INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE
ISSN: 2067-533X Volume 13, Issue 1, January-March 2022: 321-340 www.ijcs.ro

EX-SITU CONSERVATION OF FLORA SULAWESI IN INDONESIAN BOTANIC GARDENS

Mustaid SIREGAR[1,*], Agung KURNIAWAN[1], Hartutiningsih HARTUTININGSIH[1]

[1] Research Center for Plant Conservation and Botanic Gardens, National Research and Innovation Agency. Jalan. Ir. H. Juanda No. 13, Bogor, West Java, Indonesia, 16122

Abstract

Indonesian Botanic Gardens (IBGs) consist of forty-three gardens which represent distinct characteristic of Indonesian ecoregions. Thousands living collection native to Sulawesi are exist at IBGs. This study aims to reveal the Sulawesi's collections in IBGs and compared to vascular plants species across the island. The conservation status of those collections are also uncovered. Plant collections data are obtained from seven IBGs, namely Bogor Botanic Garden (BG), Purwodadi BG, Bali BG, Enrekang BG, Kendari BG, Parepare BG, and Pucak BG. A number of 1,561 species originated from Sulawesi (26,3% of total Sulawesi'species) are cultivated within seven IBGs. 1,477 species of which are angiosperms (27,7% of total Sulawesi's angiosperms), 67 species pteridophytes (12,1% of total Sulawesi's pteridophytes), and 17 species gymnosperms (34% of total Sulawesi's gymnosperms). Orchidaceae is the greatest angiosperms with 522 species. Dryopteridaceae and Polypodiaceae are the largest pteridophytes with eight species each. Podocarpaceae is the highest gymnosperms with five species. A quantity of 23 species of Sulawesi's collections is threatened with global extinction. Nine species of which already listed in IUCN red list as threatened plants of Sulawesi.

Keywords*: Indonesian botanic gardens; Vascular plant; Conservation status; Sulawesi*

Introduction

The pivotal role of botanic gardens (BGs) -as major center for the conservation of plant species diversity in *ex-situ* collections and environmental education- have meaningfully increased due to rapid global change, habitat degradation and loss of biodiversity in the last decade [1-6]. Aside from its importance scientific role, BG offers its collection and landscape as an attractive, entertaining, and enjoyable scenery to visit [2-8]. The existence of broad threats has enhanced the multiple functions of BG, for instance: research collaboration, seed banking, public awareness and engagement promotion, establishing partnerships or sponsors, improvement of daily operations as well as addressing social relevant [1, 2, 4, 7-14].

Nowadays, BGs are widely distributed around the globe, with at least one garden in each country. It exceeds 2,700 BGs worldwide, with many more under development [5, 15]. Currently, the global network Botanic Gardens Conservation International (BGCI) lists >3,600 botanical institution worldwide [16]. The global BGs maintain at least 30% of known plant species and over 41% of threatened species in the world [17]. Until 2019, Indonesian Botanic Gardens (IBGs) consists of five gardens managed by Indonesian Institutes of Sciences (LIPI) and 38 regional gardens organized by local government and universities, with at least 23 regional gardens are planned to be established in the near future [18].

* Corresponding author: mustaid_s@yahoo.co.id

Number of known plants species in the world is available on some references, however their estimated accounts differ. For examples, approximately 374,000 species [19], ca 435,000 species [20], and around 400,000 species [6]. Among plants species, ca 36,5% are suffered in rarity [20] and ca 40% of vascular plants are threatened with global extinction [21, 22]. Dissimilar number is happened to vascular plants as well, RBG Kew [23], estimated >390,000 species, *E. Nic Lughadha et al.* [24] ca 380,000 species, *M.J.M. Christenhusz and J.W. Byng* [19] ca 308,000 species. 95% of vascular plants are flowering plants [19; 23]. In addition, *D.J. Middleton et al.* [25] estimated 50,000 species of flowering plants distributed in Southeast Asia, while *A. Retnowati and Rugayah* [26] reported that known flowering plants in Indonesia are 24,632 species (10% of the world's total).

Recently, *A. Retnowati et al.* [27] reported 5,931 species of vascular plants originated from Sulawesi, Indonesia. The forest area of Sulawesi preserve unique tree floras and endemic species, however plethora of plant species remain to be discovered [28-30]. Nevertheless, many publications state that the detailed floras documentation from Sulawesi were still poorly unveiled [31-37]. The native plants species from Sulawesi have been existent in IBGs as collection for years. However, despite the clear number of known native plant species and the importance of its conservation, these native collection has not been documented as a whole, as an integrated data. Each BG manages its own plant collection data. Therefore, this study aims 1) to disclose living plant collections originated from Sulawesi in IBGs and compared to known vascular plants native across the island, 2) to expose the conservation status of the Sulawesi's collection in IBGs.

Experimental

Materials and Methods

This study was conducted by collected the data of plant collection native to Sulawesi which conserved in Indonesian Botanic Gardens IBGs). Sulawesi is one of the five major islands in Indonesia (Sumatra, Java, Kalimantan, Sulawesi and Papua). IBGs consists of national botanic gardens (BGs) managed by Indonesian Institutes of Sciences (now National Research and Innovation Agency) and regional gardens maintained by local governments or universities. These data were manually obtained from seven IBGs that one of the official tasks is conserving floras from Sulawesi. Three national BGs situated in Java and Bali, while four regional BGs located in Sulawesi. National BGs are Bogor Botanic Garden, Purwodadi Botanic Garden, and Bali Botanic Garden. Regional BGs are Enrekang Botanic Garden, Kendari Botanic Garden, Parepare Botanic Garden, and Pucak Botanic Garden. Each BGs holds different priorities on conservation target of plant collection based on its themes of collection and ecoregion compatibility [38, 39]. For example, Bogor BG is compatible with plant originated from wet lowland habitat while the regional BGs are expected to meet the categories of terrestrial ecoregion in Sulawesi.

The dataset is limited to species level. Once the datasets of plant collections are gathered and compiled, they are then merged and duplicates removed. Subsequently, the extracted data is enumerated to define the diversity of conserved plant species. Afterwards, the list divided based on informal groups and taxa to find detailed numbers. Each information then analysed, presented, and interpreted. All of these operations are performed using spreadsheet calculation. In terms of plant classification, some references are followed, i.e. *J.W. Byng et al.* [40] for angiosperms, *E. Schuettpelz et al.* [41] for pteridophytes, and *M.J.M. Christenhusz et al.* [42] for gymnosperms. Whereas the plant species names refer to online database such as: An Online Flora of All Known Plants [43], International Plant Name Index (IPNI, https://www.ipni.org/), and Plants of the World online [44].

Lastly, the conservation status of plant collections are also checked and compared to known plant species of Sulawesi based on categories of the IUCN Red List of Threatened

Species. IUCN defines the extinction risk of species assessed onto nine categories, from Not Evaluated (NE) to Extinct (EX). Here, we use only three official categories which describing the species threatened with global extinction, namely Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) [45].

Results and discussion

Recent Diversity of Sulawesi Floras

Sulawesi is a center of Southeast Asia's (SE Asia) ecoregion [46] and notable endemism in the Wallacea region [47] which is one of 'biodiversity hotspot' on Earth [48]. This island is gifted a highly endemic and unique biota that resulted from a complex geological and historical tectonic process as well as isolated from surrounding continent for ages [35, 36, 47, 49-54]. It is fortunate that forested areas of Sulawesi mostly located in extreme terrains or montane slopes. Broadly speaking, *in situ*-conservation areas are situated in the middle of this island [55] and rare plants species tend to be clustered in mountainous areas [20]. In addition, the effects of maximum isolation and moisture as well as a vast regional orogeny have successfully preserved the local biodiversity richness in SE Asia [56].

Since *M. Ardiyani et al.* [57], who summarized 540 novel species of flowering plants and pteridophytes as valuable addition to Indonesian native plant species, various novelties and new records of plant species from Sulawesi are continually described. For instances, *Aglaomorpha* (Polypodiaceae) in *S. Lindsay et al.* [58]; Bamboos in *D. Ervianti et al.* [59]; *Begonias* in *W.H. Ardi and D.C. Thomas* [60, 61], *D.C. Thomas et al.* [62], *D.C. Thomas and W.H. Ardi* [63]; *Cratoxylum* (Hypericaceae) in *W.H. Mustaqim and D.S. Amboupe* [64]; *Cyatheaceae in E.P. Coritico et al.* [65]; *Cyrtandras* (Gesneriaceae) in *A. Kartonegoro et al.* [66]; *Dicksonias* (Dicksoniaceae) in *M. Lehnert and F.P. Coritico* [67]; *Etlingeras* (Zingiberaceae) in *Trimanto and L. Hapsari* [68], *M. Ardiyani and A.D. Poulsen* [33]; *Hoyas* (Apocynaceae) in *M. Rodda and S. Rahayu* [69]; *Kalappia* (Leguminosae) in *L.A. Trethowan et al.* [70]; *Lasianthus* in *Rugayah and S. Sunarti* [32]; *Phaleria* (Thymelaeaceae) in *Z.S. Rogers* [71]; *Rhododendrons* and others Ericaceae in *G. Argent and Y.M. Mambrasar* [72], *W.A. Mustaqim and W.H. Ardi* [73]; *Syzygiums* in *F. Brambach et al.* [74]. These discoveries have certainly led to the addition of known native plant of the island and global plant species. Actual study concluded that annual rate for described new plant species in SE Asia is 364 species/year or one species/day in the past 12 years [56] and it is expected more than 2,000 species globally by the end of 2020 [21]. It is a undeniable fact due to SE Asia archipelago is one of areas rich of vascular plant species [75].

The most recent study on floras diversity of Sulawesi was conducted by *E.M. Joyce et al.* [36]. A total of 3,094 species, 1,188 genera and 212 families of vascular plants has been compiled on a dataset. Whereas *A. Retnowati et al.* [27] summarized 5,931 plant species of Sulawesi. Both data shows that flowering plants (angiosperms) are clearly abundant, while ferns and ferns allies (pteridophytes) and flowerless plants (gymnosperms) tend to be minority (Table 1).

