GENETIC CONSERVATION AND SUSTAINABLE USE OF INDONESIAN MEDICINAL PLANTS

By

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ABSTRACT

As a biodiversity hotspot and the centre of origin of many cultivated plants, including medicinal plant species, Indonesia is a country of precious value to its own people and the world at large. However, Indonesia faces the issues of severe population growth, land conversion, deforestation and climate change that threatens its biological richness. Considering the importance of these species, well-planned and pro-active research efforts, are essential to ensuring their long-term conservation and sustainable utilisation. The empiric chapters in this thesis represented some of these efforts, consisted of prioritisation of species on the checklist according to defined criteria, *in situ* and *ex situ* gap-analysis, a climate change risk assessment, and the study of DNA barcoding for medicinal plant species. These priority listings nominate 233 medicinal plant species in need of conservation and appropriate utilisation. The gap analysis resulted in the determination of where *in situ* and *ex situ* conservation of priority medicinal plants in Indonesia should be done and provided some related recommendation. In addition, based on climate change analysis, the total of 28 priority species are identified to be more threatened in the future and become species target for highest conservation action. Meanwhile, according to DNA barcoding study, we found that *matK* can be the core DNA barcoding and might be supported with *ITS2* and *rbcL*. New DNA barcoding regions of studied Indonesian medicinal plants have also been provided. Generally, the results of this project will lead to a recommendation that supports National Priority Program included in the Mid-Term National Development Plans of Indonesia and in meeting the expectations of the Convention on Biological Diversity (CBD), particularly the Aichi targets and the Global

Strategy for Plant Conservation (GSPC). Besides, this result is fully in line with Indonesia's National Policy on Traditional Medicines, known by the acronym KOTRANAS (Kebijakan Obat Tradisional Nasional).

DECLARATION

The work presented in Chapter 2, Chapter 3, Chapter 4, and Chapter 5 has been prepared for publication in journals. The content of each chapter is largely identical to the manuscript presented for publication, however that text was written by me and all chapters presented here were written in their entirety by me.

Chapter 2 (published)

Cahyaningsih, R., Magos Brehm, J., and Maxted, N. (2021) Setting the priority medicinal plants for conservation in Indonesia. *Genetic Resources and Crop Evolution,* 68, 2019-2050 (https://doi.org/10.1007/s10722-021-01115-6)

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by R.C. The first draft of the manuscript was written by R.C and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Chapter 3 (published)

Cahyaningsih, R., Magos Brehm, J., and Maxted, N. (2021) Gap analysis of Indonesian priority medicinal plant species as part of their conservation planning. *Global Ecology and Conservation*, 26, [e01459]. https://doi.org/10.1016/j.gecco.2021.e01459)

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Chapter 4 (submitted)

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Chapter 5 (submitted)

Cahyaningsih, R., Leach, L., Rahayu, S., Magos Brehm, J., and Maxted, N. (2021). Role of DNA barcoding in facilitating conservation and use of plant species: a case of Indonesian medicinal plant (submitted)

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by R.C. The first draft of the manuscript was written by R.C and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Signed:

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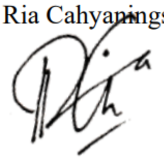

Professor Nigel Maxted Date: 03.06/21

The prophet (peace be upon him) said:

*When the human being dies, his deeds end except for three: ongoing charity, **beneficial knowledge**, or a righteous child who prays for him* [narrated by Muslim]

and

*The best of people are those that **bring most benefit** to the rest of humankind* [narrated by Daraqutni].

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

APETOI	Association of Traditional Medicinal Plant Exporters
BBG	Bogor Botanic Gardens
BOLD	the Barcode of Life Data System
CBD	Convention on Biological Diversity
CBG	Cibodas Botanic Gardens
CBOL	Consorsium for the Barcode of Life
CITES	The Convention on International Trade in Endangered Species of Wild Fauna and Flora
CR	Critically Endangered
DD	Data Deficient
EN	Endangered
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organization
GBIF	The Global Biodiversity Information Facility
GSPC	Global Strategy for Plant Conservation
IBSAP	Indonesia Biodiversity Strategy and Action Plan
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KOTRANAS	Kebijakan Obat Tradisional Nasional (Indonesia's National Policy on Traditional Medicines)
MA	Millennium Ecosystem Assesment
MDGs	Millennium Development Goals
MPNS	Medicinal Plant Names Services
MPSG	Medicinal Plant Specialist Group

MPs	Medicinal Plants
NCBI	The National Center for Biotechnology Information
NHM	Natural History Museum (UK)
PA	Protected Area
PCR	Polymerase Chain Reaction
POWO	Plants of the World Online
PROSEA	Plant Resources of South-East Asia
RBGK	Royal Botanic Gardens, Kew (UK)
RBGE	Royal Botanic Gardens, Edinburgh (UK)
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
TRNS	Taxonomic Name Resolution Service
UN	United Nation
VU	Vulnerable
WDPA	World Database on Protected Areas
WHP	Wild Harvested Plants

CHAPTER 1. GENERAL INTRODUCTION

1.1. Background

1.1.1. Biodiversity and ecosystem services

Biodiversity is the variety of all living organisms at each level from gene level, within species, species, genera, family and any higher taxonomic level to community and the variety of the ecosystem (Wilson, 1992). It is the main element of the ecosystem (Millennium Ecosystem Assessment, 2003). It is not distributed evenly around the globe. There are 36 biodiversity hotspots where high diversity living organism exist in that area yet they are threatened (CEPF, 2020).

Wilson (1992) defines ecosystems as "the organism living in a particular environment, such as a lake or a forest (or, in increasing scale, an ocean or the whole planet) and the physical part of the environment that impinges on them", whilst ecosystem services are described as "the role played by organism in creating a healthful environment for human beings, from production of oxygen to soil genesis and water detoxification". The Millennium Ecosystem Assessment (MA) defines the ecosystem services simply as everything that people benefited from the ecosystem which comprises four categories namely supporting, provisioning, regulating and cultural services (Figure 1.1). Biodiversity and ecosystem health are linked to prosperity of human health and well-being. If biodiversity and ecosystem are healthy, the health and well-being will be achieved (Millennium Ecosystem Assessment, 2005). Furthermore, biodiversity loss and ecosystems degradation can result in a reduced well-being (Sandifer *et al.*, 2015). The linkage of biodiversity and human well-being is also described in Figure 1.1.

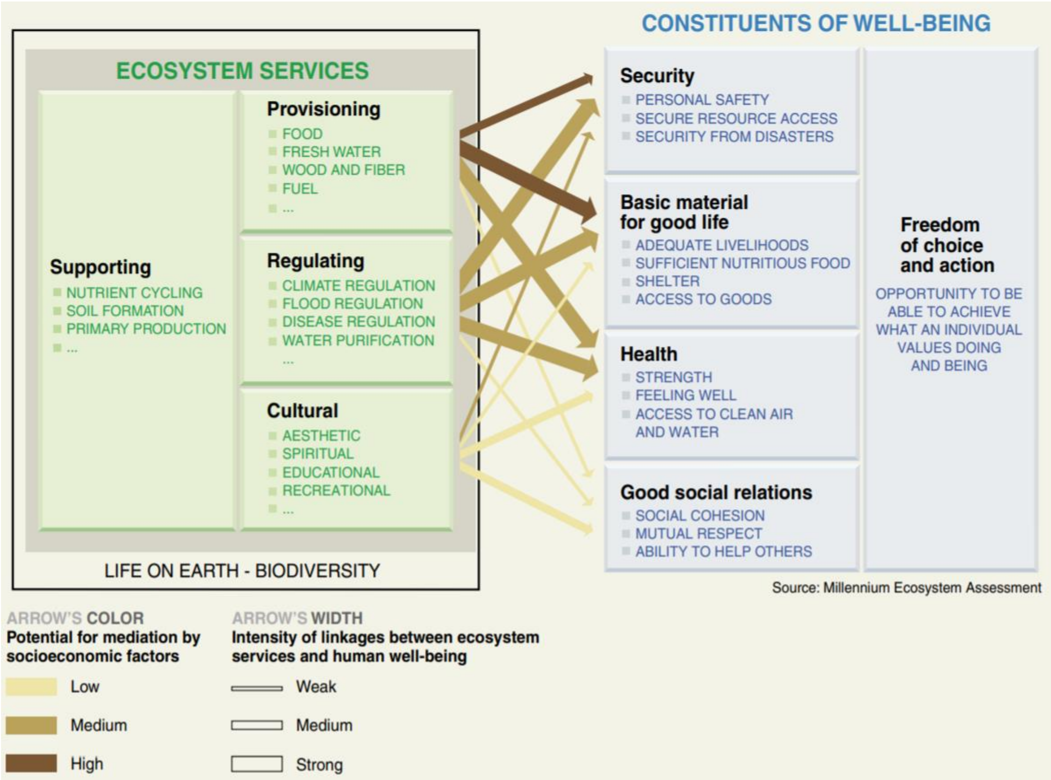

Figure 1.1. A diagram depicts the linkage between ecosystem services and constituents of well-being (Millennium Ecosystem Assessment, 2005)

1.1.2. What are medicinal plants?

Medicinal plants are plant genetic resources 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) whether harvested from the wild and cultivation (WHO, 2003). However, these plants are often wild-harvested from the forest, thus they are included in non-wood forest products, among other valuable biological items besides wood from the forest (NWFPs) (FAO, 1995). In broader view, medicinal plants are part of the biodiversity that also has a role as a provisioning service in ecosystems (Millennium Ecosystem Assessment, 2005).

More than 50,000 higher plant species are estimated to have actual or potential medicinal value (Hawkins, 2008). People worldwide have been using medicinal plants since ancient times, regardless of whether these plants' effects have received validation from modern science (Soejarto *et al.*, 2012). De Padua *et al.* (1999) and Cragg and Newman (2013) record that medicinal plants may be used directly, or for their extracts, or by processing into modern medicines. Walujo (2008) mentioned how to use the medicinal plants directly in traditional medication for examples as a concoction or decoction for internal uses and as a herb-bath and massage for external uses.

1.1.3. Floristic background to Indonesian medicinal plants

The nation of Indonesia is an archipelago consisting of more than 17,000 islands (Figure 1.2). Its land mass is 1,919,440 km^2 (though, including ocean, the total territory covers 3,257,483 km^2). There are five large islands, two groups of medium sized islands, and a multitude of smaller islands. Indonesia is situated between two great oceans — the Indian Ocean and the Pacific Ocean — between latitudes 6^o N and 11^o S, and longitudes 95^o E and 141^o E (Ministry of Environment and Forestry of Indonesia, 2014). The five large islands are Sumatera (47.5 million ha), Java (13.25 million ha), Kalimantan (the southern part of Borneo, 53.5 million ha), Sulawesi (18.6 million ha) and Papua (the western half of New Guinea, 41.5 million ha). The two groups of medium sized islands are Lesser Sunda Islands (8 million ha) and Maluku (7.8 million ha).

Each of the major islands has unique geographical and biological characteristics (Kolberg and Piterson, 1996). The Indonesian archipelago, straddling then divide between Sundaland and Wallacea, and extending to the western reaches of the Sahul shelf (Myers *et al.*, 2000). They partitioned by its flora and fauna into a distinct pattern that was first described by Wallace (Wallace 1856 and 1910 *in* Ministry of Environment and Forestry of Indonesia, 2014) and then confirmed by many other studies (Weber 1904 and Lydekker 1896 *in* Ministry of Environment and Forestry of Indonesia, 2014). Moreover, all those areas are inhabited by more than 350 ethnicities, each with unique characteristics, that comprise the Indonesian population (Ministry of Environment and Forestry of Indonesia, 2014).

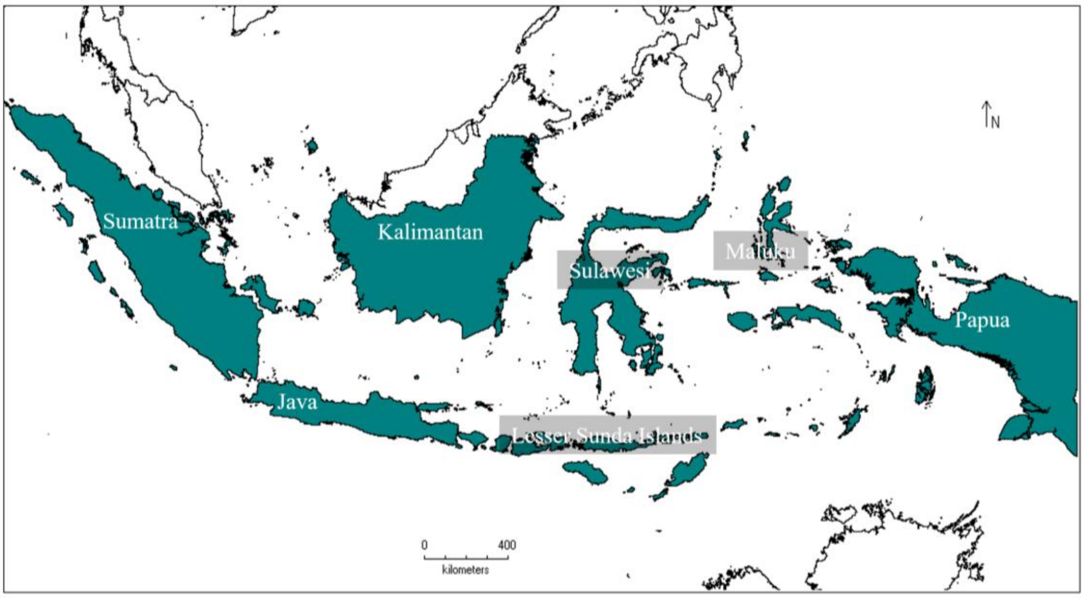

Figure 1.2. Map of Indonesia generated by DIVA-GIS version 7.5

Floristically, Indonesia is a part of the Indo Malayan Centre, one of the Centres of Origin of Cultivated Plants and therefore home to many cultivated plants (crops) used as sources of food, medicines, and material for other ethnobotanical purposes (Vavilov, 1935). Besides this, Indonesia is recognised as a "megadiverse" country and considered as a biodiversity hotspot with 30,000-40,000 plants (Myers *et al.*, 2000; Ministry of National Development Planning, 2016) out of the 90,000-100,000 vascular plant species dispersed throughout Asia (Ma, 2010) and it is estimated about 10% of global plant species (Walujo, 2008).

A number of the world's important medicinal and spice plants are of Indonesian origin (Vavilov, 1935), including ginger (*Zingiber officinale* Roscoe), candlenut (*Aleurites moluccanus* (L.) Willd.), black pepper (*Piper nigrum* L.) and nutmeg (*Myristica fragrans* Houtt.). Spices of significant commercial value exported from Indonesia include cloves (*Syzygium aromaticum* (L.) Merr. & L.M.Perry), cinnamon (*Cinnamomum verum* J.Presl) and nutmeg (Hermawan, 2015). These have traditionally been used as medicines in Indonesia. This was since Dutch colonisation, in the 17th-18th centuries, Indonesia has been cultivating cloves, nutmeg, and coffee (*Coffea arabica* L.) (Ceertz, 1963 *in* Brockway, 1979). Meanwhile, cinchona (*Cinchona officinalis* L.) (Allen and Donnithorne, 1962 *in* Brockway, 1979), coffee and cinchona were introduced species by Dutch (Brockway, 1979).

Medicinal plants have an ancient history in Indonesia. Some were depicted in stone reliefs on Javanese temples such as Borobudur, Prambanan, Penataran and Sukuh. Among the medicinal plants depicted in stone were *Aegle marmelos* (L.) Correa, *Antidesma bunius* (L.) Sprengel, *Borassus flabellifer* L., *Calophyllum inophyllum* L., *Datura metel* L. and *Syzygium cumini* (L.) Skeels. The earliest European information concerning medicinal plants in Indonesia was gathered by the Dutch physician Bontius (1658), who compiled a list of Java medicinal plants, describing their healing power and uses (de Padua *et al.*, 1999). The first detailed descriptions of Indonesian medicinal plants were recorded by Rumphius in his monumental work entitled *Het Amboinsche kruidboek* (*Herbarium Amboinense)*. This multi-volume compendium was based on Rumphius's detailed observation and experience of Indonesian people and their use of indigenous flora and fauna during the Dutch colonisation of Indonesia, especially in the Ambon area (Rumphius, 1741–1755). Other significant works on Indonesian medicinal plants, published in the twentieth century, include those of Heyne (1927), Van Steenis-Kruseman (1953) and Burkill (1966). More recently, de Padua *et al.* (1999) have comprehensively reviewed the medicinal plants (plus poisonous plants) of South East Asia, including those of Indonesia.

In Indonesia, medicinal plants are defined as those plants and/or their components used as drugs, cosmetics, or in promoting good health. It has been estimated that there are around 7,500 species of medicinal plants grown in Indonesia, of which around 187 species are used as the key ingredients in the traditional medicine industry (Hamid and Sitepu, 1990), however, Erdelen *et al.* (1999) estimated only 10% of the total plant species are medicinal. The Medicinal Herb Index in Indonesia published by PT Eisai (1995), lists more than 2500 plant species that have medical uses. Most of these plants are processed within country to produce traditional medicines (jamu) and ingredients for cosmetics (Kolberg and Piterson, 1996).

The medicinal plants as a group can be divided into rhizomatous plants (e.g. from the Zingiberaceae family) and non-rhizomatous. Many medicinal species are horticultural plants like ginger and galangal, while some of them are grown as estate crops, including pepper, cloves, and jatropha (Ministry of Agriculture, 2014, 2017). Whilst the traditional medicines based on biological activity can be grouped into (1) anticancer, (2) antiviral, (3) antimalarial and antiparasitic, (4) anti-inflammatory, antirheumatic, antipyretic and analgesic, (5) hepatoprotective, (6) antidiabetic, (7) antimicrobial and antifungal, (8) gastroprotective, (9) cardioprotective, (10) anti-asthma, antitussive and anti-allergic, (11) antihypertensive, (12) immunostimulating, (13) Central nervous system (CNS) activity, and (13) others (Elfahmi *et al.*, 2014). Nugraha and Keller (2011) have grouped Indonesian traditional medicinal plants by anti-infective agent, that is anti-viral, antimalarial, anti-bacterial and anti-fungal medicinal plants.

The medicinal plants also belong to the non-timber product group (FAO, 1995) and have twice the value of timber or are valued at US$ 14.6 billion (Ministry of Environment The Republic of Indonesia, 2013). Furthermore, 31 species are used in the wider (non-traditional) medicinal and condiment industry, as well as for export, which amounts to more than 1,000 tons/year. Out of these 31 species, 18 are cultivated (Pribadi, 2009).

1.1.4. Medicinal plant value, production and trade in Indonesia and the world at large

Globally, the international wildlife trade in medicinal plants is valued at US$ 13 billion (McNeely and Mainka, 2009). However, medicinal plant trade is extensive and could be a hundred times larger than the value of the international trade, since it is not possible to monitor all uses of medicinal plants in developing countries where people use plants directly to cure sickness and disease (de Padua *et al.*, 1999). Apart from this direct local use of medicinal plants for healing purpose, de Padua *et al.* (1999) record that medicinal plants have significant economic value as traded commodities, while Hawkins (2008) notes that medicinal plants can contribute very importantly to the livelihoods of local communities who trade in them. Hamilton (2004) clarifies the community as medicinal plant farmer and marketer.

As for many ornamental plants, the trade in medicinal plants in Indonesia has been trending upwards in recent times, such that for some types of plants demand cannot be met by current levels of supply (Ministry of Health, 2007; Ministry of Agriculture, 2015). Two institutions regularly record statistics on the medicinal (and spice) plant trade, namely the Directorate General of Horticulture-Ministry of Agriculture and Statistics Indonesia (Ministry of Agriculture, 2014, 2017). Most medicinal plants traded are cultivated on a horticultural scale (Ministry of Agriculture, 2014, 2017) and only few medicinal plant species provide raw materials on an industrial scale for strategic importance commodities in the economy (Ministry of Agriculture, 2015). The trade record consists not only of medicinal plants and their seeds or seedlings but also of derived products scale (Ministry of Agriculture, 2014, 2017).

Globally, Indonesia is recorded as an exporter and importer of group 0910 that is Ginger, saffron, turmeric (curcuma), thyme, bay leaves, curry and other spices. The three main products being imported and exported around the world are ginger, spices, and turmeric. The export and import values (US$) have fluctuated between 18.51M - 36.39M and 6.95M - 22.86M in 2015-2019 respectively (TrendEconomy, 2021).

1.1.5. Threats to medicinal plants

Medicinal plants like other plant genetic resources (plant biodiversity) are threatened by land conversion and deforestation in order to provide for more food and housing due to increasing human population need. Climate changes also threatens the medicinal plant population (Harish *et al.*, 2012).

In Indonesia, industries of oil palm, logging, fibre, and mining are the main contributors to deforestation (Abood *et al.*, 2015). Especially, palm oil plantation which is the biggest in Indonesia that comprises 8.6M ha (BPS-Statistics Indonesia, 2019). Apart from these factors, threats can come from over-exploitation in the commercial trade of medicinal plants (Hawkins, 2008), invasive species and climate change (Ma, 2010), seasonal forest fires, land and water pollution, and various natural disasters (Tambunan, 2008).

Traditionally, many ethnic communities in Indonesia have acquired considerable knowledge of their local flora's medicinal value that has been passed down from generation to generation (Chuthaputti, 2010). In some rural areas of Indonesia, apart from this communally acquired local knowledge, there are recognised specialists in traditional therapeutic practices known as '*dukun*s' who have a highly developed knowledge of their local flora's potential medicinal value. A *dukun* often knows the specific medicinal plants that can be used for curing particular diseases, as well as how to use them. This knowledge and skill are often passed on from generation to generation within a family who become acknowledged for such expertise. Unfortunately, nowadays, this locally acquired expertise is gradually being lost in many areas, except in those rural area isolated from the mainstream society (Stevenson, 1998). The loss of *dukun* is thus another factor threatening medicinal plant biodiversity. Once there are no more *dukuns*, there is the risk that medicinally important local plants will no longer be recognised as such by the broader society. Hamilton (2004) depicted declines in local medication knowledge, other than the loss and availability of the medicinal plants as a concern.

