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Gap analysis of Indonesian priority medicinal plant species as part of their conservation planning

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ABSTRACT

Indonesia is a country rich in medicinal plant biodiversity. The conservation and sustainable use of such species in Indonesia are critical because of incipient population growth, changing land usage, forest clearance, and climate change in a country where most of the population depends on traditional medicines for their health care and wellbeing. Identifying the conservation gap is crucial for planning the genetic conservation of Indonesian priority medicinal plant species. These are native plants with limited distribution, wild harvested (often to destruction) and/or included on the IUCN Red List, CITES appendices, and national legislation. Ecogeographic data were collated from online database, herbarium specimens and living collections and then subjected to *in situ* and *ex situ* gap analysis. The results of this gap analysis support our recommendation that *in situ* active conservation reserves for priority plants be established in areas of Indonesia with the greatest diversity of species. Medicinal plant species with no occurrence points in Indonesia or less than five seed samples are needed to be surveyed further. Other recommendations for active *in situ* and *ex situ* conservation are provided in this article which will help to ensure conservation of medicinal plants in Indonesia.

1. Introduction

Medicinal plants are useful and valuable. They are defined as all higher plants that have identified uses for medicinal purposes (Hawkins, 2008; WHO, 2003) arising from the bioactive properties of particular secondary metabolites they contain (de Padua et al., 1999), and have effects relevant to health as drugs, whether their use has been proven clinically or not (Farnsworth and Soejarto, 2001). These plants might be used as food and cosmetic (Astutik et al., 2019) and might be harvested from the wild and cultivation (WHO, 2003). People traditionally used plant parts, extracts, and complex products to cure illness (de Padua et al., 1999; Cragg and Newman, 2013). More than 50,000 higher plant species worldwide are estimated to be classed as medicinal plants (Schippmann et al., 2002). These plants are economically valuable to various communities (de Padua et al., 1999; Hamilton, 2004; Hawkins, 2008), but to estimate their value is a complicated process which presumably leads to undervaluation (Org and Brandon, 2014). Nonetheless, in 2018, medicinal plants and related products' global export value was estimated at $3.3 billion (Timoshyna et al., 2020).

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Indonesia is a country rich in biodiversity (Vavilov, 1935; Ma et al., 2010) with 30,000–40,000 plant species (Myers et al., 2000; Ministry of National Development Planning, 2016), and 2500–7500 of these species are medicinal plants (Hamid and Sitepu, 1990; Eisai, 1995; Erdelen et al., 1999), whether native or introduced species, and whether wild or cultivated species (de Padua et al., 1999). Their value has been recognised around the globe for centuries (Vavilov, 1935; de Padua et al., 1999), for the use as drugs and cosmetics, and their use in both traditional and current ways (Kolberg and Piterson, 1996; Ministry of Agriculture, 2014; 2015).

Due to illegal trade, overexploitation and invasive species, medicinal plant species populations in Indonesia are declining (Hawkins, 2008; Ma et al., 2010). Additionally, as with all biodiversity, plants are also lost due to forest fires, and deforestation during land conversion intended to construct plantations and public facilities (The World Bank, 2016; Gaveau et al., 2018). On a broader level, medicinal plants would also be negatively affected by climate change, especially because of rising sea levels, wave heights, and ocean temperatures (Bellard et al., 2014, Zikra et al., 2015), the soil temperature rise (Sentinella et al., 2020), and human activity (Nurse et al., 2014). In addition, the waning local knowledge and skills needed to use medicinal plants (Stevenson, 1998) might contribute to their loss, as well as a general lack of concern over these plants facing the aforementioned threats (Hamilton, 2004).

Generally speaking, conservation and conservation planning are not advanced practices in Indonesia, which is largely due to the reserved areas for the livestock and sacred areas for the religious purposes owned by local peoples (Carew-Reid, 2002). So far, *in situ* and *ex situ* conservation have been carried out in Indonesia for plant species to some extent. *In situ* conservation is defined as "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings where they have developed their distinctive properties" and *ex situ* conservation as "the protection of components of biological diversity outside their natural habitats" by Convention on Biological Diversity (UN, 1992). The home gardens as *in situ* conservation, called TOGA (Tanaman Obat Keluarga) or Family Medicinal Plant, are already considered a form of *in situ* conservation, where local people maintain the genetic diversity of these species (Watson and Eyzaguirre, 2001; Maxted et al., 2013a), in Indonesia National Policy on Traditional Medicines (KOTRANAS) (Ministry of Health, 2007). *Ex situ* field collections of medicinal plants have been undertaken in Java island, like at the Tawangmangu gardens in Central Java under the Department of Health of the Ministry of Health, two highland gardens (Manoko and Gunung Putri) and three lowland gardens (Cikampek, Sukamulya and Cimanggu) under the Research Center for Spices and Medicinal Plants (Indonesia-FAO, 2011). The Sriwijaya regional botanical garden in Sumatra islands also collects medicinal plants, other than wetlands plants (Purnomo et al., 2015). Traditional medicine industries also usually have a medicinal plants collection where *ex situ* or *in situ* gap analysis can be done (Indonesia-FAO, 2011). However, in light of the numerous medicinal plants and Indonesia's size in general, there is a big gap in their plants conservation.