The vascular plant species originated from Sulawesi which has been cultivated in Indonesian Botanic Gardens (IBGs) is still limited compared to the flora of Sulawesi listed either by *E.M. Joyce et al.* [76] or *A.* Retnowati *et al.* [27]. As many as 1,561 species or 26% of vascular plants across Sulawesi, has been registered at IBGs. In the majority of collections, angiosperms are dominant with 1,477 species or almost 95% of the total Sulawesi's collection and nearly 30% of angiosperms across Sulawesi. On the other hand, both of pteridophytes and gymnosperms are extremely low with less than 100 species. However, the ratio of pteridophytes collection in comparison to known Sulawesi pteridophytes is less than gymnosperms. These ferns and licophytes (fern allies) group is only stand at 67 species or only 12% of the total pteridophytes around the island. Whereas gymnosperms collection is just over 30% of the

Table 1. The number of known vascular plants species originated from Sulawesi (Data center of IBGs) compare to living collection in Indonesian Botanic Gardens (IBGs) which divided into three large groups. *E.M. Joyce et al.* [76] compiled flora of Sulawesi less accounts than *A. Retnowati et al.* [27]

Source	Angiosperms	Pteridophytes	Gymnosperms
A. Retnowati *et al.* [27]	5,329	552	50
E.M. Joyce *et al.* [76]	2,696	364	34
Living Collection of IBGs	1,477	67	17

Plant collections native to Sulawesi in Indonesian Botanic Gardens (IBGs)

Record of living collection does not mean to plant species but it refers to whole number of plant collection in IBGs including the similar species. Thousands living collections planted in IBGs for years, of which there are 3,412 records of plant native to Sulawesi region (Table 2). Although the forest areas are not the most extensive, plant collections originated from South Sulawesi and Southeast Sulawesi show the highest record, comprise 1,225 (35.90%) and 1,080 (31.65%) respectively. On the other hand, West Sulawesi has the less collection just 93 records, only 2.73% to the total record. Meanwhile Central Sulawesi keeps the largest forest area within the region, with 35.79% forest cover, however we found only 470 plant collections stored in IBGs. North Sulawesi, with the smallest forest area stands at 6% of the total forest area, apparently is not the lowest record of collection. It ranks in the middle, for 381 records, 11.17% to the total record.

On the whole, the percentage of plant collection from Sulawesi compare to its forest areas is very low, stand at < 1% in all provinces. South Sulawesi and North Sulawesi are the two greater percentages, for approximately 0.05%. The latter, interestingly, contributes slightly higher percentage of plant collection in comparison to South East Sulawesi which is covered with greater forest area than North Sulawesi. The largest province around the region, Central Sulawesi, evidences the lower percentage at 0.012%. It is only one level higher than West Sulawesi which occupies the lowest rank.

Table 2. Number of plant collections native to Sulawesi in IBGs based on six administrative areas. The number is given in each column with the percentage in parentheses

Province	Total of terrestrial area (km^2) (% of forest area) [77, 78]	Forest area (km^2) (% to total forest area) [78]	Record of living Collection (% to total record)	Percentage of living collection to forest area (%)
Central Sulawesi	6,184,129 (63.62)	3,934,568 (35.79)	470 (13.77)	0.012
Gorontalo	1,125,707 (73.26)	824,668 (7.50)	163 (4.78)	0.020
North Sulawesi	1,385,164 (50.17)	694,939 (6.32)	381 (11.17)	0.055
South Sulawesi	4,671,748 (45.36)	2,118,992 (19.28)	1,225 (35.90)	0.058
South East Sulawesi	3,806,770 (61.11)	2,326,419 (21.16)	1,080 (31.65)	0.046
West Sulawesi	1,678,718 (65.07)	1,092,376 (9.94)	93 (2.73)	0.009
Total	**14,180,488 (77.51)**	**10,991,962**	**3,412**	**0.031**

Overall, the domination of living specimens of angiosperms also takes place in IBGs where they distributed (Table 3). Bali BG owns the most diverse flowering plants for 514 species, in contrast Kendari BG is the lowest one for 147 species. Enrekang BG cultivates 459 species angiosperms collections as the second largest, followed by Bogor BG in the third place at 376 species. Meanwhile both of Parepare BG and Pucak BG possess almost equal number of angiosperms, for 237 species and 236 species respectively. Further, the collections of gymnosperms in all BGs are very low, which none of them is more than ten species. Neither of gymnosperms nor pteridophytes are exist as living collections in Kendari BG. Moreover, Bali BG and Parepare BG hold the first and the second highest ferns and the fern allies (licophytes) collections which stand at 54 species and 18 species respectively, by contrast they are absent in

Purwodadi BG, Enrekang BG and Kendari BG. In addition, there are a very limited numbers of Pteridophytes that planted within Bogor BG (3 species) and Pucak BG (2 species). In total, the vascular plants collection of Bali BG is the highest, in contrast with Kendari BG which the lowest one, while Enrekang BG and Bogor BG stand for the second and third largest collections respectively.

Table 3. The number of vascular plant collections native to Sulawesi that planted in seven IBGs

	IBGs						
	Bogor	**Purwodadi**	**Bali**	**Enrekang**	**Parepare**	**Kendari**	**Pucak**
Angiosperms	376	220	514	459	237	147	236
Gymnosperms	2	6	10	5	1	0	2
Pterydophytes	3	0	54	0	18	0	2

There are considerable accounts of family within angiosperms collection of IBGs. A number of 102 families of angiosperms are present in IBGs; of these, 31 families represent at least ten species each (Fig. 1a) while the rest, 71 families, hold the fewer quantities (Fig. 1b). The graph illustrates that Orchidaceae is distinctly the uppermost emerging family of IBGs with 355 species (24% of total angiosperms of IBGs) or more five times higher than the second place, Moraceae. Conversely other families are exceedingly far below, from Moraceae downwards to the lowest level that occupied by several families consist single species each, for instances, Adoxaceae, Compositae (Asteraceae), Symplocaceae, etc. Within the top ten, tree-families are predominant with seven families viz. Moraceae, Leguminosae, Rubiaceae, Euphorbiaceae, Malvaceae, Myrtaceae, and Lauraceae. It becomes eight, if Arecaceae, a tree-like family, is included. Aside from Orchidaceae, the existence of other non-tree families, such as Araceae, Begoniaceae and Zingiberaceae, is less than tree families which are obviously prominent on both graphs (Fig. 1a and b). In spite of that, these herbaceous families are virtually distinguishable amongst others due to their significant species numbers which lie at the higher position with more than 25 species.

The fact that orchids family is the greatest flowering plants in IBGs, is not surprising given that Orchidaceae is most diverse plant family both in Sulawesi and Indonesia, for 499 species and 3.561 species respectively (Fig. 1c). The orchids collection stand at over 70% of total Sulawesi's Orchidaceae. More than that, because of the unavailability of the data of orchids from Purwodadi BG, then quantity is certainly higher than 355 species collection across the IBGs.

The second largest monocots is palms family, Arecaceae, which stand at the sixth angiosperms of IBGs for 54 species (Fig. 1a). Despite the level of palms in Sulawesi and Indonesia is also at the second for the monocots, the total number of species far outnumber the collection, viz. 395 species in Sulawesi and 935 species in Indonesia. The palms collection is just nearly 15% of total Sulawesi's palms species and only 6% of Indonesian Arecaceae.

Other top six angiosperms of IBGs are eudicots, which consist of four rosids namely Moraceae, Leguminosae, Euphorbiaceae, and one asterids, Rubiaceae (Fig. 1c). As is illustrated by the graph, the collections of Moraceae, the second most diverse family, is close to 50% of total 153 species Sulawesi's mulberry family and 15% of Indonesian Moraceae. At the same time, the living specimen of Leguminosae is the third most varied family and approximately one-third of Leguminosae native to Sulawesi. The species number of legume family is the largest within rosids group in Sulawesi as well as in Indonesia which is 206 species and 907 species respectively. Another rosids family is Euphorbiaceae, spurge family, which the quantity is almost leveled Rubiaceae as the only asterids family within top six angiosperms collections of IBGs. Rubiaceae is remarkably the highest asterids either in Sulawesi (251 species) or Indonesia (1,272 species).