1.1.6. International and national legislation for conservation of medicinal plants as part of plant genetic resources

Globally, since 2015 the United Nations have had a program for people and the planet that has 17 goals to achieve by 2030 known as SDGs (Sustainable Development Goals) (Figure 1.3). Before that, the UN had the MDGs (Millennium Development Goals) program that had eight goals to achieve by 2015. In terms of medicinal plant conservation, goal number 3 (Good Health and Well-being) is the most relevant of the SDGs; goals 1 and 2 (No poverty and Zero hunger) are also relevant; and at the end goal number 15 (Life on Land) would be relevant. People health and well-being are highly connected with poverty alleviation and food security that are successfully achieved. Conserving medicinal plants may help to guarantee people sustainable income, keep people healthy, and uncover the new potential medicine discovery in the future (Sharrorck and Jackson, 2017). This has been reflected in the international Convention on Biological Diversity (CBD) in 1988.

Figure 1.3. A diagram listing the 17 Sustainable Development Goals (SDGs) by UN (www.unfoundation.org)

In 1988, the United Nations Organization flagged its intention to develop an international Convention on Biological Diversity (CBD). This convention was put forward for ratification by member nations for the first time at the Earth Summit in Brazil (Rio de Janeiro) in 1992, resulting in a multilateral treaty aimed at saving global biodiversity. The CBD itself came into effect on 29 December 1993 with three primary objectives: to conserve biodiversity, to use it sustainably, and with just and equitable sharing of the benefits from utilisation of natural genetic resources. Until 2018, there have been fourteen meetings of the Conference of Parties (COP) to the Convention on Biological Diversity (CBD, 2010). Furthermore, at Nagoya, Japan, in 2010, signatories to the Convention agreed to a CBD Strategic Plan contributing to biodiversity conservation, including plant genetic conservation (CBD, 2010). The form of this contribution was described in the framework of the CBD Global Strategy for Plant Conservation (GSPC) 2011 – 2020. The GSPC has six objectives and sixteen targets to be achieved by 2020 (BGCI, 2012). The objectives and targets have been applied by many botanic garden communities around the world. Despite being unsuccessful in the main goal of halting the species diversity loss by 2020, the GSPC has been successful in facilitating the communities to participate with CBD and contribute to reach GSPC's goals. However, redefining the objectives and targets after 2020 up to 2030 would be crutial to maintain the commitment of all conservation stakeholders (Sharrock *et al.*, 2018).

The global target set out in the GSPC reads: "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". One aspect of this target, strategic goal C, aims to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity (CBD, 2010). This goal has also been a stimulus to the global agreement for biodiversity management defined under the Aichi Targets and Nagoya Protocol. The Aichi targets define a global target to reduce genetic loss, while the Nagoya Protocols is an agreement that manages the access and benefit-sharing from the biodiversity use among the stakeholders (Ministry of Environment and Forestry of Indonesia, 2014). Sterling *et al.* (2017) define "stakeholders as the people and organisations who affect or are affected by a decision; stakeholders can be directly or indirectly involved in an endeavour" to achieve plant genetic conservation.

Pre-dating such global concerns, the 1945 constitution of the Republic of Indonesia, Article 33, Clause 3, stated that "*earth, water, and space, and the natural riches contained therein, shall be controlled by the state and used for the greatest welfare of the people*". This clause infers that the natural resources, including the genetic resources of indigenous medicinal plants are to be conserved and used sustainably for the people's benefit under the auspices of the state. Therefore, Indonesia has implemented legislation to manage conservation and use of plant genetic resources. The management of plant genetic resources includes the conservation, use, and benefit-sharing by all stakeholders as prescribed in the CBD (Ministry of Environment and Forestry of Indonesia, 2014). For example, there is legislation regarding plant conservation, that derives from Indonesian government action at several levels, from the president, through relevant ministries, down to local government instrumentalities.

The plant species' requiring particular conservation focus are listed explicitly in the Decree of the Minister of Home Affairs No. 48 Year 1989 regarding 33 plant species as representative of each province of Indonesia; in Government Regulation No. 7 Year 1999 regarding the natural genetic resources and 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 IBSAP (Indonesia Biodiversity Strategy and Action Plan) based on Rifai *et al.* (1992) and Zuhud *et al.* (2001) in The National Development Planning Agency (2003). For example, the Decree of the Minister of Home Affairs No. 48 Year 1989 nominated, while Government Regulation No. 7 Year 1999 listed 294 plant species including members of Palmae (Arecaceae), Rafflessiaceae, Orchidaceae, Nephentaceae, and Dipterocarpaceae.

Furthermore, the Ministry of Agriculture has issued Decree No. 511 Year 2006, revised with Decree No. 141 Year 2019, and revised with Decree No. 104 Year 2020 listed horticultural plants list of which medicinal plants included to be developed that is relevant to and might strengthen the conservation effort to avoid loss as well as guarantee the sustainable use of the plant. Other than that, biodiversity and ecosystem resource conservation efforts were strengthened by the government in its National Priority Program included in the Mid-Term National Development Plans of 2010-2014 and 2015-2019. In addition, ratification of CBD goals has been endorsed by several government institutions in Indonesia specialised in the use and management of Indonesian biodiversity, such as the Ministry of Environment, the Ministry of Forestry, the Ministry of Maritime Affairs and Fisheries, the Ministry of Agriculture, and the Indonesian Institute of Sciences. Concern for genetic biodiversity has always been included in their strategic plans (Ministry of Environment and Forestry of Indonesia, 2014).

1.1.7. Current *in situ* and *ex situ* conservation actions in Indonesia

Globally, medicinal plants have received attention from the IUCN (International Union for Conservation of Nature) with regard to the conservation and sustainable use of plant biodiversity. The IUCN commits to safeguard biodiversity from the level of the gene, through species level, up to whole ecosystems. The focus on biodiversity conservation of medicinal plants is mainly at the species level, with concentration on their direct curative properties; however, the way we manage medicinal plant biodiversity will also have a more general influence on human health (McNeely and Mainka, 2009). The medicinal plant specialist group (MPSG) was established by the IUCN based on the recommendation of the Plant Conservation Subcommittee in 1994 and had 50 members chaired by Dr A. B. Cunningham and Dr U. Schippman. This group is just one of about 140 specialist groups working under the Species Survival Commission

(SSC), whose network embraces 7,500 volunteers such as scientists and policyholders from 169 countries (see Kasparek *et al.*, 1996). Up to now, the MPSG has recorded 283,928 scientific names of medicinal plants of which only about 10% are derived from medicinal plant publications, while the other 90% are from Kew's database (MPSG, 2017).

Since at least the year 1980, Indonesia has adopted the Integrated Conservation and Development Project (ICDP) approach to protecting its national biodiversity. This policy links the conservation of biodiversity in a protected area (PA) to the interests of the resident people who inhabit PA surroundings and their economic development. It considers the ways in which local communities benefit from the natural resources of their protected areas while at the same time being motivated to give equal consideration to conserving the biodiversity on which they depend. Local communities were highlighted to be involved in most of the program design and implementation. Based on studies under this approach, it has been found that there are both direct and indirect threats to Indonesian biodiversity posed by economic development efforts. The direct threats can come from the way local people earn their livelihoods from activities like small-scale mining, logging, non-forest product harvesting, domestic agriculture, as well as from fishing. On the other hand, the indirect threats come from large-scale development activities regulated by the government, such as construction, large agricultural plantations, transmigration projects, and tourism, although it gave local people a benefit in terms of employment (Wells *et al.*, 1999).

Some biodiversity conservation efforts have been generated at the local level, such as by the development of medicinal plant lists and by collecting plants for *ex situ* cultivation. For example, in Riau Province (in Sumatera Island) a survey resulted in 114 species was done by Grosvenor *et al.* (1995). In West Java, where Sundanese ethnic groups live, there are 117 medicinal plants (Roosita *et al.*, 2008). In Central Kalimantan Province (Kalimantan Island) identified 21 species characterised among several species (Krismawati and Sabran, 2004). In addition, in smaller areas such as on Wawonii island, Southeast Sulawesi Province (Sulawesi Island) surveys resulted in 73 species (Rahayu *et al.*, 2006; Roosita *et al.*, 2008)

Nationally, since 2007, with the Decree of the Minister of Health No. 381/Menkes/SK/III/2007, Indonesia has pursued a comprehensive policy regarding traditional medicines that links together all stakeholders; beginning from cultivation of the medicinal resources, through to their conservation, and considering both producers and consumers. Indonesia's National Policy on Traditional Medicines is known by the acronym KOTRANAS (Kebijakan Obat Tradisional Nasional). The government acts to monitor the policy. Producers and consumers of medicinal plants in Indonesia may be individuals or industrial groups, and they can be either government or non-government stakeholders. Both producers and consumers of medicinal plant products can be researchers (like plant-breeders and conservationists), farmers or residents. On the commercial level, medicinal plant enterprises can comprise home scale industry through to large-scale industry, as well as their associations such as the Association of Traditional Medicinal Plant Exporters (APETOI) (Ministry of Health, 2007).

Some medicinal plants of Indonesia are also included in IUCN Red List (iucnredlist.org), and the appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This comes about because

Indonesia is defined as part of Asia, which as a whole has experienced much illegal trade in medicinal plants as well as in orchids, leading to large losses of plant diversity (Ma, 2010). For example, one of Indonesia's medicinal plants, *Taxus sumatrana* (Miq.) de Laub. contains recognised anti-cancer agents (taxane or paclitaxel or Taxol®) has experienced a decline in its natural population and has been listed as an Endangered Species (IUCN, 2016). Many people, worldwide, have been looking for this plant because cancer is one of the highest causes of death in the world (WHO-UICC, 2003). Apart from this species, *Euphorbia prostrata* Aiton is another species found in Indonesia (though originating from the Caribbean) that is included in the IUCN Red List as Critically Endangered, and in the CITES Appendix II, due to the fact that cultivation of the species has not kept pace with the rate of wild harvesting.

The overall strategy for conservation and sustainable use of Indonesian medicinal plant diversity has been described by Zuhud (1989). He reports that this strategy is essential because continual growth in human populations continues to diminish the nation's natural resources. A point has come when the demand for many medicinal plant commodities threatens to outstrip supply. Zuhud (1989) has recommended five solutions to overcome this problem: (1) conservation of medicinal plants *in situ* and *ex situ*; (2) domestication and propagation of medicinal plants (jamu); (3) research and development of underutilised medicinal plants; (4) development and training for the medicinal industry and dissemination to the people at large; (5) legislation and government regulation. The aim is to ensure that supply can keep up with demand. However, Hawkins (2008) has advised that medicinal plant conservation also needs to be managed on a wide front, employing several different groups with specialist expertise such as agronomists, conservationists, and ethnobotanists. Tambunan (2008) suggests that in order to ensure the preservation of the archipelago's rare and vulnerable medicinal plant life there needs to be a national strategy to provide a sustainable supply of the raw materials required by the pharmaceutical industry. This can be achieved by means of *in situ* and *ex situ* conservation, systematic cultivation, and biotechnology; a strategy that would coordinate and integrate all stakeholders in a combined effort. Chen *et al.* (2016) underlined that in situ and ex situ conservation and cultivation as the medicinal plant conservation strategy should be acknowledged to save the plants harvested from the wild and to guarantee sustainable use, whilst biotechnology can be used to provide the higher yield and modified potency needed by the pharmaceutical industry.

Convention on Biological Diversity (UN, 1992) defines *in situ* conservation 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". In regards to medicinal plant conservation implementation in Indonesia, governmental and private stakeholders have been doing the *in situ* and *ex situ* conservation whether locally or nationally. There are around 646 protected areas covering about 226,249 km^2 (11.87%) out of a total land area of 1,906,555 km^2 (UNEP-WCMC and IUCN, 2017). There is no current estimation for the percentage of medicinal plants conserved in particular *in situ* areas. It is reported that the botanical gardens of Indonesia are contributing to the GSPC Target 8's efforts to include "60% of threatened plant species in accessible *ex situ* collections, preferably in the country of origin, and 10% of them included in recovery and restoration programs" (Ma, 2010).

1.2. Aims and Objectives

Considering the value of Indonesian medicinal plants, as well as threats to them, there is a crucial need for well-planned, pro-active, and sustained, conservation efforts to head off this erosion in medicinal plant resources. It also should be acknowledged that to date, Indonesia, despite its rich floral resources, has perhaps lagged behind neighbouring Asia-Pacific countries such Indian and China, and even Malaysia and the Philippines, in placing emphasis on the need for the conservation and research of medicinal plants (Batugal *et al.*, 2004). Thus, conservation and sustainable utilisation of medicinal plants needs to be recognised as crucial research priorities for Indonesia.

This project aims to contribute to the recommendation for a national strategic action plan for the conservation and use of Indonesian medicinal plants. The specific objectives of this project are:

1. To produce a priority list of medicinal plants of Indonesia, by means of an inventory data of current checklists (including the IUCN Red List, CITES appendix 2, and in National Legislation),
2. To undertake conservation gap-analysis of both *in situ* and *ex situ* holdings for the priority species for conservation,
3. To evaluate the effect of climate change on priority species, and
4. To investigate the effectiveness of used DNA barcoding region (*ITS2*, *MatK*, *rbcL*, and *trnL*) for DNA barcoding in Indonesian medicinal plant species to aid

identification and conservation and to provide new DNA barcoding of those species (if any).

1.3. Thesis Outline

This thesis comprises five chapters. Chapter 1 introduces the PhD project **Genetic Conservation and Sustainable Use of Medicinal Plants of Indonesia**. This chapter includes a review of available literature that point to research topics. Chapter 2 presents the priority list of medicinal plants of Indonesia for conservation: this chapter analyses many existing literature and data concerning Indonesian medicinal plants for active *in situ* and *ex situ* conservation, to create the Indonesian medicinal plants and to define a priority species. Chapter 3 presents conservation gap-analysis for the priority list: this chapter provides information about where the richest areas of Indonesian priority medicinal plant species are found, where additional *ex situ* priority medicinal plant species should be collected, and recommendations related to *in situ* and *ex situ* conservation the Indonesian priority medicinal plant species. Chapter 4 presents climate change analysis study on the priority list: this chapter provides information about where and what species will be impacted by climate changes and what conclusions will come in terms of *in situ* and *ex situ* conservation strategies for medicinal plants in Indonesia and at regional and global levels. Chapter 5 presents DNA barcoding for supporting Indonesian medicinal plant conservation: this study uses a pair of *ITS2*, *matK*, *rbcL*, and *trnL* primers to aid identification of the medicinal plants in Indonesia and to decide which primers among them can identify the plants effectively and efficiently. Chapter 6 presents the general discussion of empirical chapters (Chapter

2, 3, 4, and 5), including discussion of the limitations of the study and recommendation for future research.

CHAPTER 2. SETTING THE PRIORITY MEDICINAL PLANTS FOR CONSERVATION IN INDONESIA

Abstract

Setting priority species for conservation planning in a large and biodiverse country such as Indonesia is crucial. At least 80% of the medicinal plant species in South East Asia can be found in Indonesia, whether native or introduced. However, their conservation is currently ineffective due to limited human and financial resources. By examining factors such as species occurrence status, rarity and part of the plant harvested, the various Indonesian medicinal plant species can be prioritised for conservation planning. In this study, various threatened plant species have been included in the priority list as well as those listed in related legislation. Some 233 species within 161 genera and 71 families are recommended for prioritisation. An inventory of these priority species was produced presenting compiled data including vernacular names, plant habit, harvested plant part, uses, distribution, whether it is conserved *ex situ*, and their DNA barcoding. Significantly 41.20% of priority species have no information on their current conservation status in either *in situ* or *ex situ* national or international genebanks.

Keywords: Prioritisation, priority, conservation, medicinal plants, Indonesia

2.1. Introduction

For centuries, the diversity and wealth of Indonesian medicinal plants have been recognised worldwide. This was first noted by the French botanist Bontius (1658) in the list of Java medicinal plants compilation (de Padua *et al.*, 1999) and the Portuguese botanist Georgius Everhardus Rumphius (1627–1702) in his work entitled *Het Amboinsche kruidboek* (Herbarium Amboinense) (Rumphius, 1741–1755; Veldkamp, 2011). Medicinal plants are still widely used in Indonesian traditional medicine (Jamu), a tradition that is similar to Ayurveda in India and Traditional Chinese Medicine (TCM) in China (WHO, 2009). These traditional Indonesian remedies remain widely used today, in urban as well as rural areas and among all social classes. About two-fifths of the national population use traditional medicine, and most traditional healers in Indonesia use Indonesian indigenous medicine (WHO, 2009).

As a country rich in medicinal plants, it is difficult to quantify the exact number of plants in Indonesia, but it is estimated that 2,000 (Erdelen *et al.*, 1999; WHO, 2009) to 7,500 medicinal plants (Hamid and Sitepu, 1990) are regularly used out of a total of around 30,000–40,000 plant species within the country (Ministry of National Development Planning, 2016). There are high levels of endemicity and expected medicinal plant uniqueness in Indonesia is estimated to be at about 40%–50% of the total flora of each island, except Sumatera which has only 23% (Ministry of National Development Planning, 2016).

Medicinal plants are valuable species not only for personal health care (de Padua *et al.*, 1999) but also for their economic value as they are traded by local communities (Hawkins, 2008). Indonesia's medicinal plants' economic value equates to as much as US$14.6 billion annually (Ministry of Environment The Republic of Indonesia, 2013). Globally, the trade of medicinal plants in 2005 was more than US$3 billion (Jenkins *et al.*, 2018) and this is estimated to grow to be worth US$5 trillion by 2050 (WHO, 2009).

Indonesia is a vast country, with a land area of 1,919,440 km spread over thousands of islands (Ministry of Environment and Forestry of Indonesia, 2014). Conservation of Indonesian species is thus challenging and costly. Human population growth, land conversion, deforestation and climate change all contribute to medicinal plant loss, as well as overharvesting for medicinal trade (Voek, 2004; Hawkins, 2008; Ma *et al.*, 2010). Hamilton (2004) argues that the loss of local knowledge regarding medicinal plants and their use is a global concern.

The economic value of medicinal plants in Indonesia, coupled with other threats and a lack of resources for their conservation, makes it urgent that active conservation programmes are put in place. An obvious initial step would be for some form of prioritisation of species and an assessment of the criteria which might be used. This has not been previously attempted in Indonesia, however a number of studies have been conducted elsewhere. Dhar *et al.* (2000) did undertake such an exercise in the Indian Himalayas prioritising consumers (using medicinal plants) and biologists (concerned about their conservation). The outcome was to prioritise conservation for species that are harvested in a destructive manner, that have restricted distribution and for which there are limited propagation techniques. van Andel *et al.* (2015) prioritised the medicinal plants in West Africa based on commercial demand, whether they are wild-harvested, and their occurrence in undisturbed vegetation types. Dery *et al.* (1999) conducted prioritisation in the

Shinyanga Region of Tanzania involving local people with the necessary knowledge and scored their appraisal. Allen *et al.* (2014) prioritised European medicinal plants by selecting only native species.

Producing checklists that consist of the name of the species, the author details, inventories and additional information is essential to formulating the conservation strategies (Magos Brehm *et al.*, 2017) and these form the groundwork for further action. Establishing priorities for conservation can be based on current conservation status, the threat to genetic diversity from genetic erosion, and legislation (Maxted *et al.*, 1997). Inventory is also needed to describe a country's species richness: an essential tool in conservation management (Magos Brehm *et al.*, 2008). Considering these arguments, the economic value of medicinal plants in Indonesia and the need to prioritise conservation efforts, this project aims to analyse available data concerning Indonesian medicinal plants for active *in situ* and *ex situ* conservation and to provide a priority list of species.

2.2. Methods

The checklist of medicinal plants of Indonesia was compiled in Excel from relevant literature. The literature used was as follow:

1. Plant Resources of South-East Asia (PROSEA) book series, specifically: Medicinal and Poisonous Plants 1 (de Padua *et al.*, 1999), Medicinal and Poisonous Plants 2 (van Valkenburg and Bunyapraphatsara, 2002), Medicinal and Poisonous Plants 3 (Lemmens and Bunyapraphatsara, 2003), and Spices (de Guzman and Siemonsma, 1999). Only species distributed in Indonesia were selected. Poisonous plants were included but in lower number and only if they

had a medicinal function (de Padua *et al.*, 1999) Spice plant species were included as well because traditional people use them in medication (de Guzman and Siemonsma, 1999).

2. Indonesian Medicinal Plant Indexes (Eisai, 1986; 1995).
3. Atlas of Indonesian Medicinal Plants series 1–6 (Dalimartha, 1999, 2000, 2003, 2006, 2008, 2009). *Ganoderma lucidum* (Curtis) P.Karst. (Ganodermataceae) was excluded from the list as it is fungi.
4. The Useful Plants of Indonesia (Heyne, 1987). Only species with records of medicinal use was selected.
5. Rare Indonesian Medicinal Plants stated in IBSAP (Indonesia Biodiversity Strategy and Action Plan) based on Rifai *et al.* (1992) and Zuhud *et al.* (2001) (The National Development Planning Agency, 2003). *Usnea misaminensis* (Vain.) Motyka, which belongs to the Parmeliaceae family, was excluded as it is fungi.

The taxonomic names were checked against the online taxonomic name resolution service tool by checking "Constrain by higher taxonomy" under "Best match settings", which is effective for spelling errors and for merging all the synonyms into a single accepted name (Boyle *et al.*, 2013). The steps are described in Figure 2.1.