To assist in conservation planning, gap analysis has been done in many flora species and groups. For example, it has been done in wild *Hordeum* species (Vincent et al., 2012), *Aegilops* species (Maxted et al., 2008), Crop Wild Relative (CWR) groups (Meilleur and Hodgkin, 2004; Fielder et al., 2015; Tas et al., 2019; Phillips et al., 2019), and threatened medicinal plants (Chi et al., 2017). Gap analysis is a method to identify areas in which selected elements of biodiversity are under-represented, whether on a local, national or global scale, and whether *in situ* or and *ex situ* (Burley, 1988; Margules and Pressey, 2000). Technically, it involves defining the species or species groups that would be conserved, assessing current *in situ* and *ex situ* analysis, reformulating conservation strategy, and defining future challenge gaps (Maxted et al., 2008). This study aims to analyse current Indonesian priority medicinal plant species diversity and provide recommendations for *in situ* and *ex situ* conservation action. The priority species are based on Cahyaningsih et al.'s study (2021, in press) native to Indonesia, have limited distributions, are harvested destructively, and/or those included in the IUCN Red List of Threatened Species (https://www.iucnredlist.org; IUCN, 2020), those included in Appendices I and II of the Convention on International Trade in Endangered Species of Fauna and Flora (https://checklist.cites.org; UNEP-WCMC (Comps.), 2020), those included in Indonesian national legislation, namely Indonesian Government Regulation Act. 7 of 1999 regarding Natural Genetic Resources and Its Ecosystem, Decree of Forestry Ministry No 57/MENHUT-II/2008 regarding Strategy Direction of National Species Conservation 2008–2018, Decree of Environmental and Forestry Ministry No. P.20/MENLHK/SETJEN/KUM.1/6/2018 regarding the Protected Flora and Fauna Species, Decree of Environmental and Forestry Ministry P.106/MENLHK/SETJEN/KUM.1/12/2018 revised decree of Environmental and Forestry Ministry P.92/MENLHK/SETJEN/KUM.1/8/2018 (replaced the Decree of Environmental and Forestry Ministry No. P.20/MENLHK/SETJEN/KUM.1/6/2018) regarding the Protected Flora and Fauna Species, and rare plant stated in IBSAP (Indonesia Biodiversity Strategy and Action Plan, The National Development Planning Agency (2003)). Meanwhile, there are three specific objectives, namely (1) to identify the richest area of Indonesian priority medicinal plant species, (2) to identify areas where additional ex situ priority medicinal plant species should be collected, and (3) to recommend existing protected sites and sites outside protected areas (PAs) that might create the basis of *in situ* genetic reserves to conserve the Indonesian priority medicinal plant species.

2. Methods

We used 233 Indonesian priority medicinal plant species (Cahyaningsih et al., 2021, in press; result; Table A1) in gap analysis study. The applied methods on gap analysis were adapted from Maxted et al. (2008); Fielder et al. (2015); Tas et al. (2019); Phillips et al. (2019). Data for priority medicinal plant species of Indonesia were collated from online database that was from GBIF (http://www.gbif.org; GBIF, 2020), Genesys (https://www.genesys-pgr.org; Genesys, 2020), BOLD database (http://www.boldsystems.org; Ratnasingham and Hebert, 2007), Missouri Botanical Garden's Tropicos database

(Tropicos.org, 2020) and herbarium databases from Indonesia (Herbarium Bogoriense and), and abroad (Royal Botanic Garden, Kew; Royal Botanic Garden, Edinburgh; and The Natural History Museum in the United Kingdom, and also Naturalis herbarium in the Netherlands) and living collection database from Bogor Botanic Gardens—Indonesian Institute of Sciences in Indonesia. The occurrence data were recorded as longitude and latitude decimals and nomenclature followed from Plants of the World Portal (http://plantsoftheworldonline.org/, POWO, 2020). The majority of specimens lacked coordinates therefore these were found from location data in Google Earth (http://www.cartographic.info). In some cases, some inaccurate specimens' records, for example were only found in the main island without exact location but the collector was available, the occurrences were able to track from http://www.nationaalherbarium.nl/FMCollectors/Home.htm. All collected data were examined using DIVA-GIS 7.5 software to identify locations on land and inside the Indonesia border, otherwise to re-examine the data and either correct the record or exclude it.

An examination of the richness of species and potential bias of observation analyses were undertaken in the DIVA-GIS 7.5 (Hijmans et al., 2001). Country boundary files were obtained from www.diva-gis.org. The species richness was used to identify diversity hotspots that contain the highest number of different medicinal plant species in Indonesia. The bias was used to identify areas where a majority of species (or collections or observations) are located based on occurrence data. Species richness was assessed using the Point to Grid function. The parameter of species name was selected. A new grid was created with a grid cell size set at 0.45 (equivalent to 50 km × 50 km or 2500 km^2), the point to grid procedure of Simple was selected, and the output variable was set as Richness with No Data hidden. For observational bias, the steps were the same; however, the output variable selected was set at Number of Observations. The program automatically defined the number class, the value in each class of species richness, and the observation bias.

A complementarity analysis (reserve selection) was conducted in DIVA-GIS 7.5 by selecting Reverse Selection in the Point to Grid function. The scoring approach parameters used was Equal weight with the maximum number of iterations chosen. This analysis was undertaken with the Point to Grid procedure. To establish an effective network (reserve site) for *in situ* conservation, grid cells were selected that capture a maximum number of plant species (Hijmans et al., 2001). The application was used to adapt the work of Rebelo (1994), in that the study selected the grid cells with the highest number of species, and then selected species within the cell were excluded from the analysis (this is repeated until all species have been selected). The complementary analysis value was obtained by the Arc-Map 10.4.1 tool, that is number of different species in a cell compared to previous cells (unique species). The results were overlapped with 733 protected areas (PAs) in Indonesia, which were downloaded from the World Database on Protected Areas (the "WDPA Materials") available at the ProtectedPlanet.net website (UNEP-WCMC et al., 2018). The complementarity map would be the proposed *in situ* reserve site, which will help to conserve most Indonesian medicinal plant species efficiently. An *ex situ* gap analysis was undertaken by comparing the maps of all species richness (= all observations) with *ex situ* collected species richness using the overlay function in DIVA GIS 7.5.

