuminate, midrib sunken above, bullate between veins, prominent below, drying blackish, lateral veins prominent below, 8-11 pairs, arching and diminishing toward leaf margin, intercostal venation prominulous below, petiole 1 cm. Male inflorescence 0.5-0.8 cm long, each with 3 crowded flowers. Male flowers with calyx divided into 4 imbricate rounded lobes; corolla salverform, c. 0.7 cm long. Female inflorescences c. 0.3 cm long, each bearing 1-3 flowers. Female flowers with calyx divided into 4 imbricate ovate lobes. Fruits usually solitary, on c. 0.5 cm long stalks, depressed globose, to c. 5 cm diameter, not grooved, symmetric, woody, finely velvety when young, becoming glabrous with age. Fruit calyx accrescent, rugose, woody, initially cup-shaped with 4-5 valvate rounded lobes tightly clasping the lower three-quarters of the fruit, then half as the fruit enlarges and finally a shallow tray when the fruit is fully grown; during the enlargement, the calyx lobes are stretched so that they look valvate in fruit; veins invisible. It is endemic in Borneo. Its ecology is in lowland mixed dipterocarp forest. It is used as fish poison. This species was easily recognized by its woody and cup-shaped fruit calyx which clasping the whole fruits and continuously shortens with age [14].





**Figure 2.** Six species of *Diospyros* spp. identified in PBG. A) *Diospyros pilosanthera* var. *Polyalthioides*. B) *Diospyros perfida* C) *Diospyros diepenhorstii* D) *Diospyros amboinensis* E) *Diospyros greshoffiana* F) *Diospyros pilosanthera*.

**3.2.3. *Diospyros diepenhorstii*.** It is found in Sumatra by H. Diepenhorst. Local name is “arang, buey” and synonym is *D. Pyrifer*. Tree 5 to 25 m tall, trunk straight, cylindric. Twigs brownish, glabrous, rugose, greeny when young. Leaves alternate, coriaceous, glabrous; oblong 13-55 x 4.5-17 cm, base rounded to subcordate, apex acute to acuminate; midrib sunken above, lateral veins prominent below, 8-15 pairs, arching and diminishing toward leaf margin; intercostal venation prominent below, laxly reticulate, petiole 0.5-2 cm long. Male inflorescence axiler or on branches, many flowers, female inflorescence on branches. Male flowers 1.5-1.65 cm long, yellowish-white to pinkish-white, outer corolla tube glabrous, apex inner curved, calyx and corolla glabrous to pubescent. Female flowers small, with calyx lobed 5-7, outer part is pubescence, inner side is glabrous. Fruits large, symmetric, obovate,

apex concave, glabrous, bright, 6-10 cm long, 5-6 cm diameter, vertically ribbed, soft and yellow when mature, edible. Fruit calyx slightly accrescent, bright green, glabrous, 1.25-1.7 cm diameter, apex obtuse to rounded, 2 cm diameter. Distribution is in Peninsula Malaya, Sumatra, Borneo to Philippines. Its ecology is in lowland and hill mixed dipterocarp to lower montane forest, 1800 masl. Its fully riped fruits are edible. It can be easily identified mainly from the habit and very large leaves. This specimen is a male plant with glabrous calyx and corolla. These characters are additional to the previous description by Bakhuizen [3], which only recorded a specimen with densely pubescent calyx and corolla.

**3.2.4. *Diospyros amboinensis*.** A medium-sized tree up to 10 m, bark brown to dark brown, vertically cracked. Twigs hairy when young, glabrous with age. Leaves alternate, coriaceous to membranaceous, oblong, oblong-elliptic, ovoid-obovate, 15-32 cm long, 10-15 cm wide, margin undulate, apex acute, basally truncate to subcordate, upper smooth, bullate between veins, hairy on below surface, veins 11-17 pairs, intercostal veins reticulate, arching and joining to form intramarginal veins-loops near leaf margin, petiole 0.5-1.5 cm, twisted, midrib not sunken above prominent below, drying blackish. Female flowers 1-3, yellowish-white with densely white to yellowish pubescent calyx and corolla, 4-5 lobes, corolla salverform, 1.2-1.5 cm long, lobes apex acute and spreading, petiole 0.2-0.4 cm. Fruit 1-3, large, depressed globose to globose, 7-9 cm long, 8-11 cm in diameter, greenish-yellow and velvety yellow silvery hairs when young, easily removed hairs; green, yellow to orange, glabrous when mature, surface smooth, petiole 0.5-1 cm, subsessile. Fruit calyx accrescent, 3 cm in diameter, divided into 4-triangular lobes, 1.5 cm long, red-brown velvety, thin and leafy, apex acute to acuminate. Seed many 7-8. Distribution is by Mollucas. Its ecology is in lowland forests. This study's female flower characters are added to the previous "unknown" characters [3].