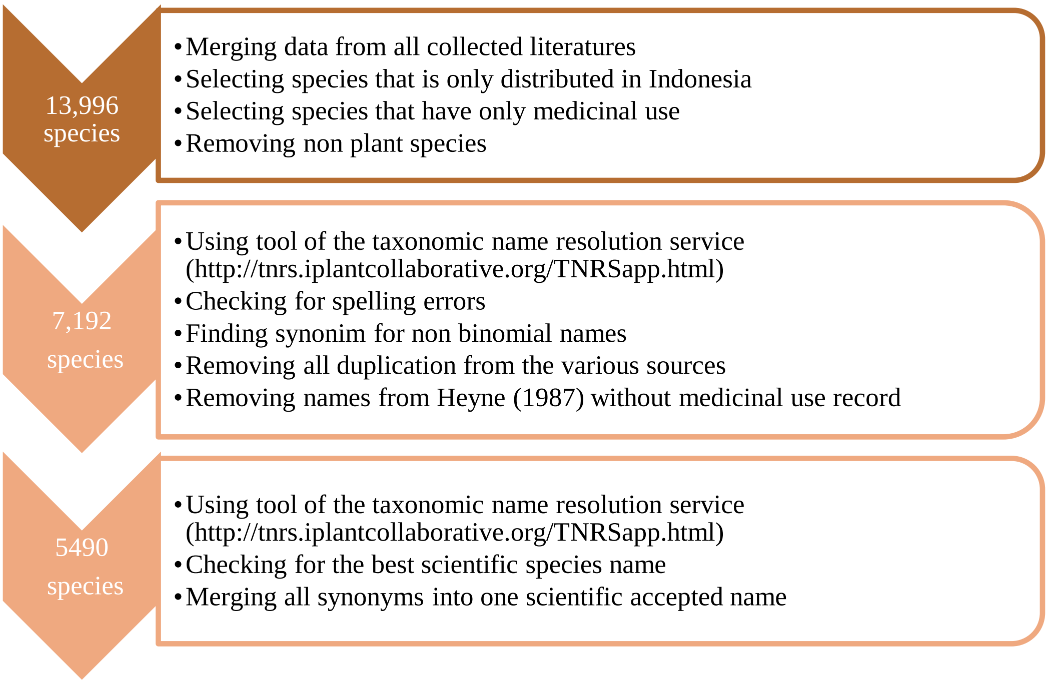

Figure 2.1. Flowchart of setting checklist of medicinal plants of Indonesia

After the literature review, prioritising the checklist was done serially with the collected information, namely, (a) occurrence status, (b) rarity, (c) part of the plant harvested, (d) threat status, and (e) legislation (Figure 2.2).

a. Native status. Similarly to Allen *et al.* (2014), only species native to Indonesia were prioritised.

b. Rarity. This criterion is based on the distribution of the species in Indonesia. Only medicinal plant species that are endemic, distributed on one of seven major areas in Indonesia (*i.e.* the main islands of Sumatera, Java, Kalimantan, Sulawesi, and Papua, and the area of the Lesser Sunda Islands and Maluku) regardless of their global distribution, and that has never been introduced elsewhere (with data obtained from literature and online through http://POWO.science.kew.org/; POWO, 2020) are listed as a priority. Plants never introduced elsewhere could describe their slow natural distribution and unavailability of propagation technique.

c. Part of the plant harvested. The species for which the root or non-aerial parts such as tuber and rhizomes, complete bark, or whole plants are harvested were prioritised (as suggested by Dhar *et al.*, 2000) as this is detrimental to the persistence of the species in the wild.

d. Threat status. Since Indonesia does not have a national red list, the threat status at the global level for each species was retrieved from the IUCN RedList (https://www.iucnredlist.org/).

   The medicinal plant species that have been assessed as Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) are considered a priority.

e. Legislation. This criterion refers to the prioritisation of those species included in national or global legislation. This is very important because it depicts that the listed species need conservation and the government should be responsible for them (Magos Brehm *et al.*, 2010). At a global level, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) was used. Thus, the species threatened with extinction(listed in Appendix I) and the species which may be threatened with extinction if their trade is not closely monitored (listed in Appendix II of CITES (UNEP-WCMC (Comps.), 2014)) were prioritised. At the national level, the legislation related to medicinal plant conservation included the following:

   1. Indonesian Government Regulation Act. 7 of 1999 regarding Natural Genetic Resources and Its Ecosystem.
   2. Decree of Forestry Ministry No 57/MENHUT-II/2008 regarding Strategy Direction of National Species Conservation 2008–2018.

3. Decree of Environmental and Forestry Ministry No.P.20/MENLHK/SETJEN/KUM.1/6/2018 regarding the Protected Flora and Fauna Species.
4. 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 ProtectedFlora and Fauna Species.
5. IBSAP (Indonesia Biodiversity Strategy and Action Plan) based on Rifai *et al.* (1992) and Zuhud *et al.* (2001) in The National Development Planning Agency (2003).

The listed plant species protected by Indonesian laws are classified as requiring protection due to their limited or small population, decreasing number of individuals and endemicity. The medicinal plants that were included in the related legislation are considered priority.

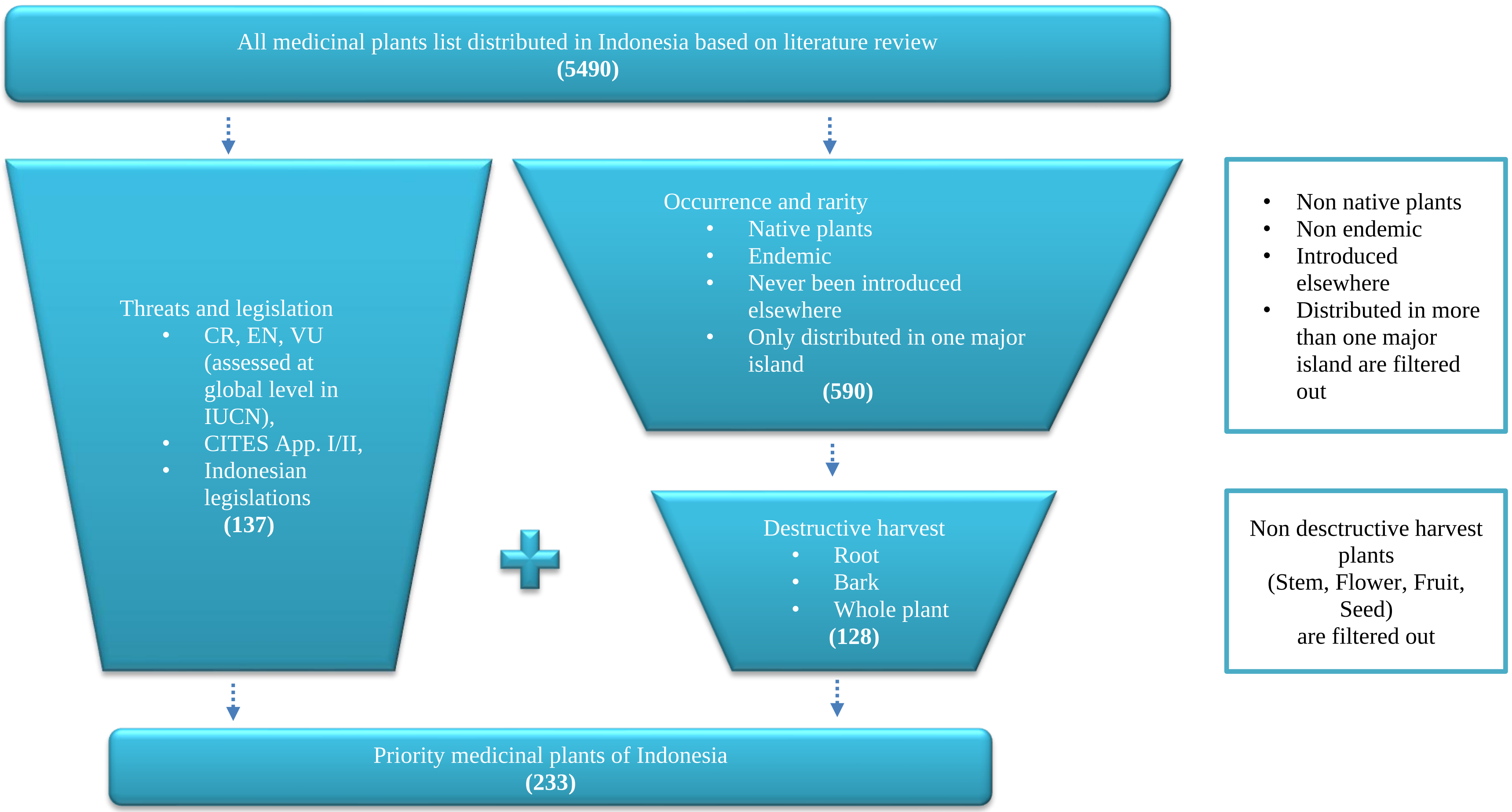

Figure 2.2. Flowchart of setting prioritisation of medicinal plants of Indonesia

Due to the primary data for prioritisation, the checklist that consists of a scientific name and author are obtained online from POWO (2020). An inventory of priority medicinal plant species was compiled with their vernacular names, plant habit, used plant parts, uses, and DNA barcoding data (http://www.boldsystems.org/; Ratnasingham and Hebert, 2007). Group plants that were selected based on criteria of limited distribution, destructive harvest, CITES, IUCN, and National legislation were showcased with a Venn diagram generated by Bioinformatics and Evolutionary Genomics (http://bioinformatics.psb.ugent.be/cgi-bin/liste/Venn/calculate_venn.htpl).

Ex situ conservation status information on whether the species has been collected or not was obtained from Indonesian botanic gardens through direct communication with Bogor Botanic Gardens, and by mining data online from Purwodadi Botanic Garden (http://www.krpurwodadi.lipi.go.id/koleksi/) and Cibodas Botanic Garden (http://sindata.krcibodas.lipi.go.id/Cibodas-Botanic-Gardens-Record/CBGR/) as well as from Genesys (https://www.genesys-pgr.org/).

2.3. Result

2.3.1. Establishing the checklist of Indonesian medicinal plants

Indonesia has a total of 5490 medicinal plant taxa, of which 5408 are identified species, and 82 can only be identified at the genus level. No further information can be identified for the 82 genus-level species; hence it cannot be concluded that they are new species. The 5408 Indonesian medicinal plant species are within 245 families and 1809 genera; 3312 are native (61.24%), 1754 (32.43%) are introduced, and 342 species (6.32%) are of unknown status. Most medicinal plants (8.84%) belong to the Fabaceae family (Figure 2.3) since it is one of the biggest families of medicinal plants in the world (Willis, 2017). There is estimated to be a total of 27,734 medicinal plant species around the world (MPNS, 2020), meaning that Indonesia's medicinal species make up around 20%of the global population.

2.3.2. Prioritising and inventorying Indonesian medicinal plants

A total of 233 species of Indonesian medicinal plants, within 161 genera and 71 families, were prioritised for conservation (Table Appendix 2.1) according to the criteria discussed above (Figure 2.3). The higher priority medicinal plant families belong to the Orchidaceae (34 species or 14.59%) and Dipterocarpaceae (26 species or 11.16%). Most of these are included in Appendix II of CITES or have been assessed as threatened in the IUCN Red List (Table Appendix 2.2). Some 127 out of the 233 priority species are known as medicinal plants worldwide (MPNS, 2020), whereas 106 species are used as commercial timber (Dipterocarpaceae), ornamental plants (Orchidaceae) and sources of fibre (Nepenthaceae).

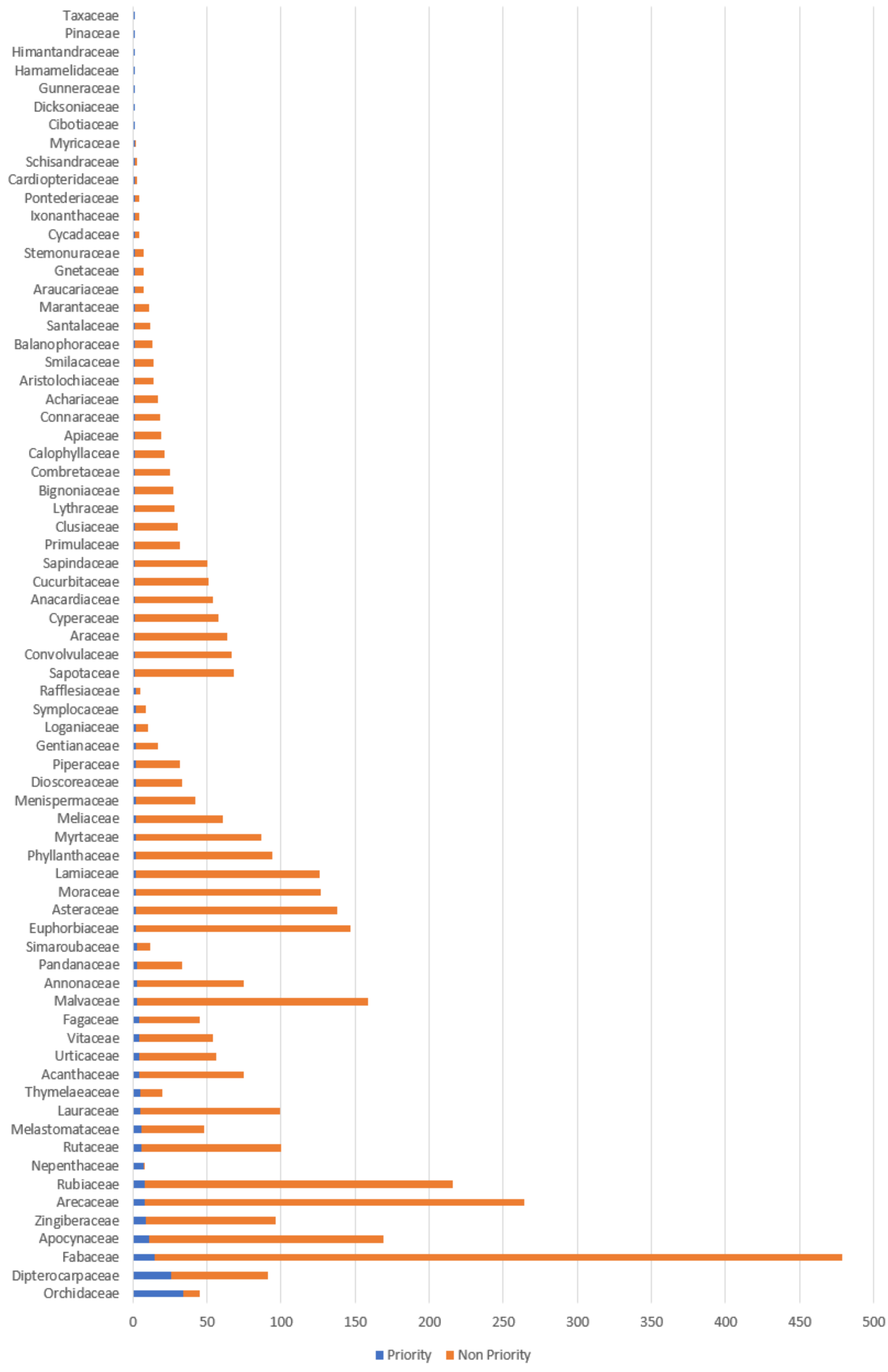

Figure 2.3. The families represented in the Indonesian Medicinal Plant Species Checklist with priority species for conservation from the highest priority number

Some 96 out of 233 (41.20%) major priority medicinal plants are distributed in one major area/island and harvested in a destructive manner. Based on the Figure 2.4, some species are included on the priority list solely based on the IUCN threatened list (2), CITES Appendix II list (25), and in Indonesian legislation (11), but no species become priority based on solely destructive harvesting and limited distribution, or a combination of all five criteria.

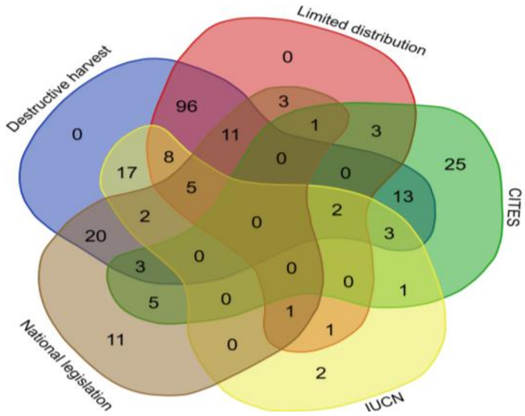

Figure 2.4. Venn diagram of priority medicinal plant species grouped into prioritisation criteria

The rest of the species in the CITES Appendices may represent global demand, and da Silva and Conde (2019) have used it for their own prioritisation. Moreover, the CITES Appendices are managed based on trading data and are very important in Indonesia. Throughout Asia, as Ma *et al.* (2010) argue, the illegal trade in medicinal plants like orchids cause losses in plant diversity. However, it is difficult to assess this adequately in Indonesia due to its size and large remote areas.

Most of the medicinal plants that can be classed as priority (77.25%) are harvested destructively either by removing the rooting parts (root, rhizome, or tuber), bark, or harvesting the entire plant. The remaining plants (14.59%) are harvested through other parts such as their leaves, sap, stems, fruits, or flowers. Some 8.15% of the priority species have no information regarding how they are harvested, as their harvesting methods were not necessarily designed solely for medicinal use. Harvesting non-aerial parts of the plant (root, rhizome and tuber, bark and rhizome) makes the plants highly susceptible to failure or can directly kill the plants. Other parts of the plant, such as leaves, flowers, and seeds, are excluded from the prioritisation criteria, although they can also affect the plant's vigour and fitness. Nevertheless, the harvesting of root and bark might affect mostly shrubs and trees, whereas the collection of seed affects mainly annuals and biannuals (Schippmann and Cunningham, 2002).

In terms of the habit types of priority medicinal species, the majority type consists of trees (32.62%), shrubs (27.03%), herbs (24.03%), lianas (6.44%), climbers (6.01%), tree like-palms (3.00%), and holoparasite (0.86%). Some 97of the 233 priority species have been identified through DNA barcoding and provided online (http://www.boldsystems.org/; Ratnasingham and Hebert, 2007). The taxonomic identification via DNA barcoding is of high importance for conservation. Since plant phenotypic characteristics are affected by physiology and environmental factors (Chen *et al.*, 2010; Techen *et al.*, 2014), it may become difficult to identify certain species. Thus, for conservation purposes, consistent results of DNA barcoding can help to prevent deception and theft of protected and commercial species (Kress *et al.*, 2014; Mishra *et al.*, 2016). Furthermore, it also protects the rights of consumers to use authentic plant species for their medicines, as the barcoding can be conducted on both fresh and dried plants (Dick and Webb, 2012) as well as on market products (Eurlings *et al.*, 2013; Newmaster *et al.*, 2013).

Regarding their distribution, 53 priority species are endemic to Indonesia (see Table 2), 179 species are distributed in both Asia and Australia, and one species

(*Dodonaea viscosa* Jacq. subsp. *angustifolia* (L.f.) J.G.West) is distributed worldwide. Sundaland and Wallacea, with 93 and 24 endemic medicinal plant species respectively, are included in the hotspot areas identified by Myers *et al.* *(*2000) and Mittermeier *et al.* (2011) as having significant endemism and threats. The number of native medicinal plants in Indonesia showcases how rich Indonesia's biodiversity is, a point also noted by Vavilov (1935) who identified it as a centre of origin/diversity of cultivated plants.

Table 2. Level of endemism of priority medicinal plant species within Indonesia

Distribution	Endemic to one major island	Endemic to ≥2 islands/areas	Total occurrence
Sumatera[a]	43	78	121
Java[a]	33	62	95
Kalimantan[a]	17	68	85
Papua[c]	13	35	48
LSI[b]	12	44	56
Maluku[b]	11	37	48
Sulawesi[b]	1	43	44

Biogeographical regions of Southeastern Asia: [a]Sundaland, [b]Wallacea, [c]Australia (according to Myers *et al.*, 2000, Mittermeier *et al.*, 2011).

Indonesian people in villages often intensively use a traditional medicinal plant that they collect from the wild and plant in their home gardens (Astutik *et al.*, 2019). Nevertheless, we could not identify the priority species data regarding their collection and planting locally as medicinal plants. In addition, *ex situ* conservation institutions have been actively collecting priority medicinal plants. More than half of the 233 species have been planted in nurseries or botanical gardens either nationally or internationally. Some 137 priority species are cultivated in the Indonesian Botanic Garden–Indonesian Institutes of Sciences and one species [*Phyllodium elegans* (Lour.) Desv.] can be found at the International Livestock Research Institute (ILRI) (Ethiopia) with Forages as its common name. Despite being distributed in more than two islands/areas, 107 priority species that are threatened globally have been listed in national legislation. Likewise, *Borassus flabellifer* L. (Arecaceae) and *Dalbergia latifolia* Roxb. (Fabaceae) are threatened based on IUCN red list criteria but have been introduced to other parts of Indonesia as well as to other countries. *Borassus flabellifer* has been introduced into other countries, such as China, Thailand, and Mauritania, meanwhile *Dalbergia latifolia* has been introduced into Australia, Sri Lanka, and Tanzania (POWO, 2020).

2.4. Discussion

2.4.1. Checklist of Indonesian medicinal plants

As Paton *et al.* (2016) have argued, plant species names serve as "a key to communicating and managing information about plants". Creating a national checklist of Indonesian medicinal plant species, and annotating with additional data to allow for prioritisation, is essential groundwork for conservation. As the information is currently located in different sources and is arguably incomplete, there are many areas of literature and numerous journals that discuss medicinal plants that need to be collected and reviewed. The Medicinal Plant Names Services (MPNS, 2020) can be useful to access the global information for medicinal plants and to build up understanding amongst both scientific and non-scientific users. Many journals report ethnobotanical studies of Indonesian people that are rich in ethnicity, but the MPNS to date has little information regarding Indonesia plants. For this project, the literature that is estimated to have a complete species list of Indonesian medicinal plants was selected for further study.