3. Results and discussion

3.1. Species richness and observation bias of Indonesian priority medicinal plant species

A map of species' richness and observation bias of priority medicinal plant species in Indonesia was created from a total of 6704 occurrence points. The map of species richness (Fig. 1) showed that the richest area (red colour) is in the western part of Java, particularly around the West Java and Banten province region, Mount Gede-Pangrango and Mount Halimun-Salak. Here,

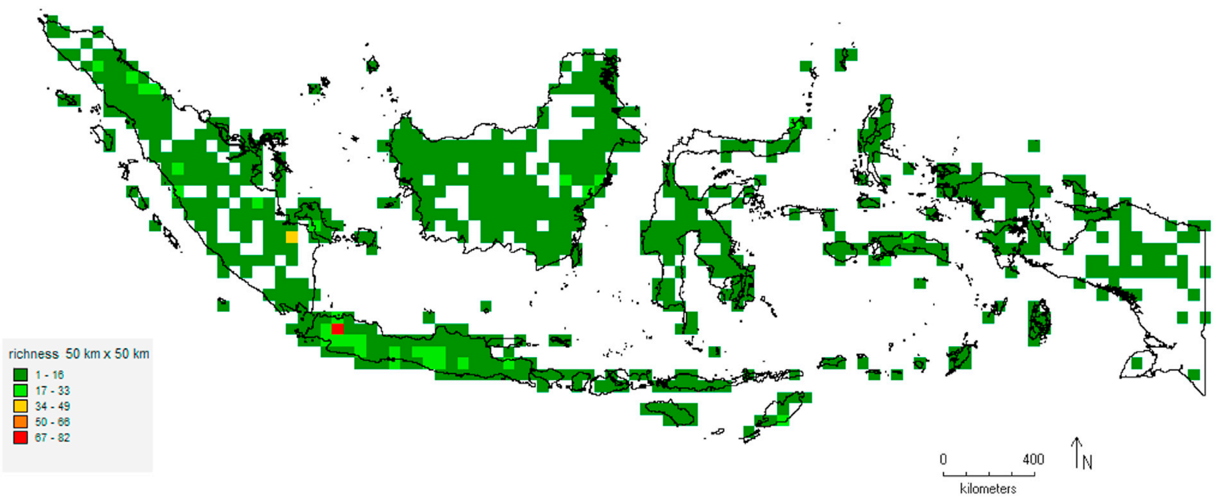

Fig. 1. Species richness map of priority medicinal plant species (grid of 50 km x 50).

67–82 priority species are found per area of 2500 km^2 (grid size) and are mostly found within PAs, for example Gunung Halimun Salak National Park, Gunung Gede Pangrango Nature Park, and Gunung Mega Mendung Nature Reserve.

Medicinal plant species are distributed across all the major islands but there is at least one grid cell that is richer than its surrounding area (other cells), apart from Papua. The richness map shows the Sundalands which encompasses Sumatra, Java, and Kalimantan island, the Wallacea which encompasses the Lesser Sunda Islands (LSI), Sulawesi, and Maluku islands, and the Australia area which encompasses Papua. According to Myers et al. (2000), Sundalands and Wallaceae are included in a hotspot meaning they have richer biodiversity than Australia, although it is allegedly because there has been less collection in Papua than in other areas.

The observational bias map of Indonesian priority medicinal plant species (Fig. 2) shows that almost all of the species rich areas occur also contain high number of species observations, particularly in the western part of Java island with 291–363 priority species per one grid cell (2500 km^2). Western Java, especially Bogor Regency and its surroundings, are mountainous areas such as Mount Salak and Mount Gede-Pangrango where many plants are located, as well as the nearby capital city of Jakarta. Most research on medicinal plant species is currently conducted in the Natural Reserve of Mount Gede Pangrango (Fahrurozi et al., 2016; Astutik et al., 2016). Jepson and Whittaker (2002) stated that botanists collect plants in easy-to-access areas more often than not so most of the sites with species richness may be due to the ease of plant collection rather than reflecting true diversity itself. However, since western Java island, namely Banten, West Java, and the Special Region for the Capital City Jakarta (DKI Jakarta) province have the highest population density in Indonesia (BPS-Statistics Indonesia, 2019), it is a concern for the area to save the medicinal plant species in active *in situ* conservation.

The identified areas where observation bias occurred can be traced to a current lack of knowledge for most species or species group distribution; this is known as the Wallacean shortfall (Bini et al., 2006; Hortal et al., 2014). This mostly occurs in tropical biodiversity hotspot areas (Bini et al., 2006), when high plant diversity in one area is in line with a high collection number, then the area may not represent the actual plant diversity that occurs in reality (Monsarrat et al., 2019). Distribution modelling of species may rectify the bias in data since it will reveal the predicted distribution of the plants that represent the diversity, regardless of the attractiveness of area to plant collectors (Bini et al., 2006; Monsarrat et al., 2019).

3.2. *In situ and ex situ gap analysis of Indonesian priority medicinal plant species*

The complementary analysis resulted in 41 grid cells of networks (reserve sites), shown in Fig. 3 and Table 1. Some 33 out of 41 reserve sites overlap with protected areas (PAs) and can be found in Indonesia's major islands. These overlapping areas currently have passive conservation for Indonesian priority medicinal plant species that could be sites for future active conservation plans for medicinal plants. In addition, outside of the current PAs, eight reserve sites are recommended for priority purposes as potential new protected areas, four in Kalimantan, three in Sumatra and one in Java island (Fig. 3).