**3.2.5. *Diospyros greshoffiana*.** S.H. Koorders described it from plant collection in Manado collected by M. Greshoff). A medium-sized tree, 15-32 m, bole straight, rigid, lenticellate. Twigs reddish pubescent, then glabrous, sparse lenticellate. Leaves alternate, membranaceous, petiolate, oblong-elliptic to oblong-lanceolate, base acute to obtuse-cuneate, apex obtuse-acuminate to obtuse, margin entire, 7-17 cm long, 3.5-5.5 cm wide, membranaceous, chartaceous to coriaceous, upper surface dark green, glabrous. Inflorescence axillary, cymose, reddish tomentose. Female inflorescence semi-pedunculate to subsessile, 1-5 flowers, reddish tomentose, and 0.5 cm long, which is at a depth of 0.3 cm wide. Female flowers 3-5 flowers, 4-5 –meri, white grayish, 0.6-0.8 cm long, tube with outer brownish pubescent, inner glabrous. Male flowers 1-5 flowers, 4-5-meri, tube with outer brownish pubescent 1.2-1.4 cm long, 0.4-0.5 cm diam., with calyx 0.8-0.9 cm long, lobe apex obtuse, green, reddish pubescent, 0.5-0.6 cm diam.. Fruits generally solitary, semi-pedunculate to subsessile, depressed globose with gray pubescent, 1.5-2 cm diam., 2-2.5 cm long. Fruit calyx flattened 4-5 lobes, 1-1.5 cm long, 1.5-2.5 cm diam., reddish or brown hairy on outer side, glabrous inner side, lobes ovate to triangular, narrowly marginate, lobes coriaceous. Distribution is in Celebes (Manado) and its ecology is in forest 500-700 masl. The entire leaf margin serves as additional characters that are not recorded before [3][4]. This species is close to *D. javanica*, with smaller and simpler fruit calyx.

**3.2.6. *Diospyros pilosanthera*.** Local name is "Kayu arang" and its synonym is *D. plicata* Merr., *D. cubica* Bakh. and *D. Helferi*. Tree to 35 m tall. Twigs slender, glabrous, drying greyish or blackish. Leaves coriaceous, not bullate between veins, glabrous, tends to dry black on both sides; elliptic, oblong-elliptic or oblong obovate with 5-25 cm long and 2.5-10 cm wide, base cuneate to subcordate, margin not undulate, apex acute to acuminate, midrib not sunken above, lateral veins slightly prominent below, 10-15 pairs, inarching faintly to form multiple anastomosing loops near leaf margin, intercostal venation not prominent below and reticulate; petiole 0.5-1.5 cm long. Male inflorescence 1 cm long, bearing 1-5. Female flowers calyx 4-5 valvate lobes, margin plicate, slightly wavy, enlarge until 1.5 cm long and 3 cm in diameter. Fruits 1-3, subsessile on 0.5 cm long stalks or shorter, globose 1.8-2.5 cm diam, not ribbed, yellowish pubescent when young, maturing hairy, apex acute. Fruit calyx slightly accrescent; green, lobes spreading, enlarged only to 2.5 cm diam., slightly wavy, veins faint. Distribution is in

Borneo and Sulawesi. Ecology is in Hill primary lowland forest under 1000 masl. It is valuable ebony with a hard and large stem. *D. pilosanthera* covers many variants with wavy fruit calyx. The degree of calyx wave is one of characters that determines the varieties. This specimen was described as *D. pilosanthera* because of simpler wavy calyx, distinguishing it from *D. pilosanthera* var. *Polyalthioides*.