Using the TRNS tool (Taxonomic Name Resolution Service; Boyle *et al.*, 2013) to help with the taxonomical check name was helpful for this research but some issues were unable to be resolved. Homonyms and ambiguous names needed to be checked manually. Some plant names are Rumphius-related names such as *Sampacea montana* Rumph. and *Arbor spiculorum aeruginea* Rumph. that are pre-binomial names, not binomial. This is because Rumphius' works had not been recorded in Species Plantarum, the starting point of binomial names by Linnaeus (1753) (Margulis and Raven, 2009) and was resolved by available synonyms in the available literature (Eisai, 1986). The value of this "resolution" is also constrained by the quality of the underlying taxonomic resources available. To resolve the taxonomic status would allow for better tracking of the plant to the names employed in original publications, enabling them to be matched to modern comprehensive nomenclatural and taxonomic datasets.

Allkin (2014) and Rivera *et al.* (2014) describe the frequent use of ambiguous names and even misleading names that exist in the literature, scientific journals, and international legislation in terms of medicinal plant names. Some 3,445 names out of 9,178 Latin names from 308 scientific articles were incorrect, as identified by Rivera *et al.* (2014). This might happen because, in certain circumstances, more than one name can refer to a plant, while on the other hand, one name can refer to more than one plant, or the name can keep changing (Allkin, 2014). Dauncey *et al.* (2016) suggested authors use the proper and unambiguous scientific plant(s) names of medicinal plants or their products before publishing their articles in order to maintain scientific integrity. The confusion concerning the identity of plants employed is made even more complex because of the widespread use in health legislation of common, trade, product and pharmaceutical names (the latter also written in Latin) which are inherently ambiguous (Allkin, 2014). Labelling plant materials correctly and unambiguously is a key step in researching medicinal plant use (Allkin and Patmore, 2018).

The checklist resulting from this study might not be perfect and can only reduce the pitfall of medicinal scientific names, that is synonym names and homonyms (Allkin and Patmore, 2018). However, it can also be a reasonable basis for future research and coordination in discussing whole species to conserve, considering many medicinal plants can be found in Indonesia. As the ethnobotanical knowledge, especially regarding new medicinal plants, is still increasing this study serves as a foundation for future work.

2.4.2. Priority of Indonesian medicinal plants, their current conservation and conservation planning

Prioritisation has been done for some plant taxa in Indonesia, but this research was not specifically for medicinal plants. Studies include those by Mogea (2001), Risna *et al.* (2010), and Hamidi *et al.* (2019). Mogea *et al.* (2001) listed 200 rare plant species in Indonesia and 29 priority medicinal plants are included in his list, namely *Anaxagorea javanica* Blume (Annonaceae), *Pimpinella pruatjan* Molk. (Apiaceae), *Alstonia scholaris* (L.) R.Br., *Alyxia halmaheirae* Miq., *A. reinwardtii* Blume, *Rauvolfia serpentina* (L.) Benth. ex Kurz, *Urceola laevigata* (Juss.) D.J.Middleton & Livsh., *Voacanga grandifolia* (Miq.) Rolfe (Apocynaceae), *Caryota no* Becc., *Phoenix paludosa* Roxb. (Arecaceae), *Oroxylum indicum* (L.) Kurz (Bignoniaceae), *Cibotium barometz* (L.) J.Sm. (Cibotiaceae), *Shorea palembanica* Miq. (Dipterocarpaceae), *Euchresta horsfieldii* (Lesch.) Benn., *Koompassia malaccensis* Maingay, *Parkia intermedia* Hassk., *P. timoriana* (DC.) Merr. (Fabaceae), *Scutellaria javanica* Jungh (Lamiaceae), *Cinnamomum culilaban* (L.) J.Presl, *C. sintoc* Blume, *Cryptocarya massoy* (Oken) Kosterm. (Lauraceae), *Strychnos ignatii* Bergius, *S. lucida* R.Br. (Loganiaceae), *Vanda miniata* (Lindl.) L.M.Gardiner (Orchidaceae), *Kadsura scandens* (Blume) Blume (Schisandraceae), *Symplocos odoratissima* (Blume) Choisy ex Zoll (Symplocaceae), *Aquilaria hirta* Ridl. (Thymelaeaceae), *Amomum sumatranum* (Valeton) Skornick. & Hlavatá, and *Curcuma petiolate* Roxb. (Zingiberaceae). Risna *et al.* (2010) prioritised the family of Arecaceae, Cyatheceae, Nepenthaceae, and Orchidaceae as a taxa unit considering the nature of each plant and the natural habitat, with the result of *ex situ* conservation recommendations on some taxa. Three priority medicinal plants are in line with other results and are *Nepenthes reinwardtiana* Miq., *Johannesteijsmannia altifrons* (Rchb.f. & Zoll.) H.E. Moore, and *Nepenthes ampullaria*. *Anisoptera costata* Korth. (Dipterocarpaceae), *Castanopsis argentea* (Blume) A.DC. (Fagaceae), and *Eusideroxylon zwageri* Teijsm. & Binn. (Lauraceae) are also included in priority plant taxa that need to be conserved in Indonesia (Hamidi *et al.*, 2019). Moreover, the Ministry of Agriculture published Decree No. 511 Year 2006, which was first revised with Decree No. 141 Year 2019, and finally revised with Decree No. 104 Year 2020, which lists horticultural plants grown in Indonesia. This includes a number of medicinal plants that are produced and processed for market. Three priority species, *Curcuma aeruginosa* Roxb., *Lunasia amar*a Blanco, and *Rauvolfia serpentina* (L.) Benth. ex Kurz, have already been included in horticulture plant priority lists since 2006. Thus, some priority Indonesian medicinal plants identified in this study have been confirmed as priority species by other studies. These depict the need for a priority conservation list for sustainable use.

This priority list can be used to help formulate *in situ* and *ex situ* conservation plans through the National Priority Program included in the Mid-Term National Development Plans of Indonesia, in line with the Convention on Biological Diversity regarding the conservation of biodiversity and its sustainable use (CBD, 2010). The priority list also helps to achieve the Global Strategy for Plant Conservation 2011–2020 objectives and its targets: objective I ("Plant diversity is well understood documented and recognised"), II ("Plant diversity is urgently and effectively conserved"), III ("Plant diversity is used in a sustainable and equitable manner"), IV ("Education and awareness about plant diversity, its role in sustainable livelihoods and importance for all life on earth is promoted"), and V ("The capacities and public engagement necessary to implement the strategy have been developed").

The stakeholders involved in the conservation and use of medicinal plants, particularly in Indonesia, can use the priority list of medicinal plants developed here as a basis for coordinated and systematic active conservation work. It is clear that conservation efforts on Indonesian medicinal plants have already been made, but the information and network of stakeholders either does not currently exist or is difficult to access, hence the need to make it more widespread and strengthened. This network will find what has and what has not been done regarding conservation so that active conservation may utilise its limited resources on the conserving those Indonesian medicinal plants that most need it.

2.5. Conclusion

This study has identified a total of 5490 medicinal plant species of which 233 are a priority for conservation. Not all priority species are well-known as medicinal plants, such as those that belong to Dipterocarpaceae (mostly timber plants) and Orchidaceae (mostly ornamental plants). An inventory of priority medicinal species was developed, and it is hoped that this can be used to help the medicinal plant's stakeholders, mainly comprising researchers and government officials working on the systematic conservation of priority Indonesian medicinal plants. This priority list can be used to help formulate *in situ* and *ex situ* conservation plans at regional and national levels. Furthermore, dissemination to a wider public will help in raising knowledge and awareness of medicinal plants, which is essential towards the conservation of these valuable resources.

CHAPTER 3. GAP ANALYSIS OF PRIORITY INDONESIAN MEDICINAL PLANT SPECIES AS PART OF THEIR CONSERVATION PLANNING

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.

Keywords: conservation, gap analysis, Indonesia, medicinal plant species.

3.1. 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, Pretzsch and Kimengsi, 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).

Indonesia is a country rich in biodiversity (Vavilov, 1935; Ma *et al.*, 2010) with 30,000–40,000 plant species (Myers *et al., 2*000; Ministry of National Development Planning, 2016), and 2,500–7,500 of these species are medicinal plants (Hamid and Sitepu, 1990; Eisai, 1995; Erdelen *et al., 1*999), whether native or introduced species, and whether wild or cultivated species (de Padua *et al., 1*999). 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 contemporary 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., 2*015). 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., 2*008), Crop Wild Relative (CWR) groups (Meilleur and Hodgkin, 2004; Fielder, 2015; Tas *et al.*, 2019; Phillips *et al., 2*019), 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., 2*008). This study aims to analyse current Indonesian priority medicinal plant species diversity (see Chapter 2, Cahyaningsih *et al.*, 2021) and provide recommendations for *in situ* and *ex situ* conservation action. 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.

3.2. Methods

We used 233 Indonesian priority medicinal plant species in gap analysis study (see Chapter 2, Cahyaningsih *et al.*, 2021; Table A.3.1). The applied methods on gap analysis were adapted from Maxted *et al.* (2008), Fielder (2015), Tas *et al.* (2019), and 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 Gardens, 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, they were only found on the main island without exact location but the collector was available, the occurrences were tracked 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 x 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 and IUCN, 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.

3.3. Results and Discussion

3.3.1. Species' richness and bias map of Indonesian priority medicinal plants

A map of species' richness and observation bias of priority medicinal plant species in Indonesia was created from a total of 6,704 occurrence points. The map of species richness (Figure 3.1) 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, 67–82 priority species are found per area of 2,500 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 Wallacea are included in a hotspot meaning they have richer biodiversity than Australia area, although it is allegedly because there has been less collection in Papua than in other areas.

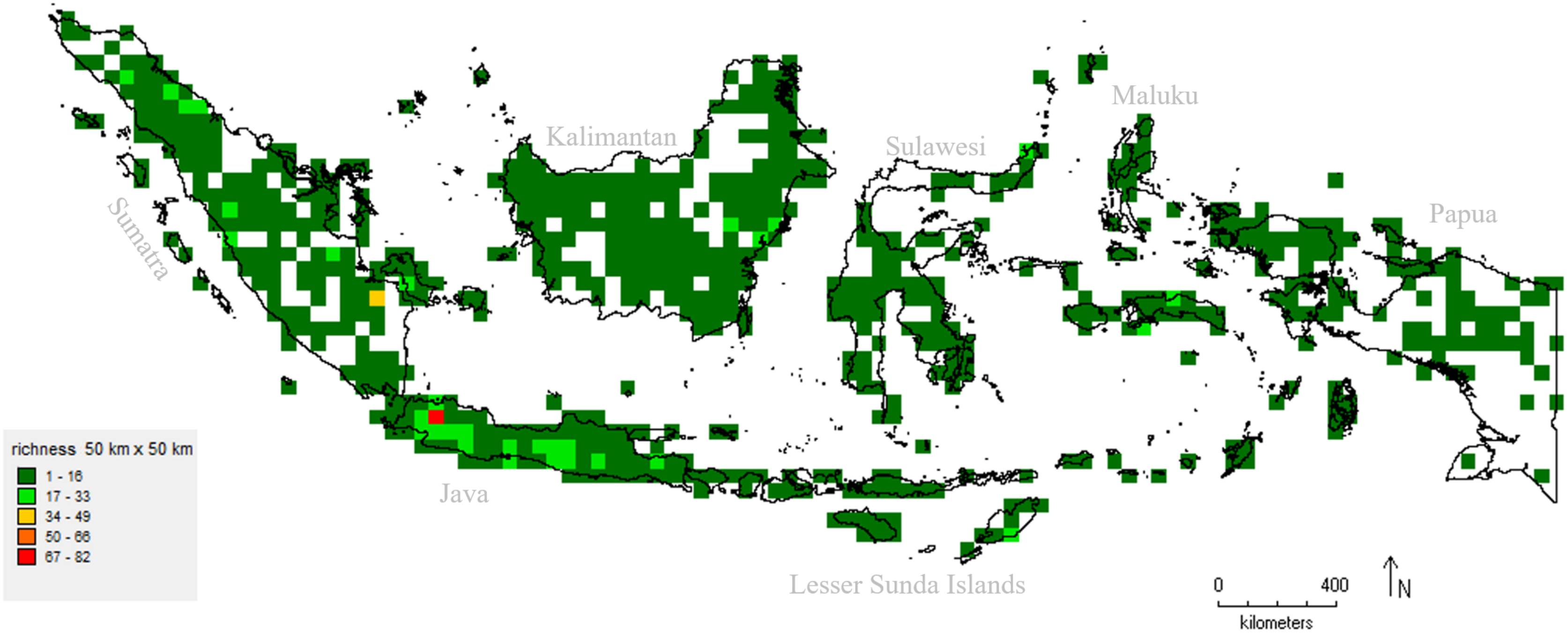

Figure 3.1. Species richness map of priority medicinal species (grid of 50 km x 50 km)

The observational bias map of Indonesian priority medicinal plant species (Figure 3.2) 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 (2,500 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). Wallacean shortfall is defined as "the paucity of information on the geography of nature" (Lomolino, 2004). 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).

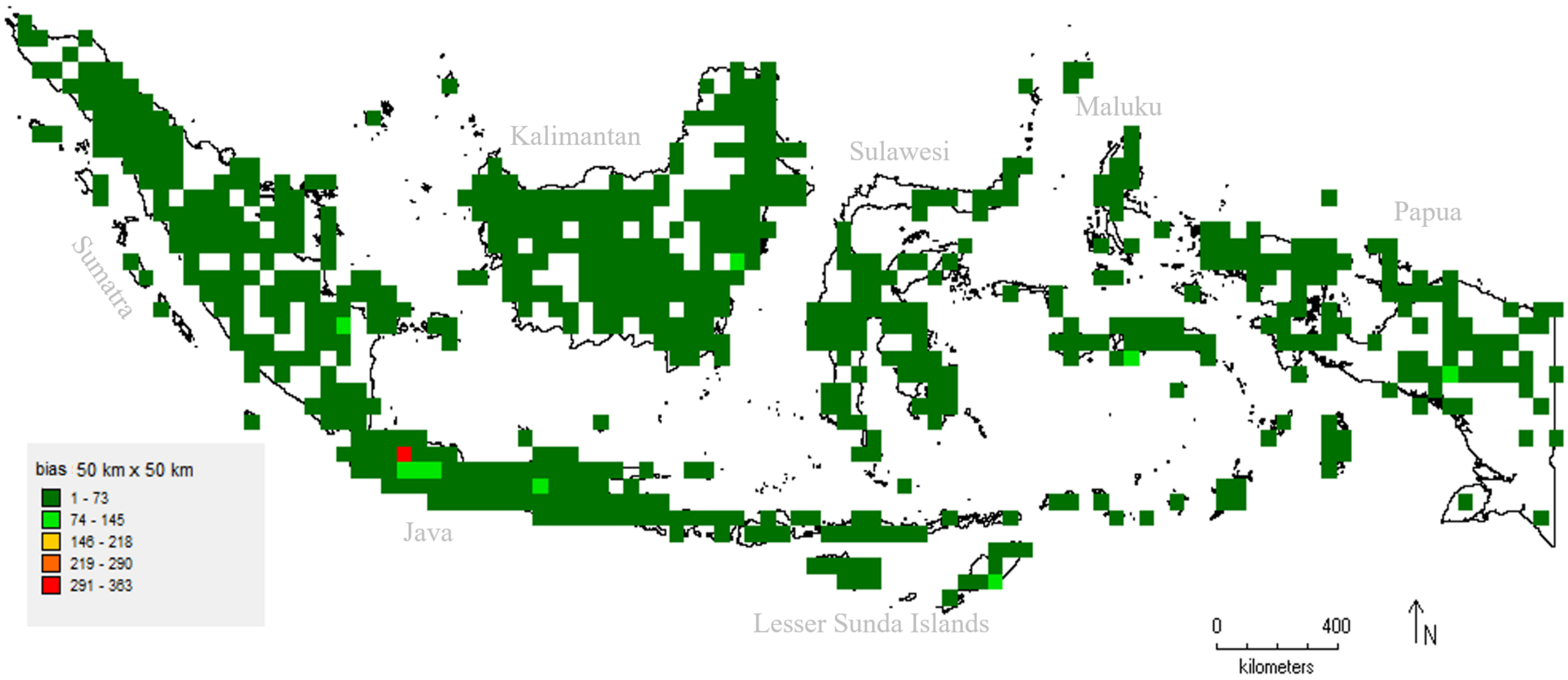

Figure 3.2. Bias of observation map of priority medicinal species in Indonesia (grid of 50 km x 50 km)

3.3.2. *In situ* and *ex situ* gap analysis of Indonesian priority medicinal plants

The complementary analysis resulted in 41 grid cells of networks (reserve sites), shown in Figure 3.3 and Table 3.1. 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 (Figure 3.3).

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 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 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).

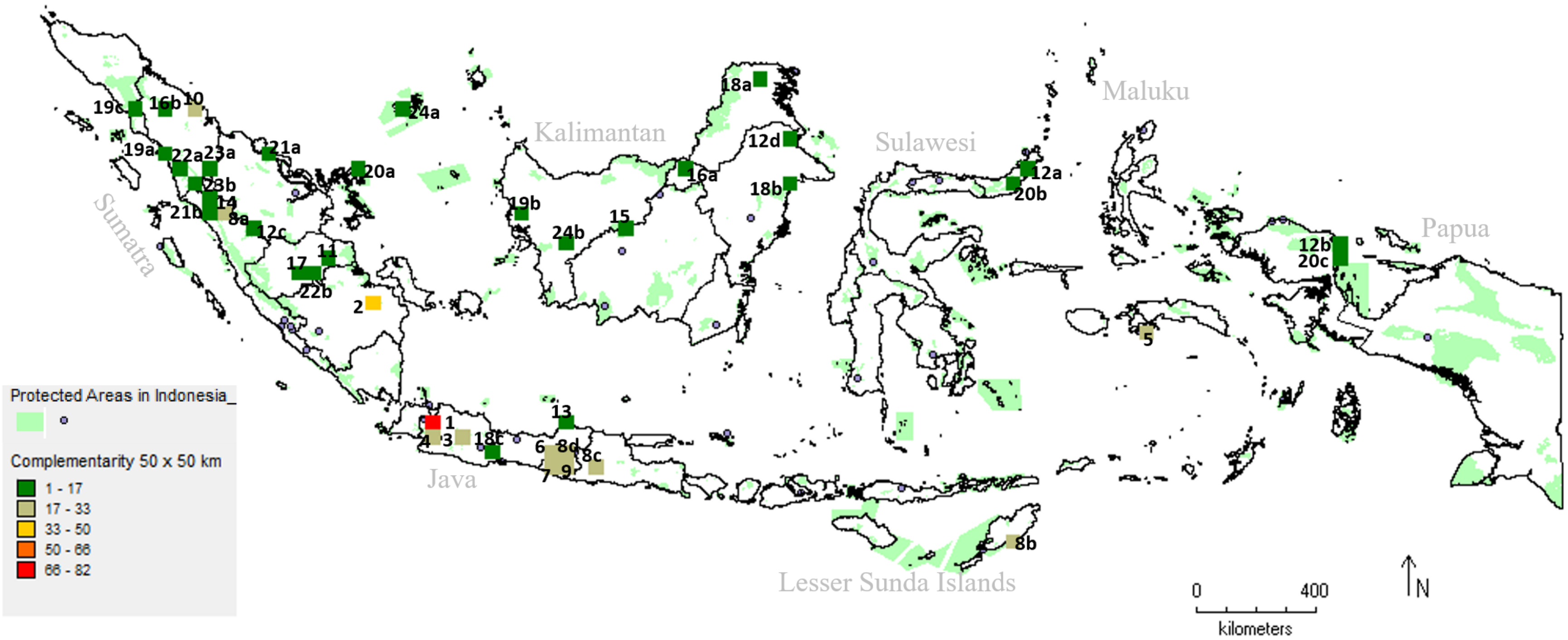

Figure 3.3. The complementary network areas map (grid of 50 km x 50 km) which conserve priority medicinal plant species in Indonesia and overlapped with PA (in light green) for *in situ* conservation of priority medicinal plants in Indonesia

Table 3.1. Site proposed for *in situ* conservation of priority medicinal plant 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 Sumatera	Sumatera
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	28	1	Central Java, Yogyakarta	Java

	National Reserve; Paliyan Wildlife Reserve; Plawangan Turgo Nature Recreation Park				
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 Sumatera	Sumatera
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 Sumatera	Sumatera
11	No	17	2	Jambi	Sumatera
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 Sumatera, Riau	Sumatera
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 Sumatera, North Sumatera, Riau	Sumatera
15	Bukit Baka-Bukit Raya National Park	10	7	Central Kalimantan, West Kalimantan	Kalimantan
17	Bukit Dua Belas National Park	8	3	Jambi	Sumatera
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 Sumatera	Sumatera
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 Sumatera	Sumatera
19b	no	6	1	West Kalimantan	Kalimantan
19c	Gunung Leuser National Park; Rawa Singkil Wildlife Reserve	6	1	Aceh; North Sumatera	Sumatera
20a	Bintan Locally Managed Marine Area	5	3	Bangka Belitung	Sumatera
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	Sumatera
21b	Malampah Alahan Panjang Wildlife Reserve; Maninjau Nature Reserve; KKPD	4	1	West Sumatera	Sumatera

	Kabupaten Agam, Kawasan Konservasi Perairan Daerah Kabupaten Agam Locally Managed Marine Area				
22a	Batang Gadis National Park	3	1	North Sumatera	Sumatera
22b	Sultan Thaha Syaifuddin Grand Forest Park; Durian Luncuk I, II Nature Reserve;	3	1	Jambi, South Sumatera	Sumatera
23a	Batang Gadis National Park; Barumun Nature Reserve	2	1	North Sumatera, Riau	Sumatera
23b	no	2	1	North Sumatera, West Sumatera	Sumatera
24a	KKPN Kepulauan Anambas dan Laut Sekitarnya Marine Recreation Park	1	1	Riau Islands	Sumatera
24b	no	1	1	West Kalimantan	Kalimantan

Noted: LSI= the Lesser Sunda Islands

The *ex situ* gap analysis showed that the area most in need of further collection is the Western part of Java and Maluku (Figure 3.4). 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 3.2). 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 planning 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).