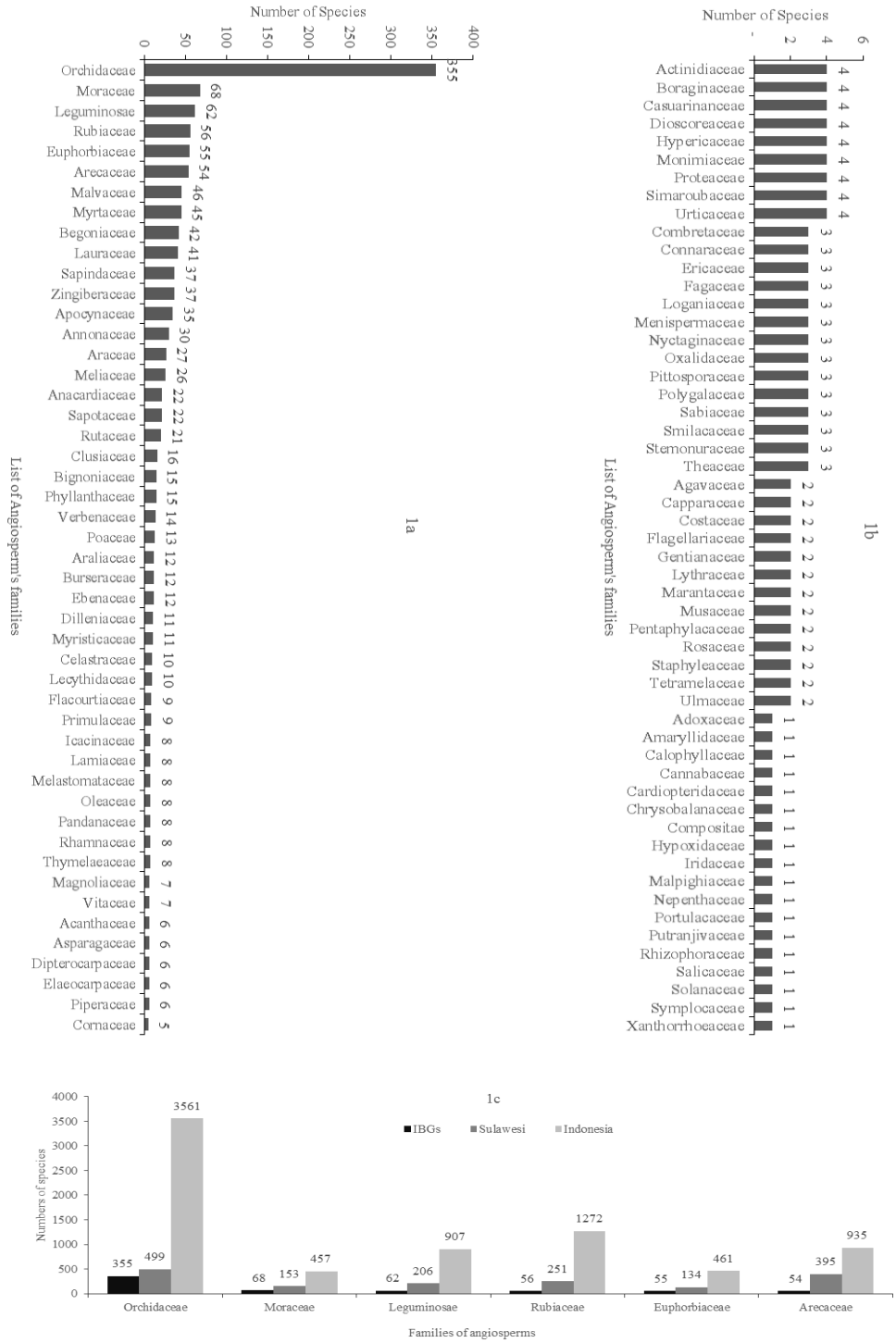

Fig. 1. The number of species of angiosperms's families. **1a**. Group of plant collection of angiosperms's families that originated from Sulawesi consists at least 10 species each. **1b**. Group of plant collection of the lesser families of angiosperms native to Sulawesi with <10 species. **1c.** Number of collections of angiosperms's species of IBGs with >50 species compared to those in Sulawesi and Indonesia [79]

Meantime, the number of Euphorbiaceae collections stands in the fifth rank which is over 40% in comparison to Sulawesi's Euphorbiaceae at 134 species, yet only 12% of Indonesia's spurge family that encompassing 461 species.

Further, the ferns and lycophytes family (Pteridophytes) are composed of 22 families which contain less than 10 species each (Fig. 2a). As is shown by the graph, Dryopteridaceae and Polypodiaceae are in the same level which leading the pteridophytes with eight species, then followed by Pteridaceae as the second highest for seven species and Thelypteridaceae as the third highest for six species. The rest families occupy the lower level with one to five species. In the majority of the category, it is nearly 75% of the total families which stand at one or two species. Two tree-fern families, e.g. Cyatheaceae and Dicksoniaceae, are included within this interval.

The state of Polypodiaceae family demonstrates a resemblance not only in IBGs collections but also either in Sulawesi region or in Indonesia, which noticeably stands for the largest ferns and licophytes, with 89 species and 266 species respectively within the top six pteridophytes (Fig. 2b). From the graph it is clear that the quantity of Dryopteridaceae collections is almost one-third (of 22 species) of Sulawesi's Dryopteridaceae and less than 10% (of 98 species) of the Indonesian one. Evidently, the family of Thelypteridaceae is the second highest pteridophytes in Indonesia with 235 species yet stands at the third highest in Sulawesi with 64 species. These numbers are far above the Thelypteridaceae collections which ten times lesser than Sulawesi's Thelypteridaceae species and nearly 40 times lower than Indonesian. In spite of the fact that Pteridaceae stands as the second largest ferns and ferns allies' family both in IBGs and in Sulawesi for seven species and 67 species respectively, it is the greatest pteridophytes in Indonesia after Polypodiaceae and Thelypteridaceae. The two families within top six pteridophytes that stand at the same level are Aspleniaceae and Athyriaceae. Moreover, both families surprisingly possess almost the similar numbers either in Sulawesi or in Indonesia.

Furthermore, Gymnosperms is actually less considerable proportion midst angiosperms and pteridophytes (Table 1). It is clear from the graph that gymnosperms is less varied than others with only five families, namely Podocarpaceae, Araucariaceae, Gnetaceae, Cycadaceae, and Pinaceae (Fig. 3). The graph shows that Podocarpaceae is the highest gymnosperms collection with five species, whereas Araucariaceae and Gnetaceae sit at the same grade with four species, then followed by Cycadaceae and Pinaceae where stay at the lower for three species and one species respectively. In brief, the group richness is the least either families or species numbers.

Conifers are the most diverse gynomsperms within IBGs, of which are Araucariaceae, Pinaceae, and Podocarpaceae, while the rest species belongs to non-confers gymnosperms, viz. gnetophytes and cycads (Fig. 3). Each family contains lesser species number, in which Podocarpaceae is eminently the highest species diversity in entire locations. The number of Araucariaceae collections native to Sulawesi is over 50% of Araucariaceae's Sulawesi which stands at seven species and nearly 30% of Araucariaceae in Indonesia. The sole collection of Pinaceae is equal to a quarter of total species of Sulawesi with 4 species, and 20% of Indonesian pines family. At the same time, Gnetaceae is a non-conifers family which occupies the second largest gymnosperms species either in the Sulawesi's collections of IBGs with four species, in Sulawesi region with 10 species, or in Indonesia with 21 species. Comparing within Cycadaceae family, the percentage of the collections at IBGs, is the greatest to Sulawesi's Cycadaceae for 75%, yet stands at the second largest percentage or nearly 25% of total cycads in Indonesia.

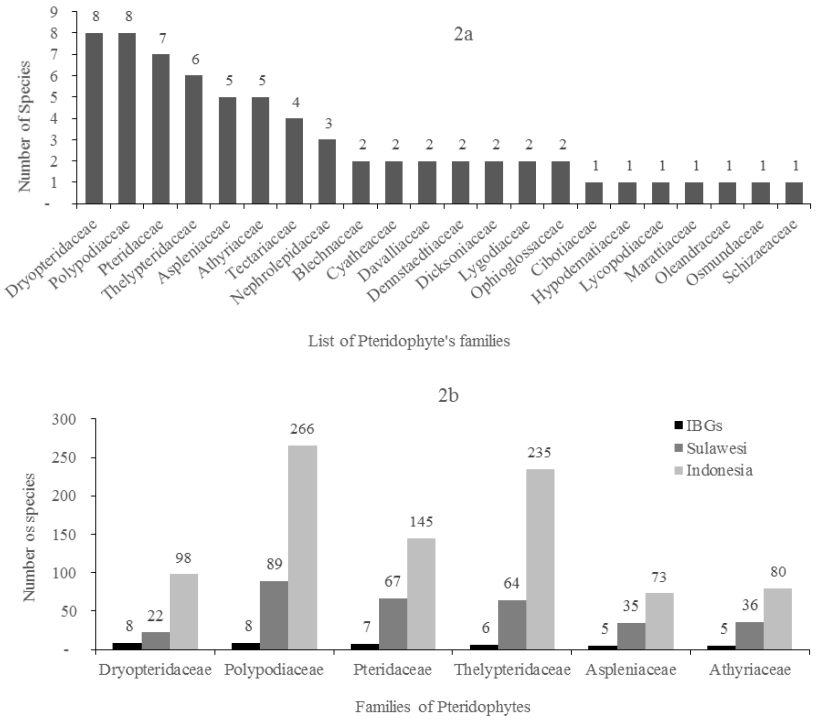

Fig. 2. The number of species of Pteridophytes's families. **2a**. The species number of collections of ferns and fern allies (lycophytes) families within IBGs. **2b**. The species number of pteridophytes's collections in IBGs compared to the species diversity of pteridophytes in Sulawesi and Indonesia [80]

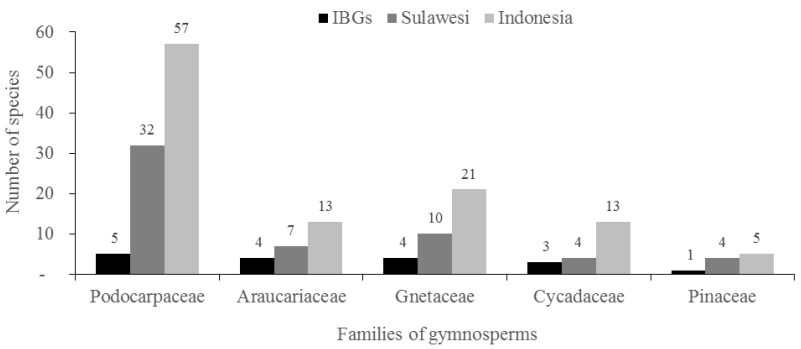

Fig. 3. The diversity of families and species of gymnosperms's collection at IBGs in comparison with living gymnosperms both in Sulawesi and Indonesia [81]

Threatened Species of Sulawesi's Collection

The region of Sulawesi harbors at least 71 plant species that threatened with global extinction in accordance with the IUCN Red List of Threatened Species [45] (Fig. 4a). As the graph shows, 13 species are experiencing Critically Endangered (CR), at the same time 30 species and 28 species are included into Vulnerable (VU) and Endangered (EN) categories respectively. The conservation status of 23 species collections from Sulawesi in IBGs or one-third compared to entire threatened floras in the region are rated as extinction as well. The great

deal of collections status is VU at 16 species, however, it is arguably that the rest collections are unfortunately at the higher risk categories for five species EN and only two species CR.