In situ conservation of Indonesian priority medicinal plant species is very important because it would protect three conditions: conservation of ecosystems, viable populations, and natural habitats (UN, 1992; Badola and Aitken, 2003). Medicinal plants have been passively conserved in existing PA, therefore species management and monitoring are conducted after as a form of active conservation (Iriondo et al., 2012). In existing PA, the *in situ* conservation could be done on-farm (Watson and Eyzaguirre, 2001; Maxted et al., 2013b). "*Quasi in situ*", or a bridge between *in situ* and *ex situ*, species conservation could be initiated, as the maintaining space for collection will be less and costs will be lower, within highly suitable

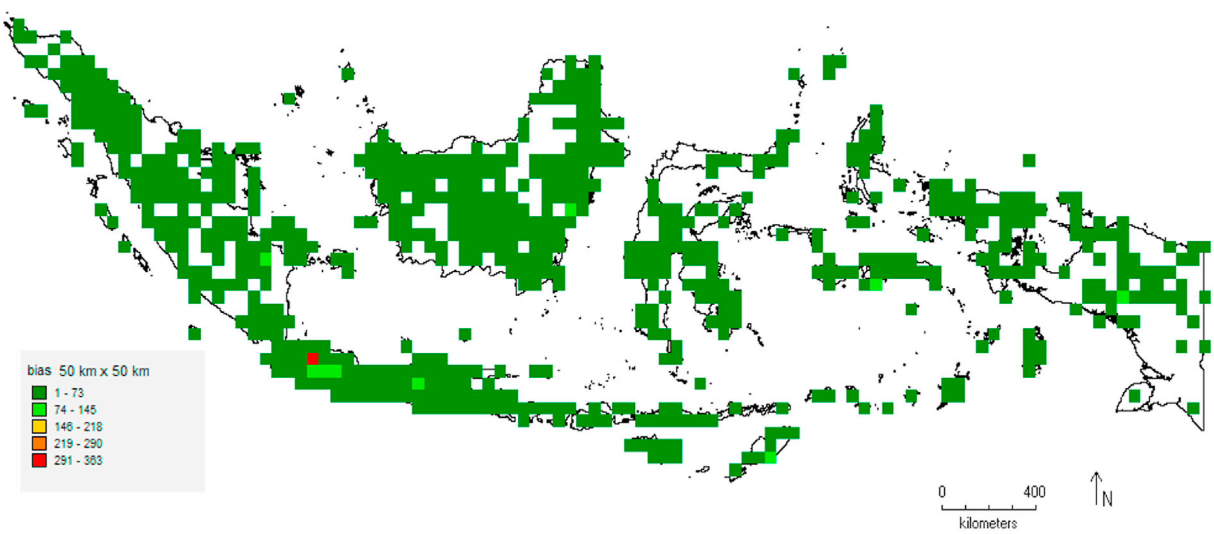

Fig. 2. Bias of observation map of Indonesian priority medicinal plant species (grid of 50 km × 50 km).

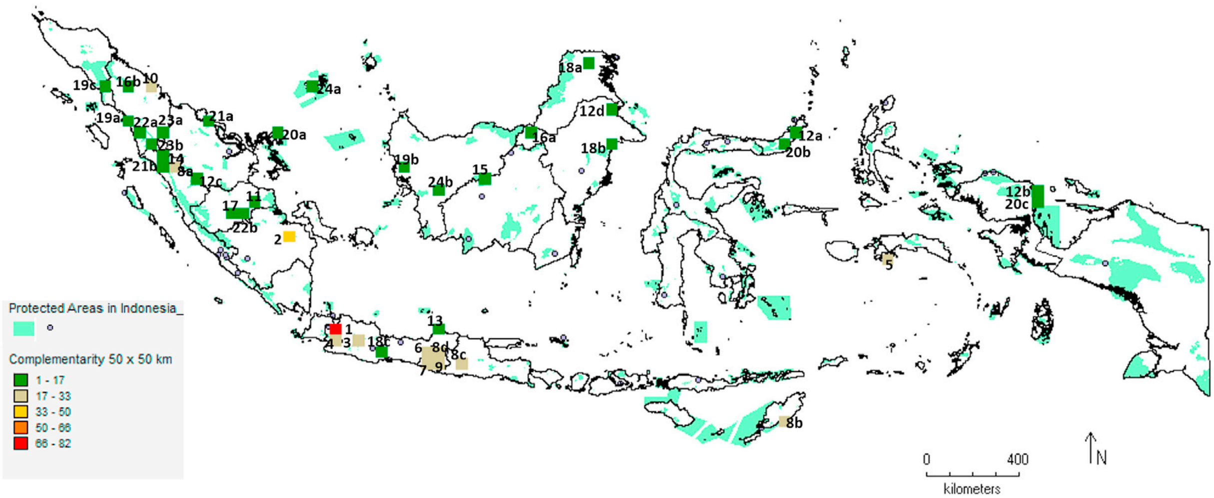

Fig. 3. The complementary network areas map (grid of 50 km × 50 km) which conserve Indonesian priority medicinal plant species and overlapped with PA (in light green) for their *in situ* conservation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Site proposed for *in situ* conservation of priority medicinal plants species of Indonesia.