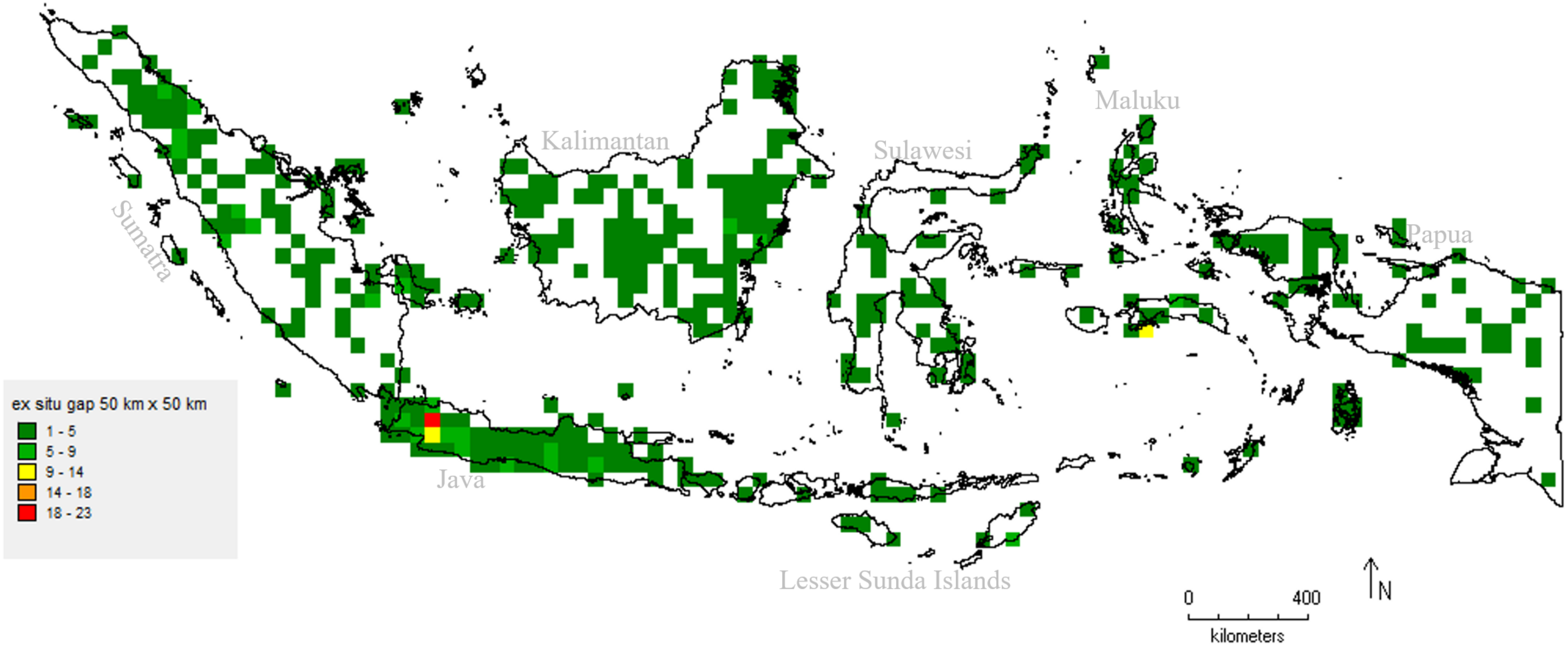

Figure 3.4. *Ex situ* gap map of priority medicinal plant species conservation in Indonesia (grid of 50 km x 50 km)

Table 4.2. Priority Indonesian medicinal plants 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

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., 2*000, van Welzen *et al.*, 2011, Mittermeier *et al., 2*011). 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, Timoshyna and Cornthwaite, 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 (Baričevič, 2009). Both approaches to conservation are inter-linked as they are complementary and 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 broad fields, namely several different groups with their expertise such as agronomy, conservation, 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, Whitehouse and Maxted, 2019).

3.4. 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 (Figure 3.3 and Table 3.1). These *in situ* reserve sites could protect priority species with threatened status assessed by IUCN, and that are threatened by international trade in wild-harvested material (included in CITES Appendix II), providing important information for medicinal plant species stakeholders. Contreras-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 cultivation and intensive propagation of six 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 to 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).

CHAPTER 4. CLIMATE CHANGE IMPACT ON MEDICINAL PLANTS IN INDONESIA

Abstract

Climate change affects biodiversity around the world, including medicinal plants in Indonesia. The future greenhouse gas emission scenarios of RCP4.5 and RCP8.5 for a mid-term future projection to 2050 and a long-term future projection to 2080 were used to simulate the effect of climate change upon medicinal plants distribution within Indonesia. Due to model validity, 43 out of 139 Indonesian medicinal plant species were used for climate change impact analyses. In 2050 and 2080, under both scenarios more than half of medicinal plants area is expected to decrease in species richness and losing up to 80 % of distribution area. Papua, Java, and Sulawesi are predicted to have high reduction in species distribution area. In addition, the turnover rate suggests two-third of species will lose rather than gain distribution area under the future climate scenarios. Twenty medicinal plant species might be possible to be the most threatened by climate change in the future and are therefore the highest priority for Indonesia's conservation actions. Furthermore, we recommend areas suitable for a long term *in situ* conservation and conversely the *ex situ* conservation in Indonesia.

Keywords: medicinal plant, climate change, impact, target species, Indonesia.

4.1. Introduction

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). The earth surface in particular, has been warmer during the past thirty years especially in the South Pole, which has experienced a temperature increase that was three times warmer than the equator (Stocker *et al.*, 2013; Clem *et al.*, 2020). Between 1850 and 2005, the earth's temperature had increased by 0.75°C, and further increased by 1°C in the ten years afterwards (IPCC, 2014). Recently, in the 2000s, data has shown that land and ocean temperatures are linearly increasing (Stocker *et al.*, 2013). Human activities influence rising levels of carbon dioxide (CO_2) and other heat-trapping 'greenhouse' gases (GHG) due to the use of fossil fuels as the largest source (Moss *et al.*, 2010; van Vuuren *et al.*, 2011; IPCC, 2014; Trenberth, 2018).

Predicted changes in climate and impacts on living species are correlated (Foden *et al.*, 2019). Phenology, temperature, rainfall, extreme events, and CO_2 concentration impact species-related phenomena, namely migration events, distribution range changes, habitat loss, resistance ability, competitive ability (Foden *et al.*, 2009) and vulnerability to extinction (Foden *et al.*, 2019). The Arctic and alpine plants are predicted to be the most negatively affected due to snowmelt (Cavaliere, 2009; Anthelme *et al.*, 2014) as well as tropical areas that lie in the equator due to the rise in sea level (Bellard *et al.* 2014) and rise in soil temperature (Sentinella *et al.*, 2020). In terms of climate change and medicinal plants, the compounds production in medical plants might be affected by temperature stress, for instance, St. John's Wort (*Hypericum perforatum,* cv. 'Topas') (Zobayed *et al.*, 2005) and *Crataegus* spp. (Kirakosyan *et al.*, 2003). Changes in medicinal plants in the Central Himalaya (India) have been detected, such as changes in plant phenology, distribution of plant species, and habitat (Maikhuri *et al.*, 2018). Studies regarding climate change affecting medicinal plants have been conducted in Thailand (Tangjitman *et al.*, 2015), China (Yi *et al.*, 2016; Wei *et al.*, 2018), Pakistan (Khanum *et al.*, 2013) and Africa (Asase and Peterson, 2019).

Indonesia is an archipelagic country with seven main islands/areas (Sumatra, Java, Kalimantan, Lesser Sunda Islands/LSI, Sulawesi, Maluku, and Papua), has 1,916,906.77 km^2 and is located on the equator line that almost spans 1/8 of world circumference, thus it has a long coastal area (BPS Statistics Indonesia, 2020). Given this geographical condition, Indonesia is vulnerable to climate change, especially due to rising sea levels, wave heights, and ocean temperatures (Zikra *et al.*, 2015) due to its long coastal area. An observation of big cities in Indonesia from the 1980s to 2016 the temperature and rainfall was shown to have generally increased (Suryadi *et al.*, 2018). Sundaland, which comprises Sumatra, Java, and LSI (which is one out of thirty-six global biodiversity hotspots) (Myers *et al.*, 2000) and where many rare plants are found (Enquist *et al.*, 2019) is predicted to be lost by 2100 due to a rise in sea levels (Bellard *et al.*, 2014). Furthermore, the Indonesian population reached 269 million in 2020 (Statistic Indonesia, 2020) and ranks 4^{th} in the world for population size after China, India, and the USA (US Census Bureau, 2020). Therefore, apart from threatening the habitat where the species grow (Ma *et al.*, 2010; Voeks, 2004), the high population might contribute to climate change through the intensive use of fossil fuels. As such, it is important that conservation planning of medicinal plants in Indonesia should take climate change into consideration.

Studies of the impact of climate change have been used to help identifying areas suitable for *in situ* and *ex situ* conservation, that is plant species habitat predicted to have no negative impact as a result of climate change and vice versa, respectively (Sanchez *et al.*, 2011; Asase and Peterson, 2019; Vincent *et al.*, 2019; Gaisberger *et al.*, 2020). Following up our last studies on gap conservation of Indonesian medicinal plants to create species distribution map for detracting observation bias (Cahyaningsih *et al.*, 2021a), we analyse the impact of climate change on medicinal plant species distribution and vulnerability in Indonesia under future climate scenarios. The objectives of this study are to estimate the richness of species under current and future scenarios for all studied medicinal plant species in Indonesia, to identify the environmental variables affecting the distribution of the species, to assess the potential impacts of climate change on the predicted distribution of the species under future scenarios, and to aid further prioritisation of species for conservation. Indonesia is a vast country with 3 out of 25 global biodiversity hotspots, including Asian and Australasian biodiversity (Myers *et al.*, 2000). This study will contribute towards a long-term, sustainable and robust *in situ* and *ex situ* conservation strategy for medicinal plants in Indonesia and regional and global levels.

4.2. Materials and Methods

4.2.1. Medicinal plants and occurrence records

139 of 233 priority species of medicinal plants in Indonesia were used for the climate change analysis (see Chapter 2; Table Appendix 4.1). Only those with ten or more occurrence points were selected to ensure a more accurate analysis

(Wisz *et al.*, 2008) resulting in 4446 presence points for the 139 species which were checked for consistency of their coordinates at the country level using DIVA GIS 7.5. Their occurrence records were gathered from GBIF (http://www.gbif.org; GBIF, 2020), BOLD database (http://www.boldsystems.org; (Ratnasingham and Hebert, 2007), Genesys (https://www.genesys-pgr.org; Genesys, 2020), and herbarium databases from Indonesia (Herbarium Bogoriense), and abroad (Royal Botanic Gardens, Kew and Royal Botanic Garden, Edinburgh in the United Kingdom, and also Naturalis herbarium in the Netherlands), and collection in Bogor Botanic Gardens–Indonesian Institute of Sciences.

4.2.2. Environmental variables for current and future analyses

A total of 19 environmental variables were used in the predictive analysis which consisted of geophysical, bioclimatic, and edaphic layers at a resolution of five arc-minutes (approx. 10 x 10 km at the equator). They were selected with the Random Forest (RF) procedure (Cutler *et al.*, 2007) implemented in the SelecVar tool of the CAPFITOGEN 2.0 tools (Parra-Quijano *et al.*, 2016, www.capfitogen.net/en) (Table 4.1). Additionally, correlation analysis with MINITAB 19 proved no significant correlation between any variables within the 19 selected variables.

Table 5.1. Environmental variables used for the analyses (generated from CAPFITOGEN 2.0 tools; Parra-Quijano *et al.*, 2016)

Variable	Code	Description	Unit	Source
Geophysics	alt	Altitude, metres above sea level	M	A
	aspect	Orientation (in degrees) of the land surface	°	B
	slope	Gradient (in degrees) of the land surface	°	
	northness	Northness. 1 if it faces northwards, -1 if it faces southwards		
	eastness	Eastness. 1 if it faces eastwards, -1 if it faces westwards		

Bioclimatic	bio_4	Temperature seasonality (standard deviation*100)		A
	bio_12	Annual rainfall	Mm	
	bio_13	Rainfall during the wettest month	Mm	
	bio_14	Rainfall during the driest month	Mm	
	bio_16	Rainfall during the wettest quarter (three rainiest months)	Mm	
	bio_17	Rainfall during the driest quarter (three driest months)	Mm	
	bio_18	Rainfall during the hottest quarter (three hottest months)	Mm	
	bio_19	Rainfall during the coldest quarter (three coldest months)	Mm	
Edaphic	s_oc	Content of organic carbon in subsoil	% weight	C
	s_ph_h2o	pH in subsoil in soil-water solution	-log(H+)	
	s_teb	Total exchangeable bases in subsoil	cmol/kg	
	t_oc	Organic carbon content in surface soil	% weight	
	t_ph_h2o	Surface soil pH in a soil-water solution	-log(H+)	
	t_teb	Total exchangeable bases in surface soil	cmol/kg	

Note: a= Worldclim Version 1.4; b= SRTM DEM Version 4; c= HWS Database Version 1.2

The current climate refers to a representation of the years 1960 to 1990 (Hijmans *et al.*, 2005). Future bioclimatic variables were collected from CCAFS (www.ccafs-climate.org), which are based on the fifth IPCC report (IPCC, 2014). The other variables are assumed not to be significantly affected by climate change (Pearson and Dawson, 2003; Phillips *et al.*, 2017). The future climatic model used was the Model for Interdisciplinary Research on Climate-Earth System Models (MIROC-ESM) (Watanabe *et al.*, 2011) for the Representative Concentration Pathways (RCP), RCP4.5 (Thomson *et al.*, 2011), and RCP8.5 (Riahi *et al.*, 2011) for a mid-term future projection of 2050 and a long-term future projection of 2080. The MIROC-ESM model has been used in plant species distribution studies individually or combined with other models (Robiansyah, 2018; Xu *et al.*, 2019; Shabani *et al.*, 2020). RCP4.5 represents a medium-range emission scenario (high mitigation scenario) that applies policies to reduce greenhouse gas emissions, so the radiative forcing stabilises at 4.5 W m^{-2} (approximately 650 ppm CO2-

equivalent) in 2100. RCP8.5 represents a high range emission scenario that applies the policies to reduce greenhouse gas emissions, so the radiative forcing stabilises > 8.5 W m^{-2} (>1,370 ppm CO2-equivalent) in 2100 (a possible development for high population numbers with high fossil fuel use) (Moss *et al.*, 2010; van Vuuren *et al.*, 2011).

4.2.3. Species Distribution Modeling (SDM)

Current and future climate scenarios for the potential distribution of medicinal plants in Indonesia were generated. The maximum entropy (MaxEnt) algorithm (Phillips *et al.*, 2006) was used to generate for each species an individual distribution model, under both current and future conditions. A cross-validated method was chosen to train and test the models (Elith *et al.*, 2011). Equal test sensitivity and specificity was used for the threshold in MaxEnt (Liu *et al.*, 2005; Gaisberger *et al.*, 2020). To check whether models were accurate and stable, three criteria were applied; the Area under the ROC (Receiver Operating Characteristic) Curve of the test data (AUCTest) > 0.7; standard deviation of the AUCTest data (STAUC) < (±) 0.15, and the proportion of potential distribution area with a STAUC > 0.15 below 10% (ASD15 < 10%) (Ramírez-Villegas *et al.*, 2010; Castañeda-Álvarez *et al.*, 2015; Contreras-Toledo *et al.*, 2019). Maps of accurate and stable distribution models under current and future climate conditions were displayed and analysed in DIVA-GIS 7.5 (Hijmans *et al.*, 2001). Three environmental variables that contributed most to the current models were identified in order to understand the SDM map (Tangjitman *et al.*, 2015).

4.2.4. Impact of Climate Change

The impact of climate change on medicinal plants in Indonesia was analysed using species richness maps, as well as figures relating to the loss and gain of species, turnover, and threat level based on the IUCN Red List adopted from Thuiller *et al.* (2005), Ramirez-Villegas *et al.* (2014), and Phillips *et al.* (2017).

Gain in species richness was measured when a species was absent in the current SDM but present in the future SDM, while loss was calculated based on the species present in the current scenario but absent in the future. Gain has a positive value, while loss has a negative value. Presence and absence were calculated from the species presence or absence within the grid cells extracted in text files for each species.

The turnover rate (T) was calculated for both RCP scenarios with the formula $T=100 \times (L+G)/(SR+G)$, where SR was the current species richness, L was the loss of species per grid cell, and G was the gain of species per grid cell (Phillips *et al.*, 2017; Ramirez-Villegas *et al.*, 2014; Thuiller *et al.*, 2005). The turnover rate always ranges from 0 to 100: that is, 0 when no species are gained or lost, and therefore species composition remains the same, and 100 when complete species gain or species loss occurs and species composition has changed (Phillips *et al.*, 2017; Ramirez-Villegas *et al.*, 2014).

The threat level for each medicinal plants species in Indonesia under future scenarios was assessed using the IUCN Red List criterion A3(c): namely, Extinct (EX) when predicted a loss of 100 %, Critically Endangered (CR) when predicted a loss of >80%, Endangered (EN) when predicted a loss of >50%, and Vulnerable (V) when predicted a loss of >30%; the time frame used for Criterion A should be

3 generations or 10 years, whichever or these is longer (IUCN, 2019). Due to the varied generation length of the medicinal plants species used, the time frame used for the future climate change assessment is assumed applicable for each species. The medicinal plants included in the IUCN red list based on distribution loss percentage were the highest conservation concern species list. In addition, ten species identified with smallest projected future range size of distribution area in each future scenario was included in the list (Jarvis *et al.*, 2008).

4.3. Results and Discussion

4.3.1. Species Richness of Medicinal Plants in Indonesia Under Current and Future Scenarios

The species richness of medicinal plants in Indonesia is shown in Figure 4.1. It is predicted under the present climate that between 1 and 21 species of medicinal plants are found in every grid cell (around 10 km squared area). Many areas with the richest medicinal plant diversity are found in four main islands, Java, LSI, Sumatra, and Sulawesi, with few plants found in Kalimantan. The area with the highest species richness is located on Java, extends from western to eastern part, and is wider compared to previous study regarding gap analysis (see Chapter 3) regardless the studied species number used as the observation bias has been detracted therefore the map might represent species diversity (Bini *et al.*, 2006; Monsarrat *et al.*, 2019).

Forty-three out of 139 medicinal plants had valid species distribution model in the current scenario. The low stable projection map might be because of the low occurrences of studied species considering their limited distribution, that was only distributed in one or two main areas of Indonesia (see Chapter 3). Each species distribution on the current map model was influenced by a different combination of variables (Table Appendix 4.2). Nevertheless, the dominant environmental variables which have influenced the model are; altitude/alt (metres above sea level), temperature seasonality (SD*100)/bio4 and rainfall during the driest month (mm)/bio14 (Figure 4.1). Altitude as non-climatic environmental variable had an obvious impact on species richness at a large scale within this study, even though Pearson and Dawson (2003) and Blach-Overgaard *et al.*(2010) found otherwise.

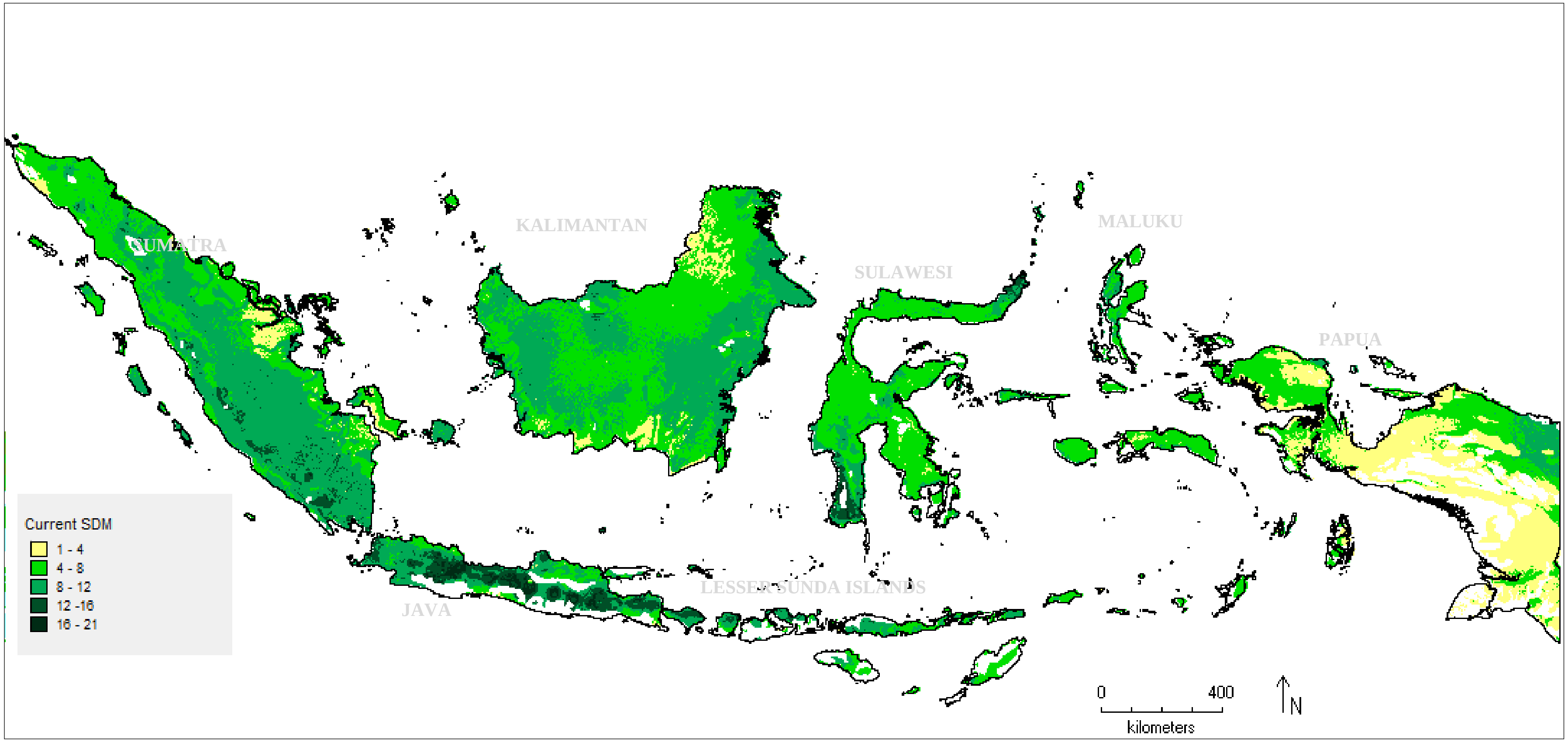

Figure 4.1. The predicted species richness of 43 medicinal plants in Indonesia under the current climatic conditions with a grid cell resolution of five minutes (approximately equal to 10 x 10 km2) used

The richness of medicinal plants is predicted to increase in the future according to four predicted future conditions: two scenarios of RCP4.5 in 2050 and 2080 (Figure 4.2), and two scenarios of RCP8.5 in 2050 and 2080 (Figure 3). It is because the grid of high diversity is seen increasing in both future scenarios, although the average value of both future species richness is lower than current (Table 4.2). It is predicted that, in the future, the four islands (Sumatra, Kalimantan, Java, and Sulawesi) will have more areas containing the highest number of medicinal plant species found within 10 x 10 km^2, although the number of species found within is fewer than the number of species of the richest area in the present,

Table 4.2. Overall descriptive value of species richness of medicinal plants in Indonesia under different scenarios

Observation	Current	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080
Average	17349.44	16084.88	15716.74	15979.28	14831.67
± stdev	8154.586	8193.829	8857.813	8356.029	9090.073
Min. value	31140	32519	33915	32653	34533
Max. value	2110	1858	1629	1562	1163

The minimum and maximum species richness value per grid cell (10 km x 10 km) in the future was projected to change. In the RCP4.5 future scenario, the richness value was within the range 1-22 (2050) and 1-20 (2080) species per grid cell (Figure 4.2) while under the RCP8.5 scenario the value was 1-20 (2050 and 2080) species per grid cell (Figure 4.3). It is assumed that an unlimited migration scenario is applied in the future models, and therefore, species are able to move freely across the landscape in response to climate change. The species might have a chance to migrate to a suitable area/environment, so extinction might not happen (Thuiller *et al.*, 2005; Phillips *et al.*, 2017; Sentinella *et al.*, 2020).