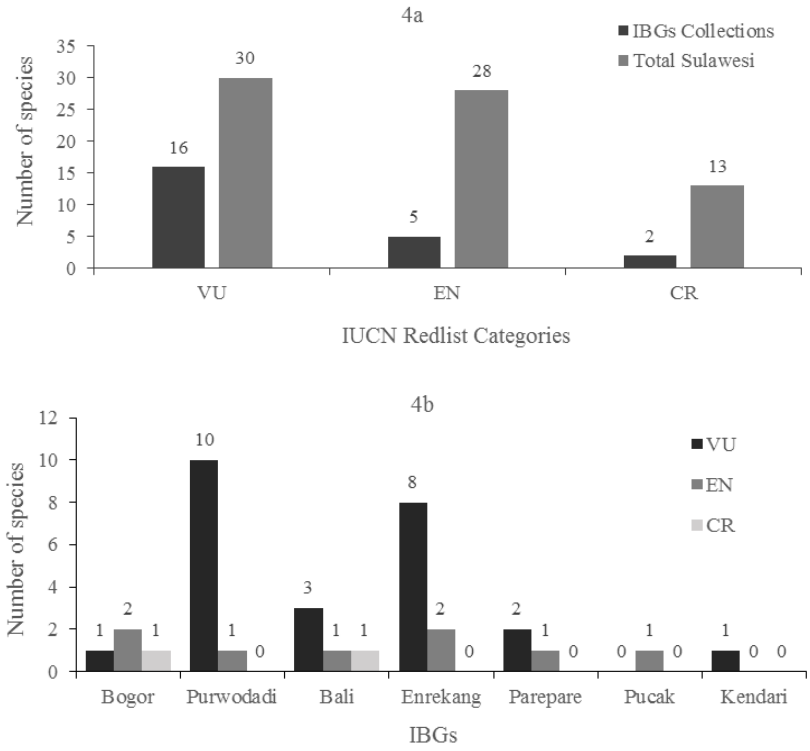

Fig. 4. Number of threatened plants native to Sulawesi based on the IUCN Redlist Category [45]. **4a**. Threatened collection originated from Sulawesi in IBGs compared to total threatened floras native to Sulawesi. **4b**. Number of threatened Sulawesi's collections of seven IBGs. VU: Vulnerable, EN: Endangered, CR: Critically Endangered

Hereinafter, 23 species of Sulawesi's collections are divided into seven IBGs, extending from Bogor BG to Kendari BG (Fig. 4b). Since Vulnerable (VU) is the most noticeable status among the others (Fig. 4a), it can be seen from the graph that, generally the conservation status of plant species in all of the BGs is VU, except at Pucak BG. Critically Endangered (CR) collection is absent at almost all IBGS yet exist in Bogor BG and Bali BG with single species each. The plant collections labeled as Endangered (EN) concurrently shows the less numbers in the majority of BGs. In general, Purwodadi BG and Enrekang BG sequentially preserving the significant number of threatened species, contrarily Pucak BG and Kendari BG protecting the lowest numbers.

Moreover, a list of threatened collections native to Sulawesi is also given. It is included 23 plant species together with the conservation status and the distribution within IBGs (Table 4). The table shows that angiosperms group has the maximum accumulations with 20 species, while gymnosperms consist only 3 species, yet none pteridophytes being rated as threatened to extinction. Excepting Leguminosae, which possess the higher species portion, each family only filled either one or two species. Within the list, there is nine species belongs to group of threatened species in Sulawesi as well [45] that presented in Figure 4a. They are *Agathis dammara* (Lamb.) Rich. & A. Rich, *Diospyros celebica* Bakh., *Eucalyptus deglupta* Blume, *Kalappia celebica* Kosterm., *Kibatalia wigmanii* (Koord.) Merr., *Mangifera altissima* Blanco,

Paphiopedilum bullenianum (Rchb.f.) Pfitzer, *Paphiopedilum lowii* (Lindl.) Stein, and *Pterocarpus indicus* Wild.

Table 4. List of threatened of living collection plants in IBGs originated from Sulawesi base on IUCN [45]

No	Plant Species	Family (Group)	Cate-gories	IBGs						
				A	B	C	D	E	F	G
1	*Agathis borneensis* Warb.	Araucariaceae (G)	EN				x			
2	*Agathis dammara* (Lamb.) Rich.&A.Rich.	Araucariaceae (G)	VU			x				
3	*Albizia carrii* Kanis	Leguminosae (A)	VU		x					
4	*Aquilaria malaccensis* Lam.	Thymelaeaceae (A)	CR			x				
5	*Artocarpus tamaran* Becc	Moraceae (A)	VU		x					
6	*Cantleya corniculata* (Becc.) R.A.Howard	Stemonuraceae (A)	VU				x			
7	*Dillenia megalantha* Merr.	Dilleniaceae (A)	VU		x					
8	*Diospyros celebica* Bakh.	Ebenaceae (A)	VU	x	x			x		
9	*Eucalyptus deglupta* Blume	Myrtaceae (A)	VU		x		x			
10	*Gleditsia rolfei* Vidal	Leguminosae (A)	EN		x					
11	*Kalappia celebica* Kosterm.	Leguminosae (A)	VU		x					
12	*Kibatalia wigmanii* (Koord.) Merr.	Apocynaceae (A)	VU		x		x			
13	*Livistona robinsoniana* Becc.	Arecaceae (A)	VU					x		
14	*Mangifera altissima* Blanco	Anacardiaceae (A)	VU		x					
15	*Palaquium bataanense* Merr	Sapotaceae (A)	VU		x					
16	*Palaquium luzoniense* (Fern.-Vill.) Vidal	Sapotaceae (A)	VU				x			
17	*Paphiopedilum bullenianum* (Rchb.f.) Pfitzer	Orchidaceae (A)	EN	x						
18	*Paphiopedilum lowii* (Lindl.) Stein	Orchidaceae (A)	EN	x						
19	*Pinus merkusii* Jungh. & de Vriese	Pinaceae (G)	VU			x	x			
20	*Psidrax dicoccos* Gaertn.	Rubiaceae (A)	VU				x			
21	*Pterocarpus indicus* Wild.	Leguminosae (A)	EN			x	x	x	x	
22	*Sandoricum koetjape* (Burm. f.) Merr.	Meliaceae (A)	VU		x	x	x			x
23	*Zingiber odoriferum* Blume	Zingiberaceae (A)	CR	x						
			Total species	4	11	5	10	3	1	1

Notes:
- Family (Group): A= Angiosperms, G= Gymnosperms.
- IBGs coding: A. Bogor BG; B. Purwodadi BG, C. Bali BG, D. Enrekang BG, E. Parepare BG, F. Pucak BG, G. Kendari BG.
- IUCN Redlist categories: VU= Vulnerable, EN= Endangered, CR= Critically Endangered

Discussions

Despite the availability of the checklist of plant species at *E.M. Joyce et al.* [36], the main sources of species name particularly for Sulawesi region that acquired by Joyce et al [36] are just two publications and an online plant database, GBIF. Otherwise, *A. Retnowati et al.* [27] demonstrated more comprehensive sources which primarily based on herbarium specimens of Herbarium Bogoriense and supplemented with published data, some online herbaria and plant database. Hence, we preferred to use the data of *A. Retnowati et al.* [27] as the reference in order to compare to plants collection maintained at IBGs. Apart from discrepancy between data resources and approaches, the number of plant species native to Sulawesi given in Fig. 1 is significantly dissimilar due to some reasons, for instance, it might be different opinions on species circumscriptions, especially in large species group as well as fluctuations dynamic on taxonomic research. Thus, real number are difficult to find or only estimation [19].

Ministry of Environment and Forestry [77] reported that the vast majority of Sulawesi is covered by forest areas which comprise over 75% of total landmass area (Table 2), on the contrary, the vascular plants collection is severely low at 1,561 species within total terrestrial area of Sulawesi at 14,180,488 km^2. In other words, it is approximately 0.00011 species per km^2. Meantime the Sulawesi region has 0.0088 vascular plant species per km [36]. Then it may be highlighted that the hard works of conservation ex-situ in IBGs need about eighty times higher to be parallel with today's state of the Sulawesi floras. Thus, a great deal of efforts would be faced in particular by IBGs. Meanwhile, the forest loss, as one of major world threats

to plants species, is accelerating globally and unfortunately with higher initial forest cover in developing regions, notably in Indonesia [82, 83]. Moreover, 79% of threatened plant species inhabits forest area [84]. Even though the rate of forest conversion is still significantly lower within protected areas than outside [82]. Sulawesi experienced the deforestation for more than 60,000 hectares in 2017-2018, of which nearly 30% took place inside the protected areas [77].

In the last three decades, IBGs had actually conducted meaningful efforts to conserve flora of Sulawesi. The field works to collect living plants species around the Sulawesi region were established. As an example, for Bali BG, Sulawesi region was one of the main destinations of flora expeditions for over a ten-year period. The Bali BG arranged at least 29 flora expeditions in the various forest areas of Sulawesi during 1996 - 2006 [85] and the last, one expedition in 2013 (Data center of Bali BG). These resulted plenty of vascular plants collection, mainly angiosperms and pteridophytes, by now growing across Bali BGs (Table 3).

The flowering plants own the highest diversity in plant realm and occupies large scale land plants habitat globally [27, 86-92]. Historically, the domination of angiosperms was started in Cretaceous period, when it evolved and diversified, then gradually taking over the gymonsperms and pteridophytes dominance until most of them experienced the extinction [89, 93-96]. Moreover, insect pollination [90, 97] and fire behavior [95] had been suggested to be accountable for the radiation of angiosperms during Cretaceous era. Nowadays, the large number of angiosperms, which is over 90% of the total vascular plant's species across the planet [19, 23], have led a greater number of the flowering plants collection in IBGs (Table 3). Besides, broadly speaking that human choose flowering plants in preference rather than ferns, mosses and their relatives [8]. This also made the expedition flora's team tends to collect more flowering plants than other vascular plants apart from the existence of angiosperms is, indeed, numerous.

Vascular plants consist of 452 known families across the globe [98]. Following Asteraceae as the largest family and the widespread angiosperms with 32,581 species in the world, Orchidaceae is the second largest flowering plants and the greatest monocots with more than 28,000 species [98-100]. Nearly one of three monocots is Orchidaceae, in which two-third is epiphytes [101]. Being an attractive and spectacular scene in whole IBGs, the orchids has continually become the most elegant attraction to visit for decades. In spite of these advantages, almost whole of orchid species are included into the Appendix I or II, checklist of CITES (the convention on International Trade in Endangered Species of Wild Fauna and Flora) in order to be protected against over-exploitation through international trade [102]. Another monocot, *Begonias*, have exceptionally rocketed at IBGs in the last two decades and the average of discovery is 60 new species worldwide between 2014-2019, of which 46 species found mostly in SE Asia by 2019 [21].

At the same time, the *Ficus* genus (fig tree) is predominant within Moraceae (the mulberry family) collections with 43 species (63% of total collection) and the most rich-species genus of mulberry family with over 750 species worldwide [103, 104]. Even more, Euphorbiaceae, the spurge family, stands at the fourth largest of Malesian vascular plants for 1,354 species [105] and the sixth largest vascular plants globally with more than 6,200 species [19, 100]. Having the upmost asterids in Sulawesi and Indonesia which stand at 251 species and 1,272 species respectively [79] and the fourth largest family in the world with over 13,500 species [19, 100], induce the circumstances of Rubiaceae's collections become one of the most abundant family (Fig. 1) which is almost a quarter compared to the total Rubiaceae's species of Sulawesi. According to global tree assessment, Leguminosae and Rubiaceae are two of three most tree-rich families [106]. Aside from the foremost species numbers, the coffee family, Rubiaceae, possess various life forms, morphological characters, and wide range habitats as well [107].