Reserve site	PA area	No. Protected Species	No. Unique species	Location (Province)	Major island
1	Gunung Pancar Nature Recreation Park; Gunung Halimun Salak National Park; Gunung Gede Pangrango Nature Park; Pancoran Mas Grand Forest Park; Rompi Nature Recreation Park; Arca Domas Nature Reserve; Gunung Mega Mendung Nature Reserve	82	82	West Java, Banten, Jakarta	Java
2	Padang Sugihan Wildlife Reserve	34	20	South Sumatra	Sumatra
3	Ir. H. Juanda Grand Forest Park; Gunung Burangrang Nature Reserve; Gunung Tangkuban Parahu Nature Recreation Park; Gunung Masigit Kareumbi Hunting Park; Kawah Kamojang Nature Reserve; Gunung Tilu Nature Reserve	33	8	West Java	Java
4	Gunung Halimun Salak National Park; Gunung Gede Pangrango Nature Park; Takokak Nature Reserve; Tangkuban Prahu Pelabuhan Ratu Nature Reserve; Situgunung Nature Recreation Park; Cibodas Biosphere Reserve (Gunung Gede-Pangrango) UNESCO-MAB Biosphere Reserve	31	4	West Java	Java
5	Teluk Ambon Marine Multiple Use Reserve	30	10	Maluku	Maluku
6	Gebukan Nature Reserve; Sepakung Nature Reserve; Gunung Merbabu National Park; Gunung Merapi National Park; Gunung Bunder Grand Forest Park; Imogiri National Reserve; Paliyan Wildlife Reserve; Plawangan Turgo Nature Recreation Park	28	1	Central Java, Yogyakarta	Java
7	Gunung Merapi National Park; Gunung Bunder Grand Forest Park; Imogiri National Reserve; Paliyan Wildlife Reserve; Plawangan Turgo Nature Reserve	26	15	Yogyakarta, Central Java	Java
8a	Lembah Harau Nature Reserve; Lembah Harau Nature Recreation Park; Gunung Sago Malintang Nature Recreation Park; Gunung Marapi Nature Recreational Park; Singgalang Tandikat Nature Recreation Park; Batang Palupuh Nature Reserve	23	10	West Sumatra	Sumatra
8b	Ale Aisio Wildlife Reserve; KKPN Laut Sawu Marine National Park	23	4	East Nusa Tenggara	LSI
8c	Sigogor Nature Reserve; Picis Nature Reserve	23	2	East Java	Java
8d	Getas Nature Reserve	23	1	Central Java	Java
9	No	20	2	Central Java, Yogyakarta	Java
10	No	18	4	North Sumatra	Sumatra
11	No	17	2	Jambi	Sumatra
12a	Gunung Lokon National Park; Gunung Manembo-nembo Wildlife Reserve; Bunaken Marine National Park	16	6	North Sulawesi	Sulawesi
12b	Gunung Meja Nature Recreation Park; Pegunungan Arfak Nature Reserve	16	6	West Papua	Papua
12c	Bukit Rimbang Bukit Baling Wildlife Reserve; Batang Pangean I Nature Reserve	16	4	West Sumatra, Riau	Sumatra
12d	KPPD Kepulauan Derawan dan Perairan Sekitarnya Coastal and Small Island Park	16	1	East Kalimantan	Kalimantan
13	Gunung Celering Nature Reserve; Keling I Nature Reserve; Keling II/III Nature Reserve	15	1	Central Java	Java
14	Rimbo Panti Nature Recreation Park; Malampah Alahan Panjang Wildlife Reserve	11	2	West Sumatra, North Sumatra, Riau	Sumatra

(*continued on next page*)

Table 1 (*continued*)

Reserve site	PA area	No. Protected Species	No. Unique species	Location (Province)	Major island
15	Bukit Baka-Bukit Raya National Park	10	7	Central Kalimantan, West Kalimantan	Kalimantan
17	Bukit Dua Belas National Park	8	3	Jambi	Sumatra
16a	no	9	3	East Kalimantan, North Kalimantan	Kalimantan
16b	Bukit Barisan Selatan Grand Forest Park; Tinggi Raja Nature Reserve; Martelu Purba Nature Reserve	9	2	North Sumatra	Sumatra
18a	no	7	2	North Kalimantan	Kalimantan
18b	Kutai National Park	7	1	East Kalimantan	Kalimantan
18c	Rawa Cipanggang Nature Reserve	7	1	West Java, Central Java	Java
19a	KKPD Kabupaten Tapanuli Tengah, Kawasan Konservasi Perairan Daerah Kabupaten Tapanuli Tengah Locally Managed Marine Area	6	2	North Sumatra	Sumatra
19b	no	6	1	West Kalimantan	Kalimantan
19c	Gunung Leuser National Park; Rawa Singkil Wildlife Reserve	6	1	Aceh; North Sumatra	Sumatra
20a	Bintan Locally Managed Marine Area	5	3	Bangka Belitung	Sumatra
20b	Gunung Ambang Nature Reserve; Bogani Nani Wartanobe National Park	5	1	North Sulawesi	Sulawesi
20c	Pegunungan Arfak Nature Reserve	5	1	West Papua	Papua
21a	Bukit Batu Wildlife Reserve	4	1	Riau	Sumatra
21b	Malampah Alahan Panjang Wildlife Reserve; Maninjau Nature Reserve; KKPD Kabupaten Agam, Kawasan Konservasi Perairan Daerah Kabupaten Agam Locally Managed Marine Area	4	1	West Sumatra	Sumatra
22a	Batang Gadis National Park	3	1	North Sumatra	Sumatra
22b	Sultan Thaha Syaifuddin Grand Forest Park; Durian Luncuk I, II Nature Reserve;	3	1	Jambi, South Sumatra	Sumatra
23a	Batang Gadis National Park; Barumun Nature Reserve	2	1	North Sumatra, Riau	Sumatra
23b	No	2	1	North Sumatra, West Sumatra	Sumatra
24a	KKPN Kepulauan Anambas dan Laut Sekitarnya Marine Recreation Park	1	1	Riau Islands	Sumatra
24b	No	1	1	West Kalimantan	Kalimantan

Noted: LSI = the Lesser Sunda Islands.

environments allowing for natural maintenance for medicinal plants (Volis and Blecher, 2010). The human populations surrounding PAs could either actively conserve as a priority or contribute to plants' extinction. To help with *in situ* conservation action, the government could introduce legislation regarding how to protect and use medicinal plants and how to promote conservation education by conservationists (Volis, 2019).