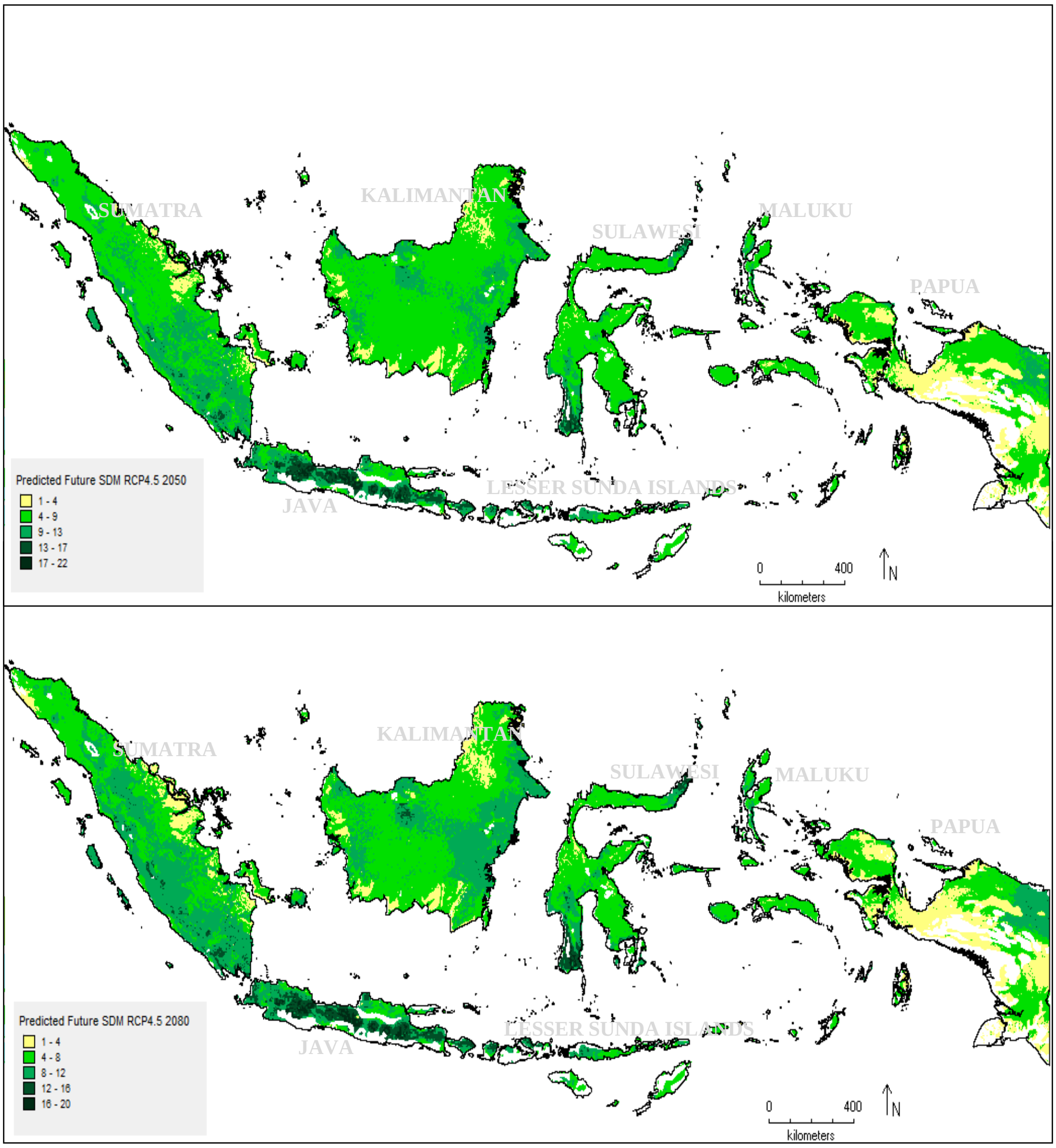

Figure 4.2. The predicted future species richness of 43 medicinal plants in Indonesia under the RCP4.5 scenario year of 2050 (above) and 2080 (below) with a grid cell resolution of five minutes (approximately equal to 10 x 10 km2) used

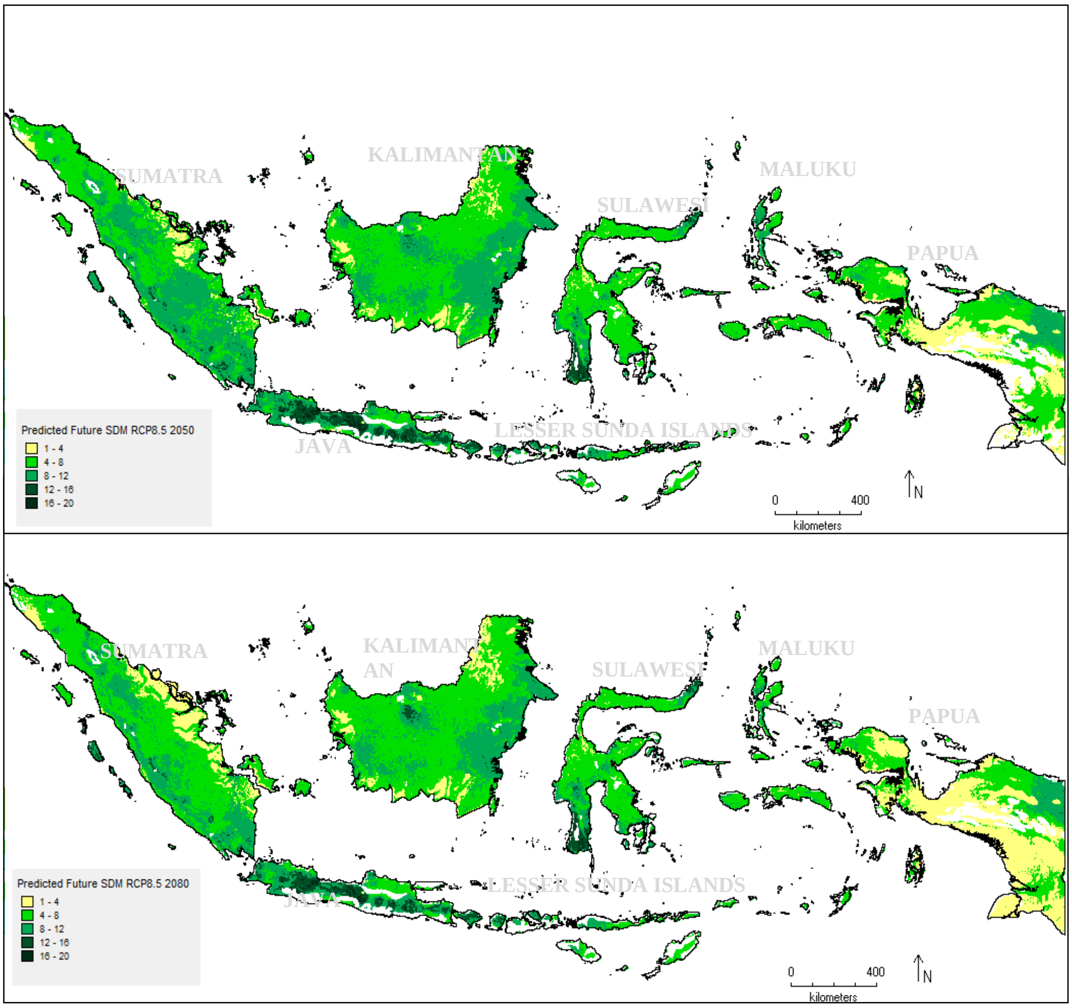

Figure 4.3. The predicted future species richness of 43 medicinal plants in Indonesia under the RCP8.5 scenario year of 2050 (above) and 2080 (below) with a grid cell resolution of five minutes (approximately equal to 10 x 10 km2) used.

4.3.2. Loss and gain of the distribution area

The distribution areas of medicinal plants in Indonesia are predicted to decrease by 2050, but some areas are expected to show an increase in species richness (shown in overall average value; Table Appendix 4.2). Papua, Java and Sulawesi are predicted to have the highest loss areas. Major distribution loss of species is predicted to occur in the Sundaland area, including Java and LSI, due to sea level rise (Bellard, Leclerc and Courchamp, 2014). Major loss of species is likely to happen in all future scenarios in the areas of East Java and South Sulawesi as they have large populations. WestJava, as the most populous province, a major loss is predicted in 2050 whilst the loss in 2080 is not as significant as in 2050 and mentioned provinces. However, the effect of climate change on small islands may be more influenced by human activity (Nurse *et al.*, 2014).

There is expected to be a noticeable change to distribution by 2080, with the gain in species spread almost equally across all islands and Sumatra showing the largest gain of species in some areas (Figure 4.4). In the future scenario of RCP8.5 in 2050 and 2080, the gain is predicted to be more widespread when compared to RCP4.5, even though the pattern of loss and gain are similar on each island (Figure 4.5). Nevertheless, the average gain and loss value in both years of RCP8.5 are smaller, while the loss value is more extensive than in RCP4.5 (Table 4.3). Under the future scenario of RCP8.5, the loss of the distribution area of species is most extensive as this scenario is the pessimistic scenario (IPCC, 2014).

Table 4.3. Overall descriptive value of loss and gain of medicinal plant's distribution area in Indonesia per future scenario

Observation	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080
Average	-0.30	-4.05	-0.40	-4.63
± stdev	1.35	40.74	1.78	31.79
Min. value	2.64	131.13	4.18	97.34
Max. value	-4.07	-68.27	-5.09	-54.38

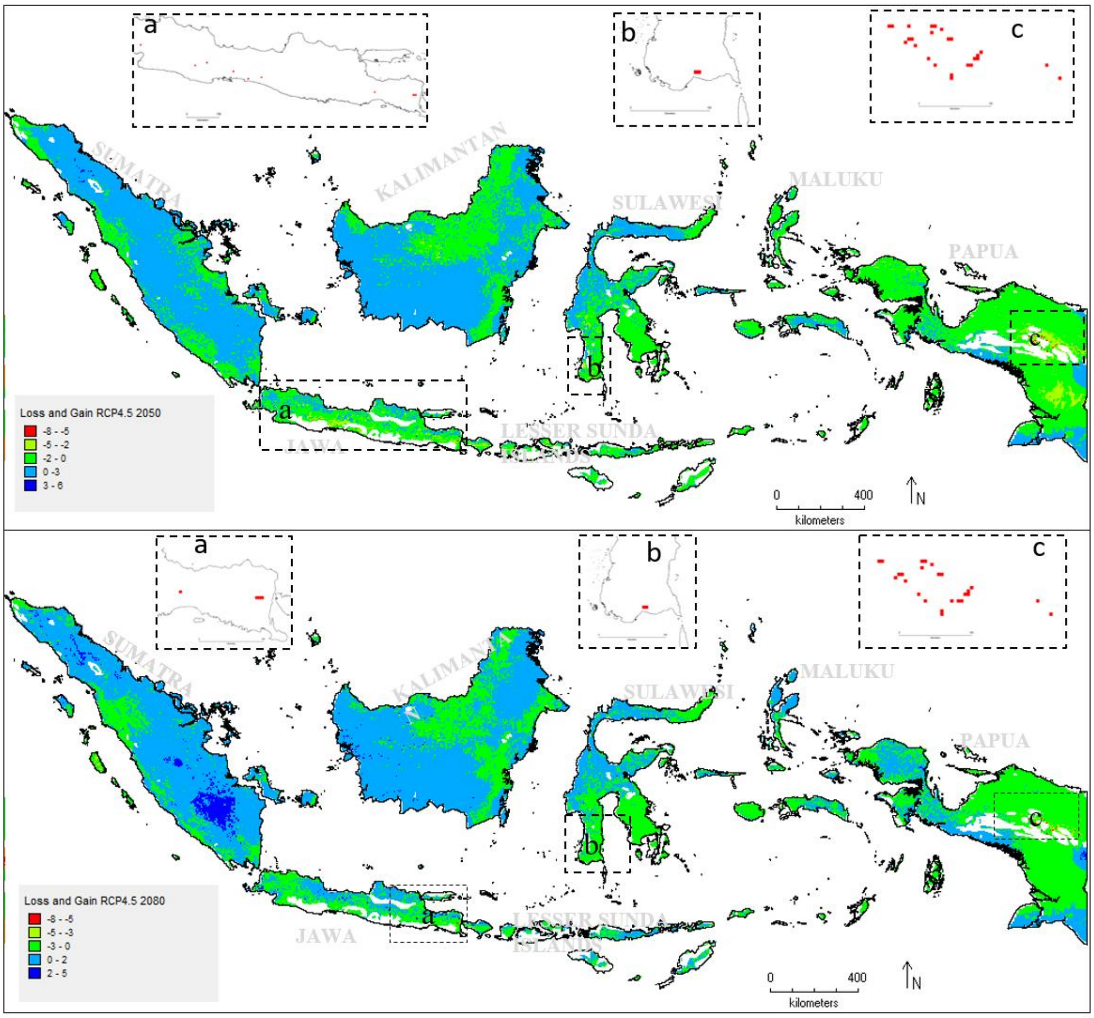

Figure 4.4. The predicted loss and gain of 43 medicinal plants in Indonesia distribution under the RCP4.5 scenario year of 2050 (above) and 2080 (below) with a grid cell resolution of five minutes (approximately equal to 10 x 10 km^2) used, with insert map where highest loss predicted

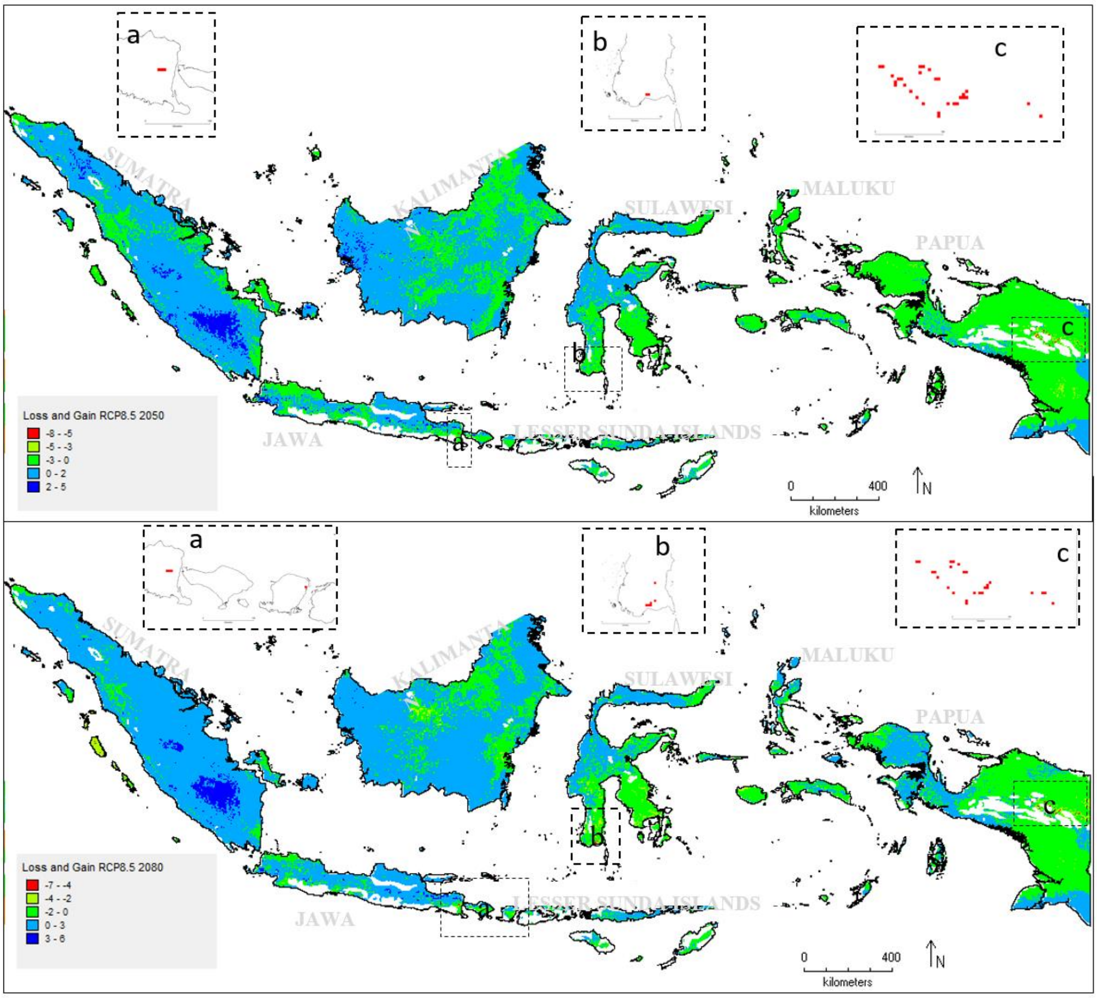

Figure 4.5. The predicted loss and gain of 43 medicinal plants in Indonesia distribution under the RCP8.5 scenario year of 2050 (above) and 2080 (below) with a grid cell resolution of five minutes (approximately equal to 10 x 10 km2) used, with insert map where highest loss predicted

The areas with gaining distribution area for species in the future are expected to have presence and abundance of population because the area is more suitable habitat **for** the species (Sanchez *et al.*, 2011; Robiansyah, 2018; Asase and Peterson, 2019; Vincent *et al.*, 2019; Gaisberger *et al.*, 2020), especially regarding harvesting and conservations (van Andel *et al.*, 2015). Here, *in situ* conservation with utilisation are recommended (Asase and Peterson, 2019). For the consequences, where overlapped with recommended potential reserve sites for medicinal plant conservation (see Chapter 3) and according to Vincent *et al.* (2019)

studied on global crop wild relatives, these areas are suitable for a long term *in situ* conservation site for Indonesian medicinal plant species because where high diversity are also found. On the contrary, the highest loss area where found in Papua, East Java and South Sulawesi in each future scenario (Figure 4.4 and Figure 4.5) would have habitat unsuitable for Indonesian medicinal plant species. Thus, these areas are priority for *ex situ* conservation action, that is to collect species if it has no representative in any *ex situ* site, for future use and domestication (Asase and Peterson, 2019).

4.3.3. Turnover

The overall average turnover rates for medicinal plant species in Indonesia were negative, but its value variation was different. The value of turnover rate variation in the RCP4.5 year 2050 and RCP8.5 year 2050 was high quite similarly, compared to other years under the same scenario. Despite having high species loss, some species with gain were also increased (Table 4.4). The data for each species identified more or less two-third of the turnover rates for the Indonesian medicinal plant species in all future scenarios had a negative value, which means the loss of species distribution area is expected to be larger than the gain, both under RCP4.5 and RCP8.5 scenario and occurred in 2050 and 2050 (Table Appendix 4.2).

However, based on predicted distribution gain and loss map (Figure 4.4-4.5), there were expected major gains experienced in each grid of observation (10 x 10 km^2 in size). The areas that experience gains are most likely a result of other species migrating into the grid. Plants species may shift to areas outside their usual favourable bioclimatic variables and thrive at different altitude or latitudes due to changing climatic conditions (Phillips *et al.*, 2017; Sentinella *et al.*, 2020; Thuiller *et al.*, 2005).