In contrary to those happen in angiosperms, the number of gymnosperms collection native to Sulawesi in IBGs is the lowest (Table 1) while the number of Sulawesi's flowerless plant is 50 species [81] and stand at over 100 species in the Malesian region [108]. At the same time gymnosperms are extremely less species diversity globally with just over 1,000 species, compared to angiosperms at 295,383 species [19, 100, 109, 110]. It is clearly suggested that the

species richness of gymnosperms is mostly distributed in Northern Hemisphere, then gradually decreased to the equatorial regions [108]. This low diversity of extant gymnosperms could be explained by high extinction rate in Cenozoic age [111], an era after Cretaceous. Modern gymnosperms are the past remnants of seed plants lineages [109, 111, 112]. Living gymnosperms comprise only four distinct lineages, viz. *Ginkgo*, gnetophytes, cycads, and conifers [42, 100, 108, 112, 113]. Conifers are the major group of the naked seed plant which constituted of several families, namely Araucariaceae, Cupressaceae, Cephalotaxaceae, Pinaceae, Podocarpaceae, Sciadopityaceae, and Taxaceae [114].

Although the vast majority number of conifers in Northern Hemisphere, the diversity of conifers decreasing toward tropics due to the tropical conifers do not tend to form forests or even single species stands, yet they are scattered either between other plants or dispersed as individual trees in the rainforests with angiosperms dominance [114]. As the highest species number of conifers, most species of Podocarpaceae successfully overcome the tall canopy angiosperms, contrast to most conifers that become evaders to angiosperms in Northern Hemisphere, temperate regions or occupying an extreme land such as sands and rocks [108, 114].

Furthermore, another plant collection of conifer family, Araucariaceae, is entirely contained with *Agathis* genus. This genus is economically important for timber source [114], which the natural occurrence is mainly in the Southern Hemisphere, i.e. Australia, but limited in tropical regions due to the higher temperature restriction to araucarian species growth and species distribution [115, 116]. This study shows that Pinaceae family, consists of the lowest species of gymnosperms (Fig. 2). It seems disagree with *M.A. Nuñez et al.* [117] who reported that many Pinaceae species are globally invasive, however they apparently did not mention that this condition takes place in equatorial regions, such as in Malesia.

Meanwhile, Gnetaceae consists of the sole genus, *Gnetum* where the largest number of species is distributed at Malesian region that contains 16 species and altogether with Podocarpaceae, Gnetaceae have the most diversity in the tropics [108]. It is then proven by *H. Rustiami* [81], who revealed that Gnetaceae is the largest gymnosperms after Podocarpaceae. In addition, it is fortunate that IBGs owned three *Cycas* species (cycads, Cycadaceae) native to Sulawesi which is the most ancient gymnosperms in the world and possess a great scientific and conservation value [118]. *Cycas*, the single genus of Cycadaceae, comprising over 100 species around the world and in Indonesia, it appears to form a sparsely distribution [119].

In addition, notwithstanding the huge decline of gymnosperms and pteridophytes during Cretaceous age, *H. Schneider et al.* [94] suggested that since angiosperms dominated, the ancient ferns of Polypodiales (>80% of the extant ferns) began to increase in the Cretaceous as response to environmental changes. *S. Lehtonen et al.* [120] then indicated that the patterns of pteridophytes diversification was strongly influenced by environmentally driven extinction and opportunistic origination. Currently, *Wardani* [80] estimated that pteridophytes are in excess of 14,000 species worldwide or the second largest lineage of vascular plant [121]. Ferns and lycophytes (fern allies) are constituents of pteridophytes, in which more than 85% is ferns and the rest belongs to lycophytes [41]. Moreover, Sulawesi's pteridophytes is the fourth highest amid major islands in Indonesia with 552 species and it is about 35% of 1,611 species ferns and fern allies in Indonesia. The recognition of Indonesian pteridophytes is a slight greater than in Brazil as another mega-diverse region that stand at 1.253 species [122].

The collection number of ferns and fern ally's native to Sulawesi in IBGs is also low compared to the total known species of pteridophytes in Sulawesi region (Table 1). The largest collection of pteridophytes families at least with five species each in IBGs are Dryopteridaceae, Polypodiaceae, Pteridaceae, Thelypteridaceae, Aspleniaceae, and Athyriaceae (Fig. 2b). Three of these take part on the top five families of Indonesian pteridophytes, namely Polypodiaceae, Thelypteridaceae, and Pteridaceae consecutively, while the most diverse pteridophytes collections, Dryopteridaceae, is outgroup [80]. As the most diverse of pteridophytes species on Earth, the quantity of Dryopteridaceae exceeds 2,000 species [41, 121]. Polypodiaceae, which is mostly small, less prominent, and not easy to cultivate [123], holds the highest genus with 65 genera and stands as the second world's largest species of Pteridophytes with 1,652 species

[41]. Pteridaceae, then, stays at the third largest with just over 1,200 species members [41]. In relation to invasiveness capability, owing the larger diverse of species, Dryopteridaceae, Polypodiaceae and Pteridaceae are evidently counted as the higher-level alien species as well and terrestrial ferns are highly potential to become invasive than epiphytic or lythophytic ones [124]. On one hand, the genus *Asplenium* occupancy is maximum within Aspleniaceae collection, so that none other genera are present. Bali BG holds whole five *Asplenium* species, of which Parepare BG shares only single species. On the other hand, the collection of Athyriaceae possess more various either in genera or species and distributes randomly in seven IBGs.

Holding the highest species collection for fern floras native to Sulawesi (Table 3), Bali BG, which is situated at mountainous area, corresponds to *M. Kessler* [125] and *N. Brummitt et al.* [101] who reported that pteridophytes are predominant in wet tropical habitat at higher altitudes of 1,000-2,500m above sea level with medium temperature. Besides, the presence of scientists related to plant taxon in BGs and particular during flora expeditions is arguably a substantial impact. Further, ferns and fern allies may represent up to 13% of the local flora within tropical forest and in montane regions, yet they can be completely absent in desert areas [125].

As many as 1,561 species of vascular plants native to Sulawesi growing within IBGs, of these, 23 species or just 0.015% of total collections are threatened with global extinction (Table 4). Nine species of those or nearly 40% intersecting with the threatened plants of Sulawesi which is enumerated at 71 species [45]. It then may be an awkward to some extents, however it can be simply explained that the assessments of status conservation for the missing 14 species of Sulawesi's collections need to be updated. As consideration, Area of Occupancy (AOO) of these species may be broaden to Sulawesi region. For example, a flowering plant, *Dillenia megalantha* Merr. (Dilleniaceae), which is assessed at the Phillipines in 2019 as Vulnerable (VU) by Energy Development Corporation [126], has native range only around the Philippines [127, 128]. Another evidence is a gymnosperms species, *Agathis borneensis* Warb., which is an Endangered (EN) species [129] and distributed in West Malesia, widespread in Borneo with some occurrences in East Malesia viz. Maluku and Papua New Guinea [128, 130]. Yet, Sulawesi region is somehow skipped, nonetheless this species is recorded as collection in Enrekang BG. However, with this study, it then can be emphasized that either *D. megalantha* or *A. borneensis* now have new distribution records in Sulawesi since they are found next to Sulawesi Island and floristic exchange is likely within Wallacea region and its boundaries [36]. Further investigations are encouraged to be established to repeat conservation risk assessment and to improve its geographical range wider onto Sulawesi region.

Moreover, within 71 threatened species of Sulawesi, 62 species are not conserved yet in IBGs. It is a great deal of efforts to continue flora expeditions across the island, save immediately the prioritized red list plants and at once counter global flora diversity loss. It also concerns with an ambitious plant conservation agenda on target 8 GSPC (The Global Strategy for Plant Conservation) which states at least 75% of threatened plant species are preserved in ex-situ collection within country of origin [131]. In addition, there are three endemic species to Sulawesi within threatened species in the island, namely *Diospyros celebica* Bakh., *Kalappia celebica* Kosterm., and *Kibatalia wigmanii* (Koord.) Merr. [128]. *K. celebica* is already re-discovered in SE Sulawesi [70] and the assessment of conservation status of *K. celebica* then recently updated by *L.A. Trethowan* [132].

Many studies have alarmed that the circumstances are now critical, for instance, *A. Antonelli et al.* [21] and *E. Nic Lughadha* [22] predicted that two in five or 39% of all vascular plants are prone to extinction worldwide, which is an unprecedented proliferation. It was just over 20% (one in five plants) half decade ago as reported by *N. Brummitt et al.* [84] and RBG Kew [23]. As the largest vascular plant, the conservation status of flowering plants has been evaluated for 41,516 species or 11% of total known angiosperms species, of which around 40% (4% of total angiosperms) is rated as threatened to extinction [45]. The extant gymnosperms also face the global risk of extinction, with approximately 40% threatened to extinction [45, 84, 108, 113] or the same percentage with whole plants estimated in *A. Antonelli et al.* [21].

Further, the species of Cycadaceae are being the most endangered gymnosperms with more than 60% threatened, contrarily Gnetaceae is less threatened with <5% at risk [108, 118]. Among vascular plant, gymnosperms is the plant group that is almost done with assessment of global extinction at over 92% of species [113]. Meantime, *N. Burmmitt et al.* [101] assumed that pteridophytes have less risk to extinction in the world, with 16% are threatened with extinction and only 6% labeled as Near Threatened (NT).

Conclusions

In conclusion, thousands plant species has been cultivated within IBGs, of which 1,561 species are known vascular plants originated from Sulawesi region or over 25% of total Sulawesi's flora, which contains 1,477 species of angiosperms (close to 30% of total flowering plants in Sulawesi), 67 species of pteridophytes (more than 10% of total ferns and lycophytes across the Sulawesi), and 17 species of gymnosperms (over 30% of Sulawesi's naked seed plants). Aside from high-cost flora expeditions, as the main method for collecting plant species from the natural habitat in order to increase the quantity of plant species within IBGs, an optimism is undoubted due to numerous living specimens awaiting to be identified or possibly to be named as new species. It is a prospective study which has been conducted well for years in IBGs.