The *ex situ* gap analysis showed that the area most in need of further collection is the Western part of Java and Maluku (Fig. 4). These areas are habitats where Indonesian priority medicinal species are found most frequently but have not been collected for ex situ conservation. Taking into account their habitat degradation, especially due to high recorded deforestation (average forest loss reaches 1.3M ha/year, 2000–2017) (FWI, 2020), *ex situ* conservation for Indonesian priority medicinal species is crucial.

Thirty-eight Indonesian priority medicinal plant species are undercollected species (having less than five occurrence records) (Table 2). Twelve species out of 38 undercollected species have no recorded occurrence in wild collections. In addition, six priority species out of them have been conserved in *ex situ* sites. These species should take first place in conservation plan that is to conduct surveys in wild habitats to record their occurrences. They would be maintained and propagated outside of their habitat using conventional methods as well as advanced biotechnology (Ford-Lloyd et al., 2011), and would be well-documented, as a genetically representative collection (BGCI, 2012) that could be in the form of seed, pollen, DNA, in vitro storage, field gene bank, or even in a botanic garden (Maxted et al., 2013b). Living collections in botanic gardens would facilitate propagation and botany research, public education, species reintroduction and habitat restoration programmes (IPGRI, 2004; BGCI, 2012).

The effective *in situ* and *ex situ* conservation of Indonesian medicinal plant species should be a regional and global priority. Considering Indonesia is one of the biggest archipelagos in South East Asia with vast size and rich biodiversity (Myers et al., 2000; van Welzen et al., 2011, Mittermeier et al., 2011). Moreover, the country is home to an estimated 10% of world plant species (Walujo, 2008). It is one of the Centres of Origin of Cultivated Plants, accommodating many cultivated plants for many ethnobotanical purposes (Vavilov, 1935).

There is a large conservation gap in Indonesian priority medicinal plant species forming part of conservation planning, although those species are part of 60–90% of global wild harvested medicinal plants and have faced a threefold increase in trade since 1999 (Jenkins et al., 2018). Thus, *in situ* and *ex situ* conservation for Indonesian priority medicinal plant species have to be combined, principally in propagation to support reintroduction and to provide suitable environmental conditions for further domestication (Baričević, 2009). Both approaches to conservation are inter-linked as they are complementary and

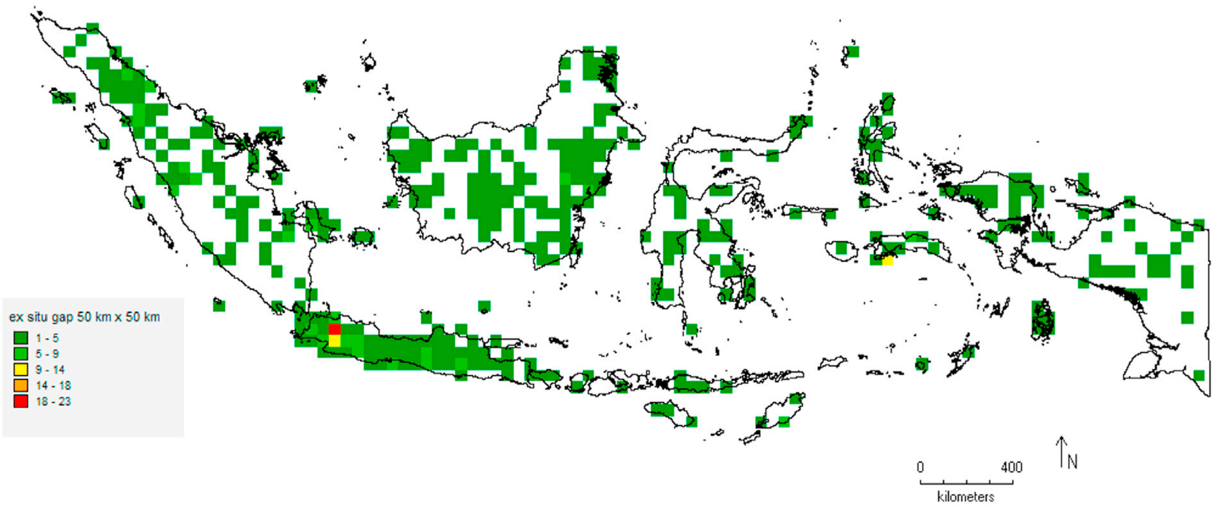

Fig. 4. *Ex situ* gap map of Indonesian priority medicinal plant species conservation (grid of 50 km × 50 km).

Table 2
Indonesian priority medicinal plant species with less than five occurrence points.