**Table 1.** The list of endemic species of *Diospyros* spp. (Ebenaceae) in Indonesia.

Region	Number of Species	Species
Java	1	<i>Diospyros sundaica</i> Bakh.
Borneo	47	<i>Diospyros alatella</i> Konterm., <i>D. brainiana</i> , <i>D. britano-boornensis</i> , <i>D. clementium</i> Bakh., <i>D. cordata</i> , <i>D. crockerensis</i> , <i>D. densa</i> , <i>D. discocalyx</i> , <i>D. eucalyptifolia</i> , <i>D. euphlebia</i> , <i>D. ferox</i> , <i>D. fusiformis</i> , <i>D. graciliflora</i> , <i>D. hallieri</i> Bakh., <i>D. havilandii</i> Bakh., <i>D. keingauensis</i> Ng, <i>D. lunduensis</i> Ng, <i>D. muricata</i> Bakh., <i>D. neurosepala</i> Bakh., <i>D. oligantha</i> Merr., <i>D. parabuxifolia</i> Ng, <i>D. penibukanensis</i> Bakh., <i>D. plectosepala</i> Hiern, <i>D. puncticulosa</i> Bakh., <i>D. sulcata</i> Kosterm., <i>D. dajakensis</i> Bakh., <i>D. campanulata</i> Bakh., <i>D. soporifera</i> Bakh., <i>D. enderti</i> Bakh., <i>D. evena</i> Bakh., <i>D. elegantissima</i> Bakh., <i>D. paraoesi</i> Bakh., <i>D. tuberculata</i> Bakh., <i>D. poiensis</i> Bakh., <i>D. sororia</i> Bakh. spec. Nova, <i>D. durionoides</i> Bakh., <i>D. hackenbergii</i> Diels., <i>D. nemorosa</i> Bakh., <i>D. crassipes</i> Bakh., <i>D. sarawakana</i> Bakh., <i>D. bintulensis</i> Konterm., <i>D. cylindrocarpa</i> Kosterm., <i>D. gigantocarpa</i> Konterm., <i>D. longepedunculata</i> Kosterm., <i>D. nidus-avis</i> Kosterm., <i>D. pulchrinervia</i> Kosterm., <i>D. turfosa</i> Kosterm., <i>Diospyros minutiflora</i> Bakh., <i>D. brevicealyz</i> Boerl. Et Kds. Ex Kds, <i>D. bangkana</i> Bakh.
Sumatra	3	<i>Diospyros celebica</i> Bakh., <i>D. eburnea</i> Bakh., spec. Nova, <i>D. venenosa</i> Bakh., <i>D. greshoffiana</i> Kds. Ex Bakh., <i>D. rumphii</i> Bakh.
Celebes	5	<i>Diospyros schmutzii</i> Kosterm.,
Lesser Sunda (Flores Island)	1	<i>Diospyros amboinensis</i> Bakh., <i>D. rostrata</i> (Merr.) Bakh.
Ambon or mollucas	2	<i>Diospyros papuana</i> Bakh., <i>D. novoguineensis</i> Bakh., <i>D. sogoriensis</i> Bakh., <i>D. adiensis</i> Konterm., <i>D. aifatensis</i> Kosterm., <i>D. alpina</i> Konterm., <i>D. areolifolia</i> Kosterm., <i>D. benstonei</i> Kosterm., <i>D. malacothrix</i> Kosterm., <i>D. mollissima</i> Kosterm., <i>D. monticola</i> Kosterm., <i>D. sleumeri</i> Kosterm.
Papua	12	

### 3.3. Identification key

1. a. Fruits large 10 cm diam., green, glabrous, vertically grooved ..... 1. *D. diepenhorstii*
- b. Fruits large 10 cm diam., green yellowish, hairy, depressed globose, not grooved..... 2. *D. amboinensis*
2. a. Fruits large 5 cm diam fruits calyx clasping the whole fruits and shorten when mature ..... 3. *D. perfida*
- b. Fruits small 2 cm diam ..... (3)
3. a. Fruits calyx small and flat ..... 4. *D. gresshoffiana*
- b. Fruits calyx large and wavy ..... (4)
4. a. Fruit calyx small, slightly wavy, margin reflexed, green, hairy..... 5. *D. pilosanthera*
- b. Fruits calyx large, wavy, expanded 4-6 cm diam ..... 6. *D. pilosanthera* var. *Polyalthioides*