A number of 23 species of entire Sulawesi's plant collections are considered threatened with global extinction, of those quantity nine species had already been listed in threatened plants of Sulawesi [45]. In order to address the extinction risk that continually increase worldwide, establishing an integrated plant conservation which incorporates both in-situ and ex-situ conservation may be one of inevitable strategy for supporting life of plants species [6, 133]. A fruitful deliberation is needed to obtain a more thorough insight of the threatened plant species both names and locations, then an effective conservation framework may be achieved and plants species loss can be avoided [23].

Acknowledgments

We thank to Mrs. Dina Safari Nugraha, Mr. Wisnu Handoyo and Mr. Daden from Bogor BG, Dr. Bayu Adjie from Purwodadi BG, Mr. Mursalim and Mr. Bustamin from Enrekang BG for their supports in providing data on the collection of botanic gardens. Thanks also to Prof. Dr. Dedy Darnaedi from the National University, Jakarta for his valuable advice.

References

[1] J. Gratzfeld, *Introduction*, **From Idea to Realisation, BGCI's Manual on Planning, Developing and Managing Botanic Gardens** (Editor: J. Gratzfeld), Botanic Gardens Conservation International (BGCI), Richmond, United Kingdom, 2016, pp. vii-viii.

[2] P. Smith, *Building a global system for the conservation of all plant diversity: a vision for botanic gardens and botanic gardens conservation international*, **Sibbaldia, 14**, 2016, pp. 5-13.

[3] C.H. Cannon, C.S. Kua, *Botanic gardens should lead the way to create a "Garden Earth" in the Anthropocene*, **Plant Diversity, 39**, 2017, pp. 331-337.

[4] V.H. Heywood, *The future of plant conservation and the role of botanic gardens*, **Plant Diversity, 39**, 2017, pp. 309-313.

[5] H. Huang, J. Liao, Z. Zhang, Q. Zhan, *Ex situ flora of China*, **Plant Diversity, 39**, 2017, pp. 357-364.

[6] * * *, https://www.bgci.org/about/about-plant-conservation/

[7] S. Krishnan, A. Novy, *The role of botanic gardens in the twenty-first century*, **CAB Reviews, 11**(23), 2016, pp. 1-10.

[8] M. Gross, *Can botanic garden save all plants*, **Current Biology, 28**, 2018, pp. R1075–R1095.

[9] B.F. Fant, K. Havens, A.T. Kramer, S.K. Walsh, T. Calicrate, R.C. Lacy, M. Maunder, A.H. Meyer, P.P. Smith, *What to do when we can't bank on seeds: What botanic gardens can learn from the zoo community about conserving plants in living collections*, **American Journal of Botany, 103**(9), 2016, pp. 1541-1543.
[10] D.A. Galbraith, *Chapter 2: Governance models, human and financial resources development*, **From Idea to Realisation, BGCI's Manual on Planning, Developing and Managing Botanic Gardens** (Editor: J. Gratzfeld), Botanic Gardens Conservation International (BGCI), Richmond, United Kingdom, 2016, pp. 31-46.
[11] C.P. Dunn, *Biological and cultural diversity in the context of botanic garden conservation strategies*, **Plant Diversity, 39**, 2017, pp. 396-401.
[12] G. Chen, W. Sun, *The role of botanical gardens in scientific research, conservation, and citizen science*, **Plant Diversity, 40**, 2018, pp. 181-188.
[13] K. O'Donnell, S. Sharrock, *The contribution of botanic gardens to ex situ conservation through seed banking*, **Plant Diversity, 39**, 2017, pp. 373-378.
[14] P. Smith, *The challenge for botanic garden science*, **Plant People Planet, 1**, 2019. pp. 38-43.
[15] K. O'Donnell, S. Sharrock, *Botanic gardens complement agricultural gene bank in collecting and conserving plant genetic diversity*, **Biopreservation and Biobanking, 16**(5), 2018, pp. 384-390.
[16] * * *, http://tools.bgci.org/garden_search.php
[17] R. Mounce, P. Smith, S. Brockington, *Ex situ conservation of plant diversity in the world's botanic gardens*, **Nature Plants, 3**, 2017, pp. 795-802.
[18] * * *, *Bidang Pengembangan Kawasan Kebun Raya*, **Laporan Perkembangan Pembangunan Kebun Raya Daerah di Indonesia: Desember 2019,** Pusat Penelitian Konservasi Tumbuhan dan Kebun Raya, Lembaga Ilmu Pengetahuan Indonesia, 2019, p. 67.
[19] M.J.M. Christenhusz, J.W. Byng, *The number of known plants species in the world and its annual increase*, **Phytotaxa, 261**(3), 2016, pp. 201-217.
[20] B.J. Enquist, X. Feng, et al. *The commonness of rarity: global and future distribution of rarity across land plants*, **Science Advances, 5,** 2019, pp. 1-13.
[21] A. Antonelli, C. Fry, et al. **State of the World's Plants and Fungi**, Royal Botanic Gardens, Kew, 2020, p. 96.
[22] E. Nic Lughadha, S. Bachman, et al*Extinction risk and threats to plants and fungi*, **Plants People Planet, 2**, 2020, pp. 389–408.
[23] * * *, **State of the World's Plants 2016,** Royal Botanic Gardens, Kew, 2016, p. 80.
[24] E. Nic Lughadha, R. Govaerts, I. Belyaeva, N. Black, H. Lindon, R. Allkin, R.E. Magill, N. Nicolson, *Counting counts: revised estimates of numbers of accepted species of flowering plants, seed plants, vascular plants and land plants with a review of other recent estimates*, **Phytotaxa, 272**(1), 2016, pp. 082–088.
[25] D.J. Middleton, K. Armstrong, Y. Baba, H. Balslev, K. Chayamarit, R.C.K. Chun, B.J. Conn, E.S. Fernando, K. Fujikawa, R. Kiew, H.T. Luu, M.M. Aung, M.F. Newman, S. Tagane, N. Tanaka, D.C. Thomas, T.B. Tran, T.M.A. Utteridge, P.C. van Welzen, D. Widyatmoko, T. Yahara, K.M. Wong, *Progress on SE Asia's flora projects*, **Gardens' Bulletin Singapore, 71**(2), 2019, pp. 267–319.
[26] A. Retnowati, Rugayah, *Prologue*, **Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia** (Editors: A. Retnowati, Rugayah, J.S. Rahajoe and D. Arifiani), LIPI Press, Jakarta, 2019, pp. 1-10.
[27] A. Retnowati, Rugayah, J.S. Rahajoe, D. Arifiani (editors), **Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia**, LIPI Press, Jakarta, 2019, p. 139.
[28] D.M. Puspitanigtyas, *Orchid inventory in Bantimurung-Bulusaraung National Park, South Sulawesi, Indonesia*, **Biodiversitas, 18**(1), 2017. pp. 341-350.

[29] F. Brambach, *Diversity, composition, and biogeography of trees in tropical mountain forests of Sulawesi, Indonesia*, **PhD Thesis**, Georg-August-Universität Göttingen, 2019, p. 322.
[30] Maskun, Naswar, Achmad, H. Assidiq, J. Raisman, *Legal protection against forest areas to ensure habitat wildlife in the Wallacea region*, **IOP Conference Series: Earth Environmental Science, 473**, 2020, pp.1-8.
[31] R. Pitopang, P.A. Ramawangsa, *Potensi Penelitian Etnobotani Di Sulawesi Tengah Indonesia (Potencial of Ethnobotanical Studies in Central Sulawesi Indonesia)*, **Online Journal of Natural Science, 5**(2), 2016, pp. 111-131.
[32] Rugayah, S. Sunarti, *The genus Lasianthus (Rubiaceae) in Wawonii Island, Southeast Sulawesi, Indonesia*, **Reinwardtia, 16**(2), 2017, pp. 97-101.
[33] M. Ardiyani, A.D. Poulsen, *An update of the genus Etlingera* (*Zingiberaceae) in Sulawesi including the description of a new species*, **Reinwardtia, 18**(1), 2019, pp. 31–42.
[34] D.M. Puspitanigtyas, *Inventory of orchids in Polewali Mandar, West Sulawesi, Indonesia*, **Biodiversitas, 20**(7), 2019. pp. 1887-1896.
[35] M.R. Fischer, B. Verheijen, M.A.K. Sahide, *Community and conservation in Wallacea: Making the case for the region, a methodological framework, and research trends*, **Forest and Society, 4**(1), 2020, pp. 1-19.
[36] E.M. Joyce, K.R. Thiele, F.J.W. Slik, D.M. Crayn, *Checklist of the vascular flora of the Sunda-Sahul Convergence Zone*, **Biodiversity Data Journal, 8**, 2020, pp.1-14
[37] L.A. Trethowan, W.L. Eiserhardt, D. Girmansyah, E. Kintamani, T.M.A. Utteridge, F.Q. Brearley, *Floristics of forests across low nutrient soils in Sulawesi, Indonesia*, **Biotropica, 00**, 2020, pp. 1–10.
[38] D.W. Purnomo, M. Magandhi, F. Kuswantoro, R.A. Risna, J.R. Witono, *Pengembangan Koleksi Tumbuhan Kebun Raya Daerah dalam Kerangka Strategi Konservasi Tumbuhan di Indonesia. Developing plant collections on the regional botanic gardens in framework of plant conservation strategy in Indonesia*, **Bulletin Kebun Raya, 18**(2), 2015, pp. 111–124.
[39] J.R. Witono, D.W. Purnomo, D. Usmadi, D.O. Pribadi, D. Asikin, M. Magandhi, Sugiarti, Yuzammi, **Rencana Pengembangan Kebun Raya Indonesia**. Research Center for Plant Conservation Bogor Botanic Garden-LIPI, Bogor, 2012, p. 82.
[40] J.W. Byng, M.W. Chase, et al., *An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV*, **Botanical Journal of the Linnean Society, 181**, 2016, pp. 1–20.
[41] E. Schuettpelz, H. Schneider, et al., *A community-derived classification for extant lycophytes and ferns*, **Journal Systematics and Evolution, 54**(6), 2016, pp. 563-603.
[42] M.J.M. Christenhusz, J.L. Reveal, A. Farjon, M.F. Gardner, R.R. Mill, M.W. Chase, *A new classification and linear sequence of extant gymnosperms*, **Phytotaxa, 19**, 2011, pp. 55-70.
[43] * * *, http://www.worldfloraonline.org
[44] * * *, http://powo.science.kew.org/
[45] * * *, https://www.iucnredlist.org/
[46] C.H. Cannon, M. Summers, J.R. Harting, P.J.A. Kessler, *Developing conservation priorities based on forest type, condition, and threats in a poorly known ecoregion Sulawesi, Indonesia*, **Biotropica, 39**(6), 2007, pp. 747-759.
[47] B. Michaux, *Biogeology of Wallacea: geotectonic models, areas of endemism, and natural biogeographical units*, **Biological Journal of the Linnean Society, 101**, 2010, pp. 193–212.
[48] N. Myers, R.A. Mittermeier, C.G. Mittermeier, G.A.B. Da Fonseca, J. Kent, *Biodiversity hotspots for conservation priorities*, **Nature, 403**, 2000, pp. 853–858.
[49] P.C. Van Welzen, J.A.N. Parnell, J.W.F. Slik, *Wallace's Line and plant distributions: two or three phytogeographical areas and where to group Java?*, **Biological Journal of the Linnean Society, 103**, 2011, pp. 531–545.