Table 4.4. Overall descriptive value of turnover rate per future scenario

Observation	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080
Average	-4.63	-0.32	-10.03	-0.60
± stdev	31.79	1.41	43.22	1.90
Min. value	97.34	3.14	138.41	4.41
Max. value	-54.38	-3.90	-71.32	-5.33

4.3.4. Identifying target species for highest conservation

Some plant species are predicted to face a high level of distribution loss under future RCP4.5 and RCP8.5 scenarios (Robiansyah, 2018; Asase and Peterson, 2019) or only under RCP8.5 scenario (Gaisberger *et al.*, 2020). Instead, some species might have a more extensive distribution than under RCP8.5 scenario (Li *et al.*, 2019; Yi *et al.*, 2016). In case of studied Indonesian medicinal plants, similar to turnover species value, the number of species having distribution loss would be around two-third higher than species having distribution gain, similar in each future scenario and occurred in 2050 and 2080. Nevertheless, the species number that gains distribution area under future RCP4.5 scenario might be increasing from 2050 to 2080, contrary to the species number under future RCP8.5 that are decreasing.

More than half of the studied species of Indonesian medicinal plants are predicted to reduce their population size because of losing an estimated 30-80% of their distribution area (Table 4.5). This would result in them being assessed as Vulnerable and Endangered based on IUCN Redlist criteria (IUCN, 2019) (Figure 4.6). The remainder of the species are predicted to suffer <30% distribution area or gain a new distribution area (Table Appendix 4.2). In line with studies by Tangjitman *et al.* (2015) suggesting that 77% of studied medicinal plants are highly threatened by climate change and need conservation. Jarvis *et al.*, (2008) suggest that species losing distribution area of above 50% in the future should be targeted for the highest level of conservation, which is similar to Endangered and Critically Endangered Species (IUCN, 2019).

Table 4.5. Observation on all studied medicinal plant species impacted by climate changes per future scenario

Observation	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080
Species gaining distribution area	17	18	18	17
Species losing distribution area	26	25	25	26
IUCN Redlist	7	13	12	14
Not IUCN Redlist	19	12	13	12

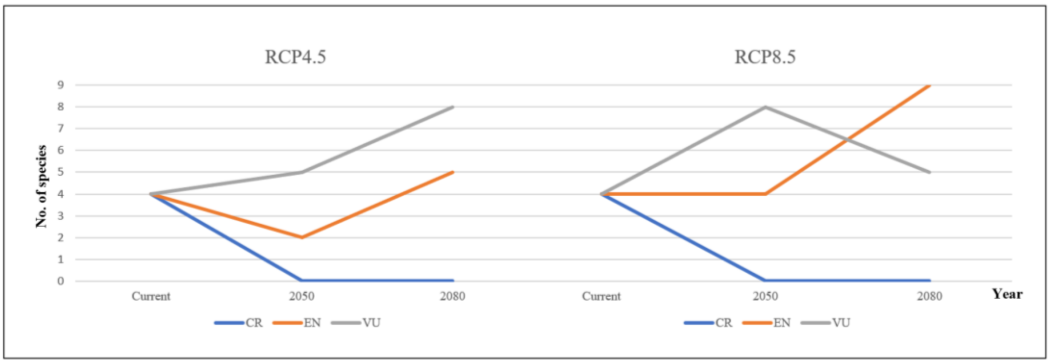

Figure 4.6. The predicted number of threatened medicinal plants in Indonesia per future scenario, as determined by the IUCN category A3(c)

The target species for highest conservation was defined based on the smallest distribution area in the future (Jarvis *et al.*, 2008) and IUCN red list A3 criterion (IUCN, 2019) (Table 6). 11 Indonesian medicinal plants are predicted to have the smallest size in all studied future scenarios and these species are included in a future IUCN red list A3 criterion (IUCN, 2019), except *Barleria prionitis* L.

and *Rauvolfia serpentina* (L.) Benth. ex Kurz. The average value of the distribution area and size of their range are both decreasing (Table Appendix 4.2). The average value of species with smallest distribution area in every future scenario is RCP4.5 2050 (554670 ± 272712 km2), RCP4.5 2080 (498110 ± 242999 km^2), RCP8.5 2050 (526100 ± 261119 km^2), and RCP 2080 (440990 ± 230521 km^2). Meanwhile, the range value of distribution area projected with scenarios of RCP4.5 2050, RCP4.5 2080, RCP8.5 2050 are 185800-914000 km^2, 162900-878600 km^2, 156200-856400 km^2, and 116300-822800 km^2 respectively.

Table 4.6. List of target species for highest conservation due to predicted climate changes impact

No.	Species	Gen. Length (year) (IUCN, 2021)	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080
1	*Agathis borneensis*[d] (EN)	70	VU		VU	EN
2	*Alstonia iwahigensis*[abcd]	NA	EN		EN	EN
3	*Anaxagorea javanica*	NA	VU		VU.	VU.
4	*Anisoptera costata*[abcd] (EN)	100	VU		EN	EN
5	*Aquilaria malaccensis* (CR)	50-100			VU	VU
6	*Barleria prionitis*[abc]	75				
7	*Castanopsis argentea* (EN)	NA				VU
8	*Dicksonia blumei*[abcd]	100		EN		
9	*Dipterocarpus baudii* (VU)	NA			VU	EN
10	*Euchresta horsfieldii*[abcd]	NA		EN	VU	EN
11	*Eurycoma longifolia*	NA	VU		EN	EN
12	*Eusideroxylon zwageri* (VU)	NA	EN		EN	EN
13	*Gentiana quadrifaria*[abcd]	50		VU		
14	*Macaranga griffithiana* (VU)	NA				VU
15	*Nepenthes reinwardtiana*	NA	VU		VU	EN
16	*Pinus merkusii*[abcd]	NA		VU	VU	EN
17	*Rauvolfia serpentina*[abcd]	50				
18	*Santalum album*[abcd] (VU)	NA		EN		
19	*Scutellaria javanica*[abcd]	NA		EN		
20	*Shorea seminis* (CR)	NA				VU

Notes: Species in grey column are included in 10 smallest distribution area according to Jarvis *et al.* (2008); a, b, c, and d refers to species included in 10 species with the smallest size in the future scenario of RCP4.5 2050, RCP4.5 2080, RCP8.5 2050, and RCP8.5 2080 respectively.

All target medicinal plant species are priority species that are rare or endemic criterion (Cahyaningsih *et al.*, 2021b) and prone to vulnerability and could become extinct due to climate change (Işik, 2011). Based on Table 6, most of them are tree species (68.18%) and shrub species (18.18%), while the rest are herb (9.09%), and climber (4.54%) (Table Appendix 2). Nevertheless, in spite of incomplete generation length data due to lack of monitoring particularly, in the long term, tree species which have longer generation length is more vulnerable to climate change (García-Valdés *et al.*, 2018; Chichorro *et al.*, 2019).

The Indonesian medicinal plant species listed in IUCN redlist composition changes are seen in each scenario (Table Appendixes 2, Table 5, and Table 6). The species included in redlist categories by IUCN currently majorly are expected to gain distribution areas due to climate change, and the other way around. Likewise, Benavides *et al.* (2020) found the same pattern on tropical cacti species distribution in Baja California Peninsula (Mexico) listed in IUCN might be benefited from climate change.

Identifying climate change impact on plant species could be overestimated because the species or population character, its biotic and abiotic interaction with habitat, and overharvesting by human were usually not considered (Thuiller *et al.*, 2005; Fordham *et al.*, 2012; Araújo and Peterson, 2012), but gain and loss patterns of the species over the distribution areas might remain (Thuiller *et al.*, 2005). Moreover, using the population size of plant with long generation length might be an inadequate predictor of population viability in the long term due to time lag in its response to habitat degradation (Colling and Matthies, 2006). However, geographic range, habitat breadth, and local abundance respectively had effects in determining extinction and the geographic range loss will lead to extinction level increasing even though the current local population is abundant (Harnik *et al.*, 2012). Given the higher threat level seen by higher distribution loss for many Indonesian medicinal plant species, the RCP8.5 scenario negatively affects species than RCP4.5. The data shows that major medicinal plant species that grow in Indonesia might be under threat due to climate change, supporting Sentinella *et al.*'s (2020) study, which identified that more than 50% of tropical species have a declining germination rate caused by climate change.

4.4. Conclusions

This study shows that Indonesian medicinal plant species are predicted to be negatively affected in both numbers and distribution as a result of a range of climatic variables under future climate change. The major environmental variables that contributed to the SDM are altitude (metres above sea level), temperature seasonality (SD*100), and rainfall during the driest month (mm). The impact varies from species to species, however there is likely to be a negative impact on the richness and distribution of certain species. The growing population of countries such as Indonesia are arguably contributing to these negative outcomes. Our results predicted that the number of medicinal plant species listed in the threatened IUCN Red List categories would increase under all future scenarios.

Distribution areas of Indonesian medicinal plant with biggest loss and the area with highest gain, respectively are recommended for *ex situ* conservation and *in situ* conservation planning. Moreover, twenty species of Indonesian medicinal plants might be listed as the most threatened in the future, but the generation length would need to be better understood; thus, conservation planning for these species are also recommended to assure long-term preservation and sustainability. In particular, the conservation planning starts from species that are predicted to be critically endangered in the future and might start from tree species and from the areas with the highest loss, which are found on East Java, South Sulawesi and Papua. This will guarantee their existence for utility and other research, such as ethnobotany, identification of medicinal plant compounds, clinical experiments with medicinal plants in Indonesia, and at regional and global levels.

CHAPTER 5. ROLE OF DNA BARCODING IN FACILITATING CONSERVATION AND USE OF PLANT SPECIES: A CASE OF INDONESIAN MEDICINAL PLANTS

Abstract

Over the last decade, plant DNA barcoding has emerged as a scientific breakthrough and is often used to help with species identification or as a taxonomical tool. DNA barcoding is very important in medicinal plant use, not only for identification purposes but also for the authentication of medicinal products. Here, a total of 61 Indonesian medicinal plant species and a pair of *ITS2*, *matK*, *rbcL*, and *trnL* primers for DNA barcoding were used in this study. This study aimed to provide region for DNA barcoding and investigate the effectiveness of each region to aid identification of the medicinal plants in Indonesia. We recommend *matK* as the main region for Indonesian medicinal plant identification, with *ITS2* and *rbcL* as an alternative or complementary region, despite no region was perfectly ideal for DNA barcoding. In addition, we herein identified new DNA barcoding sequences of Indonesian medicinal plant species accordingly for forensic studies that can support the conservation of medicinal plants and their national and global use.

Keywords: DNA barcoding; medicinal plants; conservation; forensic; Indonesia

5.1. Introduction

Plant identification used to be done only using morphological characters that can be observed visually, but today DNA can be relied on to enhance species identification and bioinventory (Miller *et al.* 2016). DNA barcoding, introduced by Hebert *et al.* (2003) based on his animal study results to identify a species through universal, short and standardised DNA regions. The process is to register the identified species DNA into a barcoding library and to match the unidentified species DNA against the DNA in the library (Kress and Erickson 2007; 2012). The library or the database can be accessed online for species identification and taxonomic clarification (Sucher *et al.* 2012), namely in the NCBI GenBank (https://www.ncbi.nlm.nih.gov/) (Sucher *et al.* 2012) and the Barcode of Life Data (BOLD) (http://www.boldsystems.org) (Ratnasingham and Hebert, 2007).

In plants, plastid DNA (*rbcL*, *matK*, *trnL*, and *trnH-psbA* region) and nucleus DNA (ITS and *ITS2* region) are often used in DNA barcoding (Taberlet *et al.*, 2007; Kress and Erickson, 2012; Fazekas *et al.*, 2012). The *rbcL* and *matK* regions are recommended by the Consortium for the Barcode of Life (CBOL) as a standard 2-locus barcode for global plant databases because of their species discrimination ability (CBOL Plant Working Group, 2009). DNA material for the barcoding can be either from living plants, herbarium specimens (Dick and Webb, 2012) and market products as well (Eurlings *et al.*, 2013; Newmaster *et al.*,2013).

DNA barcoding has become another taxonomical tool due to accuracy, repeatability and rapidity, but can also be used to identify any species under the legislation and threatened species and to check the authenticity of biological products (Kress and Erickson, 2007). It is powerful as identification will not be influenced by species morphology diversity, growth phase, and environmental factors (Schindel and Miller 2005; Chen *et al.* 2010; Techen *et al.* 2014; Huda *et al.* 2017). The forensic field even inexperienced user is assisted in assigning a taxonomic name to unidentified plant specimen from any casework (Paranaiba *et al.* 2019, *Ferri et al.* 2015). Thus, it is an effective conservation effort since it can prevent imitation of important commercial species and protected species from theft (Kress et al. 2014; Mishra et al. 2016) and define species richness in underexplored areas (Kress *et al.*, 2014).

Related to its use, DNA Barcoding is useful for medicinal plant conservation and use. It can help with plant identification, to assure the genuine product rather than a substitution so it can protect consumer rights (Vassou *et al.* 2016) and even with small and damaged plant parts used in botanical forensics (Sass *et al.* 2007; Eurlings *et al.* 2013; Ferri *et al.* 2015). Some studies have been done regarding DNA barcoding to medicinal plants, for example, *ITS2* and *matK* can distinguish *Rauvolfia serpentina* from other species in one genus (Eurlings *et al.* 2013, Mahadani *et al.* 2013) and are able to authenticate *Eurycoma longifolia* (Abubakar *et al.*, 2018). *MatK* gave the best identification for Apocynaceae that is in line with Cabelin and Alejandro (2016). In forensics, moreover, the DNA barcoding has been studied for medicinal plants used from one specific area, for example, Chen *et al.* (2010) and Gong *et al.* (2018) used the *ITS2* region as a DNA barcode for authenticating many medicinal plants and its relatives and for broader species although Chao *et al.* (2014) found that the *ITS2* region cannot authenticate all Chinese medicinal *Bupleurum* L. (Apiaceae). For Indian medicinal plants (Ayurveda), Vassou *et al.* (2016) established DNA barcoding using *rbcL* region whilst for medicinal plants of the Philippines, Suba *et al.* (2019) used *rbcL*, *matK*, and *trnL-F* region gradually according to its efficiency.

Indonesia is famous for its plant diversity and richness of ethnicity, especially in medicinal plants and their uses. Different forms of medicinal plants are used, regardless of being fresh or dried, for curing illness and diseases. Thus, the valid identity of the medicinal plants will be the main purpose of having this barcoding apart from to enrich the DNA barcoding database. DNA barcoding is an advanced technology for plant diversity inventories, which is mentioned as one of the issues and challenges of biodiversity conservation in Indonesia by von Rintelen *et al.* (2017) due to the high cost. Nevertheless, Kress *et al.* (2014) argued that DNA barcodes are useful for conservation and even for commercial purposes and it will be widely used in the future as DNA sequencing technology has become simpler and more economical. Thus, this study aims to provide new DNA barcoding of medicinal plants of Indonesia to aid identification and conservation and also to investigate the effectiveness of each DNA barcoding region (*ITS2*, *matK*, *rbcL*, and *trnL*) for DNA barcoding in medicinal plants of Indonesia.

5.2. Methods

5.2.1. Sample and literature collection

The plant materials used were 61 species of Indonesian medicinal plants, consisted of 30 families and 50 genera (Table 5.1). Some of them are priority species (See chapter 1). They are collected from botanic gardens where they have taxonomically morphological identified precisely, namely Bogor Botanic Gardens and Cibodas Botanic Gardens (Indonesia), and Hortus Botanicus Leiden

(Netherland). A leaf sample was collected from each species, except *Alstonia scholaris* (L.) R. Br. and *Spondias malayana* Kosterm, which had bark samples taken. This was due to *A. scholaris* and *S. malayana* Kosterm being high trees with unreachable leaves. Each sample of ±25 g was collected and stored in a teabag with silica gel (Wilkie *et al.*, 2013; Till *et al.*, 2015; Maurin *et al.*, 2017).

Table 5.1. 61 Indonesian medicinal plants used in this study

No.	Scientific name (POWO, 2020)	Author	Family	Location
1	*Justicia gendarussa*	Burm.f.	Acanth.	BBG
2	*Staurogyne elongata*	(Nees) Kuntze	Acanth.	CBG
3	*Pangium edule*	Reinw.	Achari.	BBG
4	*Spondias malayana*	Kosterm.	Anacardi.	BBG
5	*Toxicodendron succedaneum*	(L.) Kuntze	Anacardi.	BBG
6	*Ancistrocladus tectorius*	(Lour.) Merr.	Ancistroclad.	BBG
7	*Anaxagorea javanica*	Blume	Annon.	BBG
8	*Dasymaschalon dasymaschalum*	(Blume) I.M.Turner	Annon.	BBG
9	*Alstonia macrophylla*	Wall. Ex. G.Don	Apocyn.	BBG
10	*Alstonia scholaris*	(L.) R. Br.	Apocyn.	BBG
11	*Alyxia reinwardtii*	Blume	Apocyn.	BBG
12	*Hoya diversifolia*	Blume	Apocyn.	HBL
13	*Rauvolfia serpentina*	(L.) Benth. ex Kurz	Apocyn.	BBG
14	*Aglaonema commutatum*	Schott	Ar.	HBL
15	*Trevesia burckii*	Boerl.	Arali.	BBG
16	*Cibotium barometz*	(L.) J.Sm.	Ciboti.	BBG
17	*Decalobanthus mammosus*	(Lour.) A.R.Simoes & Staples	Convolvul.	BBG
18	*Erycibe malaccensis*	C.B.Clarke	Convolvul.	BBG
19	*Rhododendron macgregoriae*	F.Muell.	Eric.	CBG
20	*Acalypha grandis*	Benth.	Euphorbi.	BBG
21	*Euphorbia tirucalli*	L.	Euphorbi.	BBG
22	*Millettia sericea*	(Vent.) Benth.	Fab.	BBG
23	*Parkia timoriana*	(DC.)Merr.	Fab.	BBG
24	*Phanera fulva*	(Korth.) Benth.	Fab.	BBG
25	*Orthosiphon aristatus*	(Blume) Miq.	Lami.	BBG
26	*Premna serratifolia*	L.	Lami.	BBG
27	*Vitex glabrata*	R.Br.	Lami.	BBG
28	*Cinnamomum rhynchophyllum*	Miq.	Laur.	BBG
29	*Ficus deltoidea*	Jack	Mor.	BBG
30	*Myristica succedanea*	Blume	Myristic.	BBG

31	*Nepenthes ampullaria*	Jack	Nepenth.	BBG
32	*Nepenthes gracilis*	Korth.	Nepenth.	BBG
33	*Nepenthes mirabilis*	(Lour.) Druce	Nepenth.	BBG
34	*Nepenthes reinwardtiana*	Miq.	Nepenth.	BBG
35	*Acriopsis liliifolia var. liliifolia*	(J.Koenig) Ormerod	Orchid.	BBG
36	*Cymbidium aloifolium*	(L.) Sw.	Orchid.	BBG
37	*Cymbidium ensifolium*	(L.) Sw.	Orchid.	HBL
38	*Dendrobium crumenatum*	Sw.	Orchid.	BBG
39	*Dendrobium purpureum*	Roxb.	Orchid.	BBG
40	*Dendrobium salaccense*	(Blume) Lindl.	Orchid.	BBG
41	*Grammatophyllum speciosum*	Blume	Orchid.	BBG
42	*Nervilia concolor*	(Blume) Schltr.	Orchid.	BBG
43	*Nervilia plicata*	(Andrews) Schltr.	Orchid.	BBG
44	*Oberonia lycopodioides*	(J.Koenig) Ormerod	Orchid.	BBG
45	*Strongyleria pannea*	(Lindl.) Schuit., Y.P.Ng & H.A.Pedersen	Orchid.	BBG
46	*Galearia filiformis*	(Blume) Boerl.	Pand.	BBG
47	*Benstonea affinis*	(Kurz) Callm. & Buerki	Pandan.	BBG
48	*Phyllanthus oxyphyllus*	Miq.	Phyllanth.	BBG
49	*Ardisia complanata*	Wall.	Primul.	HBL
50	*Ardisia crenata*	Sims	Primul.	BBG
51	*Ventilago madraspatana*	Gaertn.	Rhamn.	BBG
52	*Psychotria montana*	Blume	Rubi.	CBG
53	*Lunasia amara*	Blanco	Rut.	BBG
54	*Melicope lunu-ankenda*	(Gaertn.) T.G. Hartley	Rut.	BBG
55	*Kadsura scandens*	(Blume) Blume	Schisandr.	BBG
56	*Smilax calophylla*	Wall. ex A.DC.	Smilac.	CBG
57	*Smilax zeylanica*	L.	Smilac.	BBG
58	*Aquilaria hirta*	Ridl.	Thymelae.	BBG
59	*Amomum hochreutineri*	Valeton	Zingiber.	CBG
60	*Etlingera solaris*	(Blume) R.M.Sm.	Zingiber.	CBG
61	*Meistera aculeata*	(Roxb.) Skornick. & M.F. Newman	Zingiber.	BBG

Note: Collection site: BBG: Bogor Botanic Gardens, CBG: Cibodas Botanic Gardens, HBL: Hortus Botanicus Leiden

A literature study has been done to collect all scientific information regarding each sampled Indonesian medicinal plant species. Information regarding available DNA data that is whether the species already have the DNA barcoding or DNA related information that can be accessed in DNA bank was identified in BOLD and NCBI; the species origin that is whether native or introduced species, and if it is native whether it is endemic or not were collected from Plants of the

World Online (http://www.plantsoftheworldonline.org/; POWO, 2020); threatened species status that is whether listed in IUCN as red list categories, namely Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct In The Wild (EW), and Extinct (EX) were collected from IUCN (2020) https://www.iucnredlist.org; global legislation regarding trade that is whether the species is included in CITES Appendixes were collected from UNEP-WCMC (Comps.) (2020) through https://checklist.cites.org. Previous research of Indonesian medicinal prioritisation's result (Cahyaningsih *et al.*, unpublished) was also used in this study. The plants embraced in IUCN Red List, CITES Appendix, Endemic, and Priority list are considered important species that need to be conserved in the first place.