No.	Scientific name (POWO, 2020)	Family	*Ex situ*	Occ. points	Note
1	*Avicennia marina* var. *rumphiana* (Hallier f.) Bakh.	Acanthaceae	A	2	
2	*Myriopteron extensum* (Wight) K.Schum.	Apocynaceae	A	0	Unclear location
3	*Alocasia cuprea* K.Koch	Araceae	A	0	No Indonesia
4	*Johannesteijsmannia altifrons* (Rchb.f. and Zoll.) H.E.Moore	Arecaceae	A	1	
5	*Saribus woodfordii* (Ridl.) Bacon and W.J.Baker	Arecaceae	A	0	No Indonesia (PNG)
6	*Balanophora fungosa* subsp. indica (Arn.) B.Hansen	Balanophoraceae	A	1	
7	*Garcinia amboinensis* Spreng.	Clusiaceae	A	0	cultivated in Bogor BG
8	*Rourea fulgens* Planch.	Connaraceae	A	1	
9	*Erycibe aenea* Prain	Convolvulaceae	A	3	
10	*Fimbristylis falcata* (Vahl) Kunth	Cyperaceae	A	0	No Indonesia (PNG)
11	*Homalanthus longistylus* K.Schum. and Lauterb.	Euphorbiaceae	A	0	No Indonesia (PNG)
12	*Entada spiralis* Ridl.	Fabaceae	A	1	
13	*Gnetum tenuifolium* Ridl.	Gnetaceae	A	1	
14	*Hibiscus celebicus* Koord	Malvaceae	A	4	
15	*Dissochaeta punctulata* Hook.f. ex Triana	Melastomataceae	A	3	
16	*Heynea trijuga* Roxb.	Meliaceae	A	3	
17	*Nepenthes ampullacea* Jack	Nepenthaceae	A	1	
18	*Dendrobium faciferum* J.J.Sm.	Orchidaceae	P (N)	4	
19	*Dendrobium hymenanthum* Rchb.f.	Orchidaceae	A	0	No Indonesia (Asean)
20	*Dendrobium utile* J.J.Sm.	Orchidaceae	P (N)	0	No gbif data
21	*Erythrorchis altissima* (Blume) Blume	Orchidaceae	A	3	
22	*Hetaeria obliqua* Blume	Orchidaceae	P (N)	3	
23	*Oberonia mucronata* (D.Don) Ormerod and Seidenf.	Orchidaceae	A	1	
24	*Strongyleria pannea* (Lindl.) Schuit., Y.P.Ng and H.A.Pedersen	Orchidaceae	P (N)	1	
25	*Vanda miniata* (Lindl.) L.M.Gardiner	Orchidaceae	A	1	
26	*Vanilla abundiflora* J.J.Sm.	Orchidaceae	P (N)	3	
27	*Vanilla* griffithii Rchbf	Orchidaceae	P (N)	3	
28	*Pandanus robinsonii* Merr.	Pandanaceae	A	2	
29	*Piper attenuatum* Buch.-Ham. ex Miq.	Piperaceae	A	1	
30	*Oldenlandia recurva* (Korth.) Miq.	Rubiaceae	A	0	No gbif data
31	*Prismatomeris tetrandra* subsp. malayana (Ridl.) J.T.Johanss.	Rubiaceae	A	1	
32	*Rennellia morindiformis* (Korth.) Ridl.	Rubiaceae	A	4	
33	*Uncaria homomalla* Miq	Rubiaceae	A	1	
34	*Palaquium hispidum* H.J.Lam	Sapotaceae	A	0	No Indonesia (Malaysia)
35	*Pipturus asper* Wedd.	Urticaceae	A	3	
36	*Ampelocissus cinnamomea* (Wall.) Planch.	Vitaceae	A	2	
37	*Amomum sumatranum* (Valeton) Skornick. and Hlavatá	Zingiberaceae	A	0	No gbif data
38	*Kaempferia undulata* Wender.	Zingiberaceae	A	0	Unclear location

Notes: A: Absent, P: Present in national *ex situ* conservation.

provide a safety back-up (Maxted et al., 2020). Conservation action applied to crop wild relatives, such as management and monitoring following the quality standards of genetic reserves (Iriondo et al., 2012), could also be applied to Indonesian medicinal plant species, which is generally for maximising their availability for users in a sustainable manner (Maxted et al., 1997). The complementary analysis within the current PA network might be more economical because it requires only a few adaptions to existing management plans (Maxted and Kell, 2009). The success of medicinal plant species conservation needs to be managed within board fields, namely several different groups with their expertise such as agronomy, conservation, and ethnobotany (Hawkins, 2008). Moreover, conducting *in situ* conservation in many reserves sites and further plant collections for ex situ conservation would be possible when local stakeholders seriously take conservation action (Phillips et al., 2019).

4. Conclusion

We propose four recommendations to conserve the Indonesian priority medicinal plant species actively for the short term and long term and to support the sustainable availability of material for related stakeholders, that are as follows:

1. Establish species distribution models for Indonesian priority medicinal plant species as base maps to decrease the bias of observation and conduct further surveying for the current population study. Scientists like botany researchers, plant conservationists and ethnobotanists from government or private institutions might complete this surveying.
2. Create active conservation in current protected areas for bridging *in situ* and *ex situ* conservation (Volis and Blecher, 2010) of Indonesian priority medicinal plant species which are used to passive conservation, and the establishment of new protected areas to strengthen the conservation of priority medicinal plant species in order to maximise the PA roles in priority conservation (Fig. 3 and Table 1). These *in situ* reserve sites could protect priority species, providing important information for medicinal plant species stakeholders. Toledo (2018) recommended new protected areas able to conserve more than 5% species of total priority species. Local or national government could create a new policy regarding active conservation for medicinal plant species in related PA. Involving local people surrounding the PA through dissemination from related scientists from government or private institutions would help the conservation action in the field, including monitoring.
3. Undertake domestication and intensive propagation of six priority species underrepresented *in situ* which have already been collected in *ex situ* areas, to support reintroduction of these species to their natural habitat (short-term conservation). Furthermore, introduction of any priority species that is already assessed as threatened with extinction according to the IUCN Red List— in particular, critically endangered species to areas that are predicted to be suitable for the species (though there are no past records that might help their conservation) (Volis, 2019). Botany researchers and plant conservationists from government or private institutions could start from the propagation research, whether conservative or advanced methods have enough provenance, or whether seedlings for planting are best used in the natural habitat of those species.
4. Maintain priority species, including propagated plants, both vegetative or generative, in current *in situ* and *ex situ* conservation areas, to ensure their long-term conservation and sustainable use. All related stakeholders, especially producers of medicinal plant species, might commit to this maintenance, through long-term conservation for sustainable use.