### 3.4. Conservation of endemic species

To improve the botanical value of plant collection, the knowledge of endemic and threatened species is important [11][15]. Indonesia has high diversity and endemism of *Diospyros* spp. (Ebenaceae) (Table

1). *D. sundaica* was reported to endemic to Java and Bali, while 3 species endemic to Sumatra. In Borneo, there are approximately 78 species and 42% (33 species) among them are endemic to Borneo, including the area of Borneo (Malaysia) [16]. While based on Bakhuizen [3][4], the total endemic species to Borneo is 47 species. Therefore Borneo is considered as the distribution center of *Diospyros* in Indonesia.

*Diospyros* of Eastern Indonesia (Celebes, Moluccas, Lesser Sunda Island and Papua) still lack investigation. There are 20 endemic species to this region. However, only three endemic species are collected by PBG (Table 2). Among many endemic species to Papua, none is collected by PBG.

**Table 2.** Endemic and threatened species of *Diospyros* spp. collected by PBG

No.	Species	Distribution	IUCN status
1.	<i>Diospyros celebica</i> Bakh.	Celebes	Vulnerable
2.	<i>Diospyros ferruginescens</i> Bakh.	Borneo	-
3.	<i>Diospyros amboinensis</i> Bakh.	Moluccas (Ambon)	-
4.	<i>Diospyros perfida</i> Bakh.	Borneo (South-East Borneo and Sabah)	-
5.	<i>Diospyros gresshofiana</i> Kds. Ex Bakh.	Celebes	-

Only five endemic species of *Diospyros* were collected in PBG (Table 2). It is 0.07% (5 out of 71 species) of the total endemic and threatened *Diospyros* species in Indonesia. The collection should be improved by adding plant species in the garden by conducting field study throughout conservation areas (protection forests or national parks). Because the planting area is very limited (85 hectares, with 11,000 plant specimens), the additional species could be collected in the regional botanic gardens, which are developed by Indonesian government in all provinces to conserve local plants from 47 ecoregions [8][13].

### 3.5. Biomass of *Diospyros* spp.

*Diospyros* spp. is an important plant group in tropics and temperate ecosystems that showed carbon storage ecological services. The biomass of *Diospyros discolor* (stem mass, in kg/ha) were compared among the species and other woody plant based on Okonkwo and Okonkwo [6], Maunier *et al.* [15], Ng [16], Rindyastuti [17] (Table 3).

**Table 3.** Comparison of biomass among woody plant species

No.	Species name	Family	Biomass (kg/Ha)
1.	<i>Diospyros discolor</i>	Ebenaceae	68.65
2.	<i>Diospyros mespiliformis</i>	Ebenaceae	356.6
3.	<i>Diospyros melanoxylon</i>	Ebenaceae	78.65
4.	<i>Diospyros montana</i>	Ebenaceae	8.91
5.	<i>Dillenia philippinensis</i>	Dilleniaceae	29.47
6.	<i>Dillenia serrata</i>	Dilleniaceae	8.58
7.	<i>Lagerstroemia parviflora</i>	Lythraceae	76.22
8.	<i>Dipterocarpus</i> sp.	Dipterocarpaceae	145,180

*D. discolor* has higher biomass than two species of *Dillenia*. Two species of *Diospyros* has relatively higher biomass than other species such as *Dillenia* spp. and *L. parviflora*, however has lower biomass compared to large tree species *Dipterocarpus* sp. In addition, *D. discolor* has high Relative Growth Rate (RGR) but low Specific Leaf Area (SLA) which indicate that this species store high carbon but have low competitiveness [18]. The biomass of *D. discolor* indicated that the genera could be promoted in revegetation programs based on their carbon storage, therefore conserving this plant group benefits in supporting climate change mitigation.



#### 4. Conclusion

This study recorded 28 species with 6 new identified species of *Diospyros* spp. in PBG, indicating the need for plant collection addition and planting in regional botanic gardens. The study results showed the importance of conserving *Diospyros* species for climate change mitigation by implementing plant-for-carbon storage to reduce pollutant risk by rehabilitating degraded areas.

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