[50] B. Stelbrink, C. Albrecht, R. Hall, T. von Rintelen, *The biogeography of Sulawesi revisited: Is there evidence for a vicariant origin of taxa on Wallace's "anomalous island"?* **Evolution, 66**(7), 2012, pp. 2252–2271.
[51] A.M.S. Nugraha, R. Hall, *Late Cenozoic palaeogeography of Sulawesi, Indonesia*, **Palaeogeography, Palaeoclimatology, Palaeoecology, 490**, 2018, pp. 191-209.
[52] A.S. Achmadi, A. Hamidy, I. Maryanto, P. Lupiyaningdyah, V.B.L. Sihotang, S. Kahono, A. Kartonegoro, M. Ardiyani, E.S. Mulyaningsih, A. Kanti, **Ekspedisi Sulawesi Barat: Flora, fauna, dan mikroorganisme Gandangdewata,** LIPI Press, Jakarta, 2018, p. 167.
[53] Fahlil, S.M. Sulaeman, R. Pitopang, *Inventarisasi Jenis-Jenis Anggrek di Sekitar Danau Kalimpaa Kawasan Taman Nasional Lore Lindu Sulawesi Tengah*, **Biocelebes, 12**(1), 2018, pp. 73-82.
[54] A. Henderson, R. Pitopang, *Rattan of the Wallacea*, **Biodiversitas, 19**(1), 2018, pp. 18-21.
[55] J. Supriatna, M. Shekelle, H.A.H. Fuad, N.L. Winarni, A.A. Dwiyahreni, M. Farid, S. Mariati, C. Margules, B. Prakoso, Z. Zakaria, *Deforestation on the Indonesian island of Sulawesi and the loss of primate habitat*, **Global Ecology and Conservation, 24**, 2020, pp. 1-14.
[56] P.H. Raven, R.E. Gereau, P.B. Phillipson, C. Chatelain, C.N. Jenkins, C.U. Ulloa, *The distribution of biodiversity richness in the tropics*, **Science Advance, 6,** 2020, pp. 1-5.
[57] M. Ardyani, D. Dwibadra, K. Dewi, Mulyadi, S. Meliah, I. Maryanto, H. Rustiami, D. Arifiani, J.S. Rahajoe, H. Sutrisno, A. Kanti, **Temuan dan Pertelaan Jenis Baru Biota Indonesia 1967-2017, Sumbangsih LIPI untuk Sains**, LIPI Press, Jakarta, 2017, p. 279.
[58] S. Lindsay, P.H. Hovenkamp, D.J. Middleton, *New combination and typifications in Aglaomorpha (Polypodiaceae),* **Gardens' Bulletin Singapore, 69**(1), 2017, pp. 149-155.
[59] D. Ervianti, E.A. Widjaja, A. Sedayu, *New species of climbing and scrambling bamboo from Sulawesi, Indonesia*, **Reinwardtia, 18**(2), 2019, pp. 115-132.
[60] W.H. Ardi, D.C. Thomas, *A new species Begonia (Begoniaceae) from South Sulawesi, Indonesia, and an augmented description of Begonia bonthainensis*, **Reinwardtia, 18**(1), 2018, pp. 19−26.
[61] W.H. Ardi, D.C. Thomas, *Begonia tjiasmantoi, a new species from West Sulawesi*, **Reinwardtia, 19**(1), 2020, pp. 61-65.
[62] D.C. Thomas, A. Bour, W.H. Ardi, *Begonia of the Matarombeo karst, Southeast Sulawesi, Indonesia, including two new species*, **Gardens' Bulletin Singapore, 70**(1), 2018, pp. 163-176.
[63] D.C. Thomas, W.H. Ardi, *Begonia mabberleyana (Begoniaceae), a new species from Central Sulawesi, Indonesia*, **Gardens' Bulletin Singapore, 71, suppl. 2**, 2019, pp. 217-223.
[64] W.A. Mustaqim, D.S. Amboupe, *Cratoxylum cochinchinense (Hypericaceae): A new record for Sulawesi, Indonesia*, **Philippine Journal of Science, 149**(3), 2020, pp. 675-678.
[65] F.P. Coritico, V.B. Amoroso, M. Lehner, *New records, names and combinations of scaly tree ferns (Cyatheaceae) in eastern Malesia*, **Blumea, 62**, 2017, pp. 92–96.
[66] A. Kartonegoro, R.E. Bone, H.J. Atkins, *Eleven new species of Cyrtandra (Gesneriaceae) from Sulawesi, Indonesia*, **Edinburgh Journal of Botany, 75**(2), 2018, pp. 173-204.
[67] M. Lehnert, F.P. Coritico, *The genus Dicksonia (Dicksoniaceae - Cyatheales) in western Malesia*, **Blumea, 63**, 2018, pp. 268–278. https://doi.org/10.3767/blumea.2018.63.03.02
[68] Trimanto, L. Hapsari, *a new record of Etlingera megalocheilos (Griff.) A.D. Poulsen (Zingiberaceae) in Sulawesi, Indonesia*, **Biodiversitas, 19**(4), 2018, pp. 1227-1235.
[69] M. Rodda, S. Rahayu, *Two new species of Hoya (Apocynaceae, Asclepiadoideae) from Sulawesi, Indonesia*, **Taiwania 65**(2), 2020, pp. 209-215.
[70] L.A. Trethowan, A. Arif, R.P. Clark, D. Girmansyah, E. Kintamani, C.J. Prychid, N. Pujirahahyu, Rosmarlinasiah, F.Q. Brearley, T.M.A. Utteridge, G.P. Lewis, *An enigmatic genus on an enigmatic island: the re-discovery of Kalappia on Sulawesi*, **Ecology, 100**(11), 2019, pp. e02793 1-4.

[71] Z.S. Rogers, *Phaleria stevensiana: A distinctive new species of Thymelaeaceae endemic to Sulawesi, Indonesia*, **Novon: A Journal for Botanical Nomenclature, 25**(4), 2017, pp. 473-481.
[72] G. Argent, Y.M. Mambrasar, *Rhododendron widjajae (Ericaceae, section Schistanthe) a new species from Sulawesi*, **Reinwardtia, 18**(1), 2019, pp. 27-30.
[73] W.A. Mustaqim, W.H. Ardi, *Ericaceae of Sulawesi: A new species of Diplycosia, a new variety of Vaccinium paludicolum and one rediscovery*, **Telopea, 22**, 2019, pp. 193-204.
[74] F. Brambach, J.W. Byng, H. Culmsee, *Five new species of Syzygium (Myrtaceae) from Sulawesi, Indonesia*, **PhytoKeys, 81**, 2017, pp. 47–78.
[75] N. Brummitt, A.C. Araújo, T. Harris, *Areas of plant diversity—What do we know?* **Plants People Planet,** 2020, pp. 1–12.
[76] * * *, http://dx.doi.org/10.25903/5ea0dd85f8ea9
[77] * * *, *Kementerian Lingkungan Hidup dan Kehutanan*, **Statistik Lingkungan Hidup dan Kehutanan Tahun 2018**, Kementerian Lingkungan Hidup dan Kehutanan, Jakarta, 2019, p. 468.
[78] * * *, Regulation of Ministry of Internal Affairs, Republic of Indonesia No. 72, 2019: Amendment to Regulation of Ministry of of Internal Affairs, No. 137, 2017: Code and Regional Data of Government Administration.
[79] D. Arifiani. *Part III, the richness of seed plant: IV. Ceratophyllales and eudicots*, in: **Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia** (editors: A. Retnowati, Rugayah, J.S. Rahajoe an d D. Arifiani), LIPI Press, Jakarta, 2019, pp. 93-102.
[80] Wardani, *Pterydophytes*, **Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia** (Editors: A. Retnowati, Rugayah, J.S. Rahajoe and D. Arifiani), LIPI Press, Jakarta, 2019, pp. 59-63.
[81] H Rustiami, *Part III, the richness of seed plant: I. Gymnosperms*, **Status Keanekaragaman Hayati Indonesia: Kekayaan Jenis Tumbuhan dan Jamur Indonesia** (Editors: A. Retnowati, Rugayah, J.S. Rahajoe and D. Arifiani), LIPI Press, Jakarta, 2019, pp. 71-75.
[82] A.C. Hughes, *Have Indo-Malaysian forests reached the end of the road?*, **Biological Conservation, 223**, 2018, pp. 129–137.
[83] R. Leberger, I.M.D. Rosa, C.A. Guerra, F. Wolf, H.M. Pereira, *Global patterns of forest loss across IUCN categories of protected areas*, **Biological Conservation, 241**, 2020, pp. 1-8.
[84] N. Brummitt, S.P. Bachman, et al. *Green Plants in the Red: A Baseline Global Assessment for the IUCN Sampled Red List Index for Plants*, **PLoS ONE, 10**(8), 2015, pp. 1-22.
[85] D.M.S. Putri, A. Kurniawan, **Koleksi Pohon Sulawesi Kebun Raya Bali**, UPT Balai Konservasi Tumbuhan kebun Raya "Eka Karya" Bali - LIPI, Tabanan, 2006, p. 126.
[86] P.S. Soltis, D.E. Soltis, *The origin and diversification of angiosperms*, **American Journal of Botany, 91**(10), 2004, pp. 1614–1626.
[87] D.E. Soltis, C.D. Bell, S. Kim, P.S. Soltis, *Origin and early evolution of angiosperms*, **Annals of the New York Academy of Sciences, 1133**, 2008, pp. 3–25.
[88] S. Magallón, A. Castillo, *Angiosperms diversification through time*, **American Journal of Botany, 96**(1), 2009, pp. 349-365.
[89] C. Coiffard, B. Gomez, V. Daviero-Gomez, D.L. Dilcher, *Rise to dominance of angiosperm pioneers in European Cretaceous environments*, **PNAS, 109**(51), 2012, pp. 20955-20959.
[90] D. Peris, C.C. Labandeira, E. Peñalver, X. Delcòs, E. Barrón, R. Pérez-de la Fuente, *The case of Darwinylus marcosi (Insecta: Coleoptera: Oedemeridae): A Cretaceous shift from a gymnosperm to an angiosperm pollinator mutualism*, **Communicative and Integrative Biology, 10**(4), 2017. pp. e1325048,1-3.
[91] H.T. Li, T.S. Yi, et al., *Origin of angiosperms and the puzzle of the Jurassic gap*, **Nature Plants, 5**, 2019, pp. 461-470.