Moreover, this action may meet Aichi Biodiversity targets, namely Target 12, Target 13, and Target 1 in direct and close order. Target 12, Target 13, and Target 1 respectively state “By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained”, “By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimising genetic erosion and safeguarding their genetic diversity”, and “By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably” (CBD, 2015).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table A.1
Priority medicinal plant species included in this study

Family	Genera	Spc. no.	Family	Genera	Spc. no.
Acanth.	Avicennia	1	Marant.	Halopegia	1
	Barleria	1	Melastomat.	Dissochaeta	1
	Hypoestes	1		Medinilla	2
	Pseuderanthemum	1		Oxyspora	2
Achari.	Pangium	1		Phyllagathis	1
Anacardi.o.	Koordersiodendron	1	Meli.	Heynea	1
	Anaxagorea	1		Toona	1
	Goniothalamus	2	Menisperm.	Stephania	1
Api.	Pimpinella	1		Tinospora	1
Apocyn.	Alstonia	2	Mor.	Ficus	2
	Alyxia	3	Myric.	Myrica	1
	Hunteria	1	Myrt.	Syzygium	2
	Rauvolfia	1	Nepenth.	Nepenthes	7
	Urceola	1	Orchid.	Acriopsis	1

Table A.1 (*continued*)

Family	Genera	Spc. no.	Family	Genera	Spc. no.
	Voacanga	1		Apostasia	1
	Willughbeia	1		Arundina	1
Araucari.	Agathis	1		Calanthe	1
Arec.	Borassus	1		Cleisostoma	1
	Caryota	1		Corymborkis	1
	Eugeissona	1		Cymbidium	1
	Iguanura	1		Dendrobium	4
	Johannesteijsmannia	1		Erythrorchis	1
	Phoenix	1		Grammatophyllum	2
	Pigafetta	1		Habenaria	2
Aristolochi.	Thottea	1		Hetaeria	1
Aster.	Blumea	2		Liparis	2
Balanophor.	Balanophora	1		Nervilia	2
Bignoni.	Oroxylum	1		Oberonia	2
Calophyll.	Mesua	1		Renanthera	1
Cardiopterid.	Gonocaryum	1		Robiquetia	1
Ciboti.	Cibotium	1		Spathoglottis	2
Combret.	Terminalia	1		Strongyleria	1
Connar.	Rourea	1		Tropidia	1
Convolvul.	Erycibe	1		Vanda	1
Cucurbit.	Trichosanthes	1		Vanilla	2
Cycad.	Cycas	1	Pandan.	Benstonea	1
Dicksoni.	Dicksonia	1		Pandanus	2
Dioscore.	Dioscorea	2	Phyllanth.	Breynia	1
Dipterocarp.	Anisoptera	3		Phyllanthus	1
	Dipterocarpus	4	Pin.	Pinus	1
	Hopea	3	Piper.	Piper	2
	Parashorea	1	Pontederi.	Pontederia	1
	Shorea	13	Primul.	Ardisia	1
	Vatica	2	Rafflesi.	Rafflesia	2
	Macaranga	1	Rubi.	Catunaregam	1
	Cajanus	1		Mussaenda	1
	Dalbergia	5		Pavetta	1
	Derris	1		Prismatomeris	1
	Entada	1		Psychotria	1
	Euchresta	1		Rennellia	1
	Intsia	1		Uncaria	1
	Koompassia	1	Rut.	Lunasia	1
	Parkia	2		Melicope	1
	Phyllodium	1		Micromelum	1
	Sindora	1		Murraya	1
Fag.	Castanopsis	2		Zanthoxylum	2
	Lithocarpus	2	Santal.	Santalum	1
Gentian.	Gentiana	1	Sapind.	Dodonaea	1
	Utania	1	Schisandr.	Kadsura	1
Gnet.	Gnetum	1	Simaroub.	Eurycoma	2
Gunner.	Gunnera	1		Soulamea	1
Hamamelid.	Exbucklandia	1	Smilac.	Smilax	1
Himantandr.	Galbulimima	1	Stemonur.	Gomphandra	1
Ixonanth.	Ixonanthes	1	Symploc.	Symplocos	2
Lami.	Scutellaria	1	Tax.	Taxus	1
	Vitex	1	Thymelae.	Aquilaria	3
Laur.	Beilschmiedia	1		Gonystylus	2
	Cinnamomum	2	Urtic.	Maoutia	1
	Cryptocarya	1		Nothocnide	1
	Eusideroxylon	1		Pipturus	1
Logani.	Strychnos	2		Poikilospermum	1
Lythr.	Woodfordia	1	Vit.	Ampelocissus	3
Malv.	Grewia	1		Leea	1
	Helicteres	1	Zingiber.	Curcuma	5
	Hibiscus	1		Kaempferia	1
				Wurfbainia	1

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