[92] S. Wu, B. Han, Y. Jiao, *Genetic contribution of paleopolyploidy to adaptive evolution in angiosperms*, **Molecular Plant, 13**, 2020, pp. 59–71.
[93] E.M. Friis, K.R. Pedersen, P.R. Crane, *Diversity in obscurity: fossil flowers and the early history of angiosperms*, **Philosophical Transactions of the Royal Society B, 365**, 2010, pp. 369–382.
[94] H. Schneider, E. Schuettpelz, K.M. Pryer, R. Cranfill, S. Magallón, R. Lupia, *Ferns diversified in the shadow of angiosperms*, **Nature, 428**, 2014, pp. 553-557.
[95] C.M. Belcher, V.A. Hudspith, *Changes to Cretaceous surface fire behaviour influenced the spread of the early angiosperms*, **New Phytologist, 213**, 2017, pp. 1521–1532.
[96] V.D. Barreda, L. Palazzesi, E.B. Olivero, *When flowering plants ruled Antartica: evidence from Cretaceous pollens grains*, **New Phytologist, 223**, 2019, pp. 1023-1030.
[97] T. Bao, B. Wang, J. Li, D. Dilcher, *Pollination of Cretaceous flowers*, **PNAS, 116**(49), 2019, pp. 24707-24711.
[98] * * *, **Royal Botanic Gardens, Kew, State of the World's Plants 2017** (editor: K.J. Willis), Royal Botanic Gardens, Kew, 2017, p. 96.
[99] M.W. Chase, K.M. Cameron, J.V. Freudenstein, A.M. Pridgeon, G. Salazar, C. van den Berg, A. Scuiteman, *An updated classification of Orchidaceae*, **Botanical Journal of The Linnean Society, 177**, 2015, pp.151–174.
[100] * * *, https://wcsp.science.kew.org/home.do
[101] N. Brummitt, E. Aletrari, M. Syfert, M. Mulligan, *Where are threatened ferns found? Global conservation priorities for pteridophytes*, **Journal of Systematics and Evollution, 54**(6), 2016, pp. 604–616.
[102] * * *, https://cites.org (last checked June 30, 2021)
[103] W.L. Clement, G.D. Weiblen, *Morphological evolution in the mulberry family (Moraceae)*, **Systematic Botany, 34**(3), 2009, pp. 530–552.
[104] Q. Zhang, R.E. Onstein, S.A. Little, H. Sauquet, *Estimating divergence times and ancestral breeding systems in Ficus and Moraceae*, **Annals of Botany, 123**, 2019, pp. 191–204.
[105] T. Djarwaningsih. *The diversity of endemic Euphorbiaceae (spurge family) in Sumatra*, **Jurnal Biodjati, 2**(2), 2017, pp. 89-94.
[106] E. Beech, M. Rivers, S. Oldfield, P.P. Smith, *GlobalTreeSearch: the first complete global database of tree species & country distributions*, **Journal of Sustainable Forestry, 36**(5), 2017, pp. 454-489.
[107] N. Wikström, K. Kainulainen, S.G. Razafimandimbison, J.E.E. Smedmark, B. Bremer, *A revised time tree of the asterids: establishing a temporal framework for evolutionary studies of the coffee family (Rubiaceae)*, **PLoS ONE, 10**(5), 2015, pp. e0126690 1-26.
[108] Y. Fragnière, S. Bétrisey, L. Cardinaux, M. Stoffel, G. Kozlowski, *Fighting their last stand? A global analysis of the distribution and conservation status of gymnosperms*, **Journal of Biogeography, 42**, 2015, pp. 809–820.
[109] J.G. Burleigh, W.B. Barbazuk, J.M. Davis, A.M. Morse, P.S. Soltis, *Exploring diversification and genome size evolution in extant gymnosperms through phylogenetic synthesis*, **Journal of Botany, 2012**, 2012, pp. 1-6.
[110] S. Rastogi, D. Ohri, *Chromosome Numbers in Gymnosperms - An Update*, **Silvae Genetica, 69**, 2020, pp. 13-19.
[111] M.D. Crisp, L.G. Cook, *Cenozoic extinctions account for the low diversity of extant gymnosperms compared with angiosperms*, **New Phytologist, 192**, 2011, pp. 997–1009.
[112] C.C. Davies, H. Schaefer, *Plant evolution: pulses of extinction and speciation in gymnosperm diversity*, **Current Biology, 21**(24), 2011, pp. R995-R998.
[113] F. Forest, J. Moat, E. Baloch, N.A. Brummitt, S.P. Bachman, S. Ickert-Bond, P.M. Hollingsworth, A. Liston, D.P. Little, S. Mathews, H. Rai, C. Rydin, D.W. Stevenson, P. Thomas, S. Buerki, *Gymnosperms on the EDGE*, **Scientific Reports, 8**(6053), 2018, pp. 1-13.
[114] A. Farjon, *Conifers of the world*, **Kew Bulletin, 73**(8), 2018, pp. 1-16.

[115] C.A. Offord, *Pushed to the limit: consequences of climate change for the Araucariaceae: a relictual rain forest family*, **Annals of Botany, 108**, 2011, pp. 347–357.
[116] I.H. Escapa, S.A. Catalanot, *Phylogenetic analysis of araucariaceae: integrating molecules, morphology, and fossils*, **International Journal of Plant Sciences, 174**(8), 2013, pp. 1153–1170.
[117] M.A. Nuñez, M.A. Chiuffo, A. Torres, T. Paul, R.D. Dimarco, P. Raal, N. Policelli, J. Moyano, R.A. García, B.W. van Wilgen, A. Pauchard, D.M. Richardson, *Ecology and management of invasive Pinaceae around the world: progress and challenges*, **Biol Invasions, 19**, 2017, pp. 3099–3120.
[118] Y. Zheng, J. Liu, X. Feng, X. Gong, *The distribution, diversity, and conservation status of Cycas in China*, **Ecology and Evolution, 7**, 2017, pp. 3212-3224.
[119] A.J. Lindstrom, K.D. Hill, L.C. Stanberg, *The genus Cycas (Cycadaceae) in Indonesia*, **Telopea, 12**(3), 2009, pp. 385–418.
[120] S. Lehtonen, D. Silvestro, D.N. Karger, C. Scotese, H. Tuomisto, M. Kessler, C. Peña, N. Wahlberg, A. Antonelli, *Environmentally driven extinction and opportunistic origination explain fern diversification patterns*, **Scientific Reports, 7**(4831), 2017, pp. 1-12.
[121] W. Testo, M. Sundue, *A 4000-species dataset provides new insight into the evolution of ferns*, **Molecular Phylogenetics and Evolution, 105**, 2016, pp. 200-211.
[122] L.S. Prado Sylvestre, P.H. Labiak, et al., *Diversity of ferns and lycophytes in Brazil*, **Rodriguésia, 66**(4), 2015, pp. 1073-1083.
[123] M.A. Sundue, B.S. Parris, T.A. Ranker, A.R. Smith, E.L. Fujimoto, D. Zamora-Crosby, C.W. Morden, W.L. Chiou, C.W. Chen, G. Rouhan, R.Y. Hirai, J. Prado, *Global phylogeny and biogeography of grammitid ferns (Polypodiaceae)*, **Molecular Phylogenetics and Evolution, 81**, 2014, pp. 195-206.
[124] E.J. Jones, T. Kraaij, H. Fritz, D. Moodley, *A global assessment of terrestrial alien ferns (Polypodiophyta): species' trait as dfrivers of naturalisation and invasion*, **Biol Invasions, 21**, 2019, pp. 816-873.
[125] M. Kessler. *Biogeography of ferns*, in: **Fern ecology** (editors: K. Mehltreter, L.R. Walker, J.M. Sharpe), Cambridge, UK: Cambridge University Press, 2010, pp. 22-60.
[126] * * *, https://dx.doi.org/10.2305/IUCN. UK.2020-1.RLTS.T33250A153533813.en.
[127] * * * ,https://doi.org/10.15468/39omei
[128] * * *, http://www.plantsoftheworldonline.org/
[129] * * *, https://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T202905A2757743.en
[130] ** *, https://doi.org/10.15468/39omei
[131] * * *, **The Global Strategy for Plant Conservation: 2011-2020,** CBD (Convention on Biological Diversity), Botanic Gardens Conservation International, Richmond, UK, 2012, pp. 13-17.
[132] * * *, https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T33287A155605251.en
[133] A. Matthew, B. Santos, E.G. Brockerhoff, P.B. Pelser, C. Ecroyd, J. Clemens, *Importance of arboreta for ex situ conservation of threatened trees*, **Biodiversity Conservation, 24**, 2015, pp. 3601–3620.
[134] E. Todirascu Ciornea, G. Dumitru, I. Sandu, *The dinitrophenol and potassium iodate influence on Hordeum vulgare seedlings viability*, **Revista de Chimie**, **69**(8), 2018, pp. 2160-2166.

Received: March 10, 2021
Accepted: February 15, 2022