5.2.2. DNA barcoding analysis

The molecular analysis was done in the University of Guelph's laboratory, Canada. The method starts with genomic DNA extraction, DNA amplification, DNA sequencing, and taxonomic identification against the DNA bank. For DNA extraction, genomic DNA was extracted from plant samples using the Maxwell® RSC Purefood GMO and Authentication Kit and the Maxwell® RSC Instrument (Promega). For the DNA amplification, primers targeting the *ITS2*, *matK*, *rbcL*, and *trnL* genes of plants were used to amplify the DNA (Table 5.2). The forward and reverse of each primer are mixed. Each PCR reaction mix (25 μL) contained 1x HotStarTaq master mix (Qiagen), 0.4 μM of each of the primers, 0.15 μg of BSA and 2 μL of template DNA. PCR thermal cycling was conducted using a GeneAmpTM PCR System 9700 (Applied Biosystems). The PCR cycling conditions were 95°C for 10 min for DNA denaturation, 45 cycles of 95°C for 15 sec for DNA annealing with the primer, 55°C for 30 sec and 72°C for 1 min for DNA extension, followed by 72°C for 7 min.

Table 5.2. Primers used for amplification of DNA regions of *ITS2*, *matK*, *rbcL*, and *trnL*

Primer	Name	Sequence	Reference
RbcL	*rbcL*a-F	ATGTCACCACAAACAGAGACTAAAGC	Costion *et al.*, 2011
	*rbcL*a-R	GTAAAATCAAGTCCACCRCG	
matK	*matK*472F	CCCRTYCATCTGGAAATCTTGGTTC	Yu *et al.* 2011
	*matK*1248R	GCTRTRATAATGAGAAAGATTTCTGC	
matK[a]	*matK*xF	TAATTTACGATCAATTCATTC	Mahadani *et al.* 2013
	*matK*5R	GTTCTAGCACAAGAAAGTCG	
ITS2	*ITS2*F	ATGCGATACTTGGTGTGAAT	Gu *et al.*, 2013
	ITS3R	GACGCTTCTCCAGACTACAAT	
trnL	*trnL-F*	ATTTGAACTGGTGACACGAG	Taberlet *et al.*, 2007
	trnL-c	CGAAATCGGTAGACGCTACG	

Note: *matK*[a] is alternative to *matK* that is used when PCR reaction failed to have an amplificon

PCR products were visualised on 2% agarose gels to check whether DNA amplification succeeded. After that, PCR products were then purified using NucleoFast® 96 PCR clean-up kit (Macherey-Nagel). The purified PCR fragments were sequenced bidirectionally with the same primers as for PCR using an ABI 3730 Genetic Analyzer (Applied Biosystems). The retrieved sequences were analysed using ABI PrismTM Sequencing Analysis software (Applied Biosystems) to obtain a consensus sequence (Q>20) for each sample.

5.2.3. Sequence analyses and data interpretation

The consensus sequences were compared with the nucleotide sequences in the Barcode of Life Data (BOLD) species ID engine and the NCBI GenBank using BLASTN (https://blast.ncbi.nlm.nih.gov/; Altschul *et al.* 1990) with Program Selection "Highly Similar Sequences (Megablast)" (Morgulis *et al.* 2008) for taxonomy identification. When no result came from Megablast due to too short sequence, the sequence was queried with Program Selection “Somewhat similar sequences (nBlast) for an alternative”.

PCR amplification, sequencing, and identification success rate will be counted in percentage. Only one best-matched species was collected from the BLASTN identification. If the best-matched species was more than one, the lowest E value and the highest coverage were chosen; otherwise, any species were chosen that were the closest related species to the query (species).

The BLASTN identification result was considered as the correct species if the highest percentage of identification referred to the right species or in another word when the species name from sequence identification matched the morphologically identified species. Otherwise, the result was considered an ambiguous species or ambiguous genus when respectively the sequence was identified as different species within genus or different species within family. Ambiguous identifications are counted as the correct identification (Amandita *et al.*, 2019). Sequences that have a percentage of 99% or more are included in the novel sequence data for specific DNA barcoding to a species. Novel sequence data will be put in the GenBank database to assist the identification.

Descriptive statistical and scatter plot analysis respectively to understand the different region of *ITS2*, *matK*, *rbcL*, and *trnL* and the relation within factors in BLAST analysis with the identification were done with MINITAB Statistical Software. Information regarding the species number per genus was obtained from Plants of the World Online (http://www.plantsoftheworldonline.org; POWO, 2020). In addition, sequence alignments were done with Muscle program, nucleotide composition of all sequences obtained from *ITS2*, *matK*, *rbcL*, and *trnL* regions was computed, and their genetic distance was computed with Kimura 2 parameters (K2P) (Casiraghi *et al.* 2010). K2P pairwise genetic distance is the percentage nucleotide sequence divergence that was used in Hebert *et al.* (2003). All analysis was done with the software of Molecular Evolutionary Genetics Analysis (MEGA X) (Kumar *et al.* 2018). Moreover, the Venn diagram consisted of the four region group was made with online software of Bioinformatics & Evolutionary Genomics (http://bioinformatics.psb.ugent.be/cgi-bin/liste/Venn/calculate_venn.htpl).

Every medicinal plant species (MP) information collected were analysed and interpreted according to the DNA barcoding use related to conservation. Any correct identification can be used as DNA barcoding for related species; thus, it can be helpful for MP conservation. Any ambiguous identification can be used as an approach to species identification until genus or family level depending on the ability; thus, it may be helpful for MP conservation. The species included in at least one of the IUCN Red List, CITES Appendixes, priority species (Cahyaningsih *et al.*, unpublished), and or Native and Endemic would need DNA barcoding used stronger than the non listed species. The sequence could be a new sequence or new DNA barcoding if it is not available in NCBI or BOLD, and it becomes novel data.

5.3. Result and Discussion

A total of 61 species of Indonesian medicinal plants have been analysed to have DNA barcoding of their four regions (*ITS2*, *matK*, *rbcL*, and *trnL*). There was a failure in DNA amplification and sequencing with the factual result of each step shown in Table 5.3. Instead of 244 sequences resulting from the sequencing as the last step, only 212 sequences were provided (Table Appendix 5.1).

Table 5.3. Success percentage in each DNA barcoding step's result

Observed parameter	*ITS2* (%)	*matK** (%)	*rbcL* (%)	*trnL* (%)
No PCR amplicon obtained	1.64	27.87	1.64	16.39
Mixed sequences -no use	8.20	0	1.64	3.28
Sequence provided	91.80	72.13	96.72	80.33
Aligned consensus sequence	90.16	65.57	96.72	73.77
Unidirectional sequence	1.64	6.56	0	6.56

*4 *matK* regions by the second primer excluded

The sequence quality is described from the easy to do alignment of both forward and reserve regions into one consensus sequence (Table 5.3). When both forward and reverse sequences were available, and of good quality, it was straightforward to have the aligned consensus sequence. If one direction of the sequence was mixed, then no alignment could occur, and then only the unidirectional sequence can be used. Kress and Erickson (2007) and Hollingsworth *et al.* (2011) mentioned the same, that *matK* has the lowest amplification success amongst the other regions that are used for DNA barcoding. Amandita *et al.* (2019) particularly showed the *matK has* lower PCR success rate then *rbcL* while amplifying DNA of Indonesian plants. The PCR amplification failure was estimated because the sequence for binding sites of the *matK* region is very varied (Hollingsworth *et al.*, 2011).

5.3.1. Description of *ITS2*, *matK*, *rbcL*, and *trnL* region of Indonesian medicinal plants

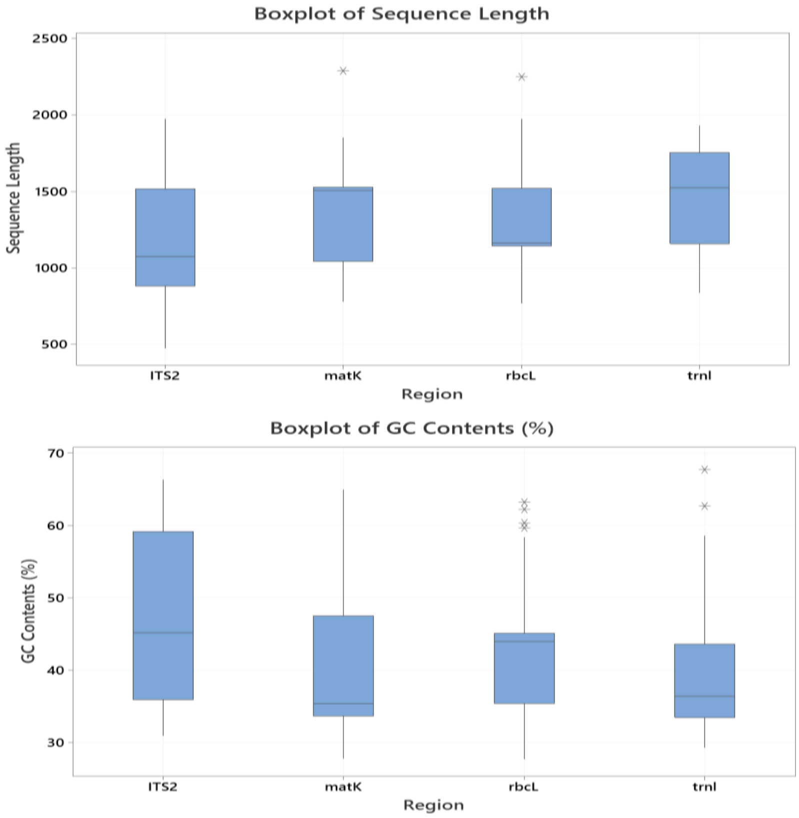

Figure 5.1. Box plots of the sequence length (left) and GC content (right) per region of *ITS2*, *matK*, *rbcL*, and *trnL* of Indonesian medicinal plants

The descriptive statistic of sequence regions *ITS2*, *matK*, *rbcL*, and *trnL* are shown in Figure 5.1. The minimum and maximum length (bp) of *ITS2*, *matK*, *rbcL*, and *trnL* region respectively varied between 473-1973, 779-2288, 767-2250 and 837-1931 for all Indonesian medicinal plant species. Whereas, the average length of them are respectively 1188.7, 1361.2, 1278.6, and 1478. In case of GC Content (%), the minimum and maximum GC Content (%) of *ITS2*, *matK*, *rbcL*, and *trnL* region respectively varied between 30.91-66.35, 27.80-64.94, 27.73-63.25 and 29.26-67.74 for all Indonesian medicinal plant species, whilst the average length of them are respectively 48.14, 41.46, 43.46, and 39.10.

The relation between identification accuracy and sequence length (bp), GC Content (%), species number per genus and percentage of identity are shown in Figure 5.2. In terms of sequence length, the longer the *ITS2* and *rbcL* sequence region the less identification accuracy, whilst other regions showed no relationships as the line almost horizontal. In terms of GC contents (%), all regions except *ITS2* tends to be less accurate for identification when the GC content increased. In terms of species number per genus, *matK*, *rbcL*, and *trnL* tends to have no correlation with the species number per genus, but ITS sequence region is more accurate in identification when the species number per genus is higher. However, this result cannot be relied on because the result will depend on the available DNA information in the bank data. Moreover, in terms of percentage of identity, all regions showed a positive relationship with the identification accuracy that is higher percentage higher the accuracy.

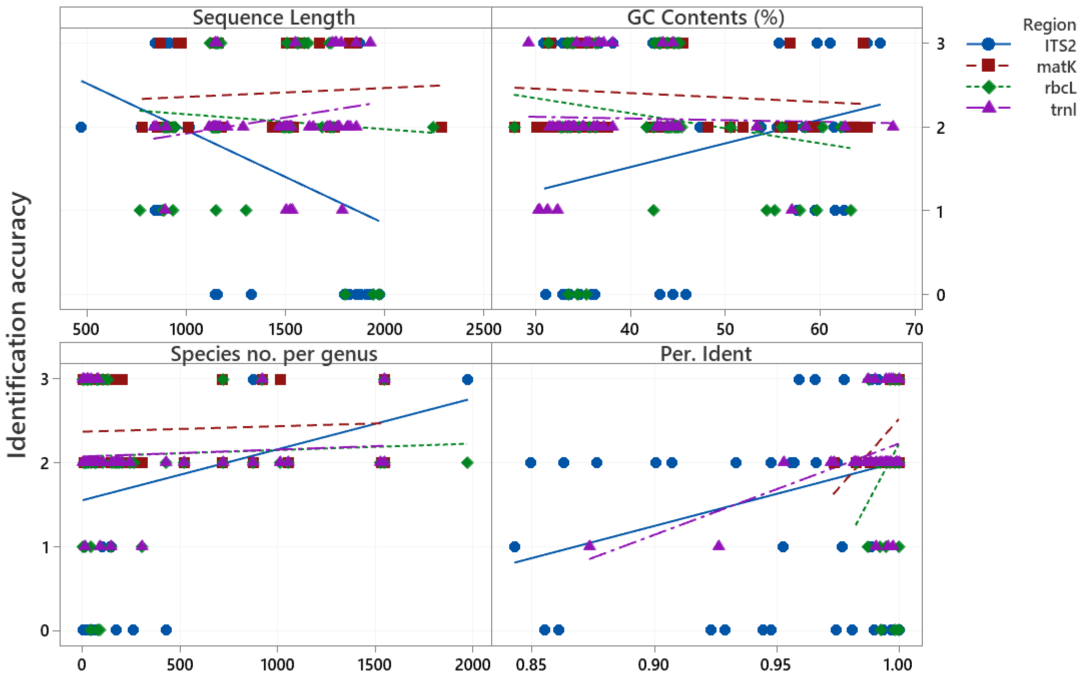

Figure 5.2. Scatterplot of Identification accuracy vs Sequence length (bp), GC Content (%), Species number per genus, and Percentage of Identity. Scale 0-3

represent the identification accuracy (0=incorrect, 1=correct in family level, 2=correct in genus level, 3=correct in species level)

Amongst the sequence region produced for Indonesian medicinal plants, *ITS2* generally has the shortest minimum length and smallest average sequence and highest GC contents (Figure 5.1 and Figure 5.2). *ITS2* generally has the shortest minimum length and smallest average sequence that means having the highest efficiency of identification. It is because there will be a short DNA sequence needed to get the correct identification. After *ITS2, matK* is following in second place in terms of the smallest average. A short length of DNA sequence may make the process of DNA barcoding technically easier and more economical from extraction to sequencing, as Kress *et al.* (2005) suggested for DNA barcoding. Meanwhile, in terms of GC contents (%), only *ITS2* has higher identification accuracy when the GC content is increasing. In some plant DNA sequences, GC contents have a positive correlation with exon sites that is the coding region (Singh *et al.* 2016). It might be mean longer exon, higher GC contents; thus, DNA regions with high GC contents are expected to have more accurate identification.

5.3.2. Identification of Indonesian medicinal plants using their sequences of *ITS2*, *matK*, *rbcL*, and *trnL* region

Identification of the sequence regions resulting from the BLAST method is shown in 1. The highest correct identification in total species is reached by the *matK* region followed by *rbcL* and *ITS2* in second place, although the percentage value amongst them may not be significantly different 31.14% compared to 29.51%. In contrast, *trnL* has the lowest correct identification with an almost 15% difference to *matK*'s correct percentage. The highest incorrect identification is reached by the *ITS2* region, followed by *rbcL* in second place. The most accurate region of the four used regions is *matK* because it is successful in having identified the highest species level, lowest in family level, and no incorrect identification is recorded.

Table 5.4. Identification success rates of each region through the BLAST method

Identification rate	Region			
	ITS2 (%)	*matK** (%)	*rbcL* (%)	*trnL* (%)
Correct identification in species level	32.14	33.93	30.51	20.41
Correct identification in genus level	35.71	51.79	54.24	60.71
Correct identification in family level	7.14	0	10.17	10.20
Incorrect identification	25	0	5.08	25

*4 *matK* regions by the second primer excluded

Some ambiguous (correct in genus and family level) and incorrect identification to Indonesian medicinal plants species in Blast occurred. This might happen as the world plant data has more than 1.1M species names (POWO, 2020), while the DNA barcoding data for the plant is only 234,692 (BOLD, 2020). The available DNA bank data is far from completion. Also, there are only 5.942 plants from Indonesia recorded in Bold (BOLD, 2020).

Venn diagrams (Figure 5.3) describe how many unique species were correctly identified by one only region and by various combination also. *ITS2* is the most region having the unique correct identification, and second is *rbcL*, then *matK* and *trnL*. Combination of three regions gave the same number of unique correct identifications, and combination of all gave the highest correct identification. In terms of unique correct identification in genus level, *rbcL* gave the most accurate identification, then followed by *ITS2* and *trnL* in the same position, and *matK*. Combination of *matK*, *rbcL* and *trnL* gave the best unique accurate identification compared to the other three combinations, and combination of all gave the biggest number of unique species amongst all possibilities. The unique correct species in family level were obtained from highest to lowest by *rbcL*, *ITS2*, and *trnL*.

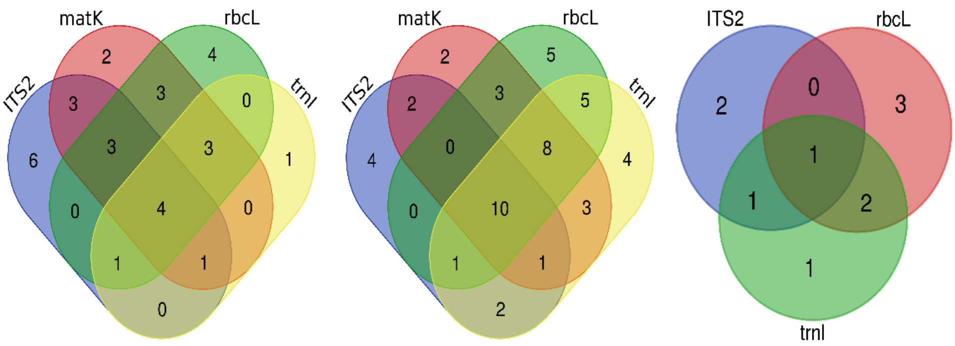

Figure 5.3. Venn diagrams for correct identification in species level, in genus level, and in family level (from left to right)

According to Table 5.5, the overall average of each region that describes the genetic distance between two species compared is almost similar to each other, that is above 1.1% and below 1.2%, except *ITS2* with the percentage of 1.29%. The lower the taxon unit relation, the lower the percentage, while the higher the taxon unit relation, the higher the percentage. Only the minimum distance of the *matK* region can describe the same genera related species, but not with other regions. Nevertheless, all maximum distance of each region describes the different family-related species that is the highest level. In principle, the genetic distance of interspecific relation species (within genus level and above) will be greater than the intraspecific relation species (within species level).

Table 5.6. K2P pairwise genetic distances (%) of each region summary at different species levels

Region	Observation	Value (%)	Related species
	Overall average	1.29503	
ITS2	Minimum distance	0.00440	*Nepenthes reinwardtiana* and *Nervilia concolor****
	Maximum distance	2.70903	*Erycibe malaccensis* and *Acalypha grandis****
matK	Overall average	1.12567	

	Minimum distance	0.00615	*Nepenthes mirabilis* and *N. ampullaria*[*]
	Maximum distance	2.62368	*Nepenthes reinwardtiana* and *Parkia timoriana*[***]
	Overall average	1.19148	
rbcL	Minimum distance	0.00350	*Amomum hochreutineri* and *Etlingera solaris*[**]
	Maximum distance	2.62587	*Phyllanthus oxyphyllus* and *Galearia filiformis*[***]
	Overall average	1.11310	
trnL	Minimum distance	0.02887	*Alstonia scholaris and Rauvolfia serpentina*[**]
	Maximum distance	2.59858	*Millettia sericea and Cymbidium aloifolium*[***]

Notes: [*]: same genera related species; [**]: same family related species; [***]: different family-related species

The percentage of the identity of each sequence of *ITS2*, *matK*, *rbcL*, and *trnL* region is directly proportional to identification accuracy. The higher the percentage, the more accurate the identification is. *MatK* can identify the species with the highest percentage correct, and *rbcL* is next (Table 5.4). Only the *matK* region can differentiate species in the same genus level and species in the different family in the closest and furthest genetic distances respectively compared to other regions. In contrast, *ITS2* cannot differentiate all species distance appropriately (Table 5.5). Hollingsworth *et al.* (2011) explain that actually DNA barcoding application can be divided into two purposes. The first is the DNA barcoding to provide information into the species-level taxon unit, and the second is to help identification of an unknown specimen to a known species. Thus, all regions tested are all useful, depending on the purpose.

5.3.3. Understanding the use of DNA barcoding for Indonesian medicinal plants

Out of 61 sampled Indonesian medicinal plants (MPs) species, 55 species are native to Indonesia, and 6 are introduced, of which 29 species are endemic species (POWO, 2020). Some of MPs may need to be conserved in the first place, that is two species included on IUCN Red List Categories (IUCN, 2020), 19 species listed in CITES Appendix (UNEP-WCMC (Comps.), 2020), and 26 priority MPs (see Chapter 2). The two species included in IUCN Red List are as vulnerable that are *Aquilaria hirta* Ridl. VU (Harvey-Brown, 2018) and *Etlingera solaris* (Blume) R.M.Sm. (Olander, 2019) so these species are considered to be facing the high extinction risk in the wild in the near future (IUCN, 2012). The other 19 species are listed in CITES II, which are maybe extinct if the trade is not controlled because species are collected from the wild without sufficient propagation (UNEP-WCMC (Comps.), 2020). The species listed in priority list by Cahyaningsih *et al.* (2020) were only native species with limited distribution and harvested in a destructive manner and included with the protected species by national or and global legislation. Against the DNA bank data (NCBI) and DNA barcoding data (BOLD) availability, there are 13 species have not had DNA barcoded but has DNA sequences data in NCBI, and 10 species neither has their sequences stored in NCBI nor BOLD. The detailed information is shown in Table Appendix 5.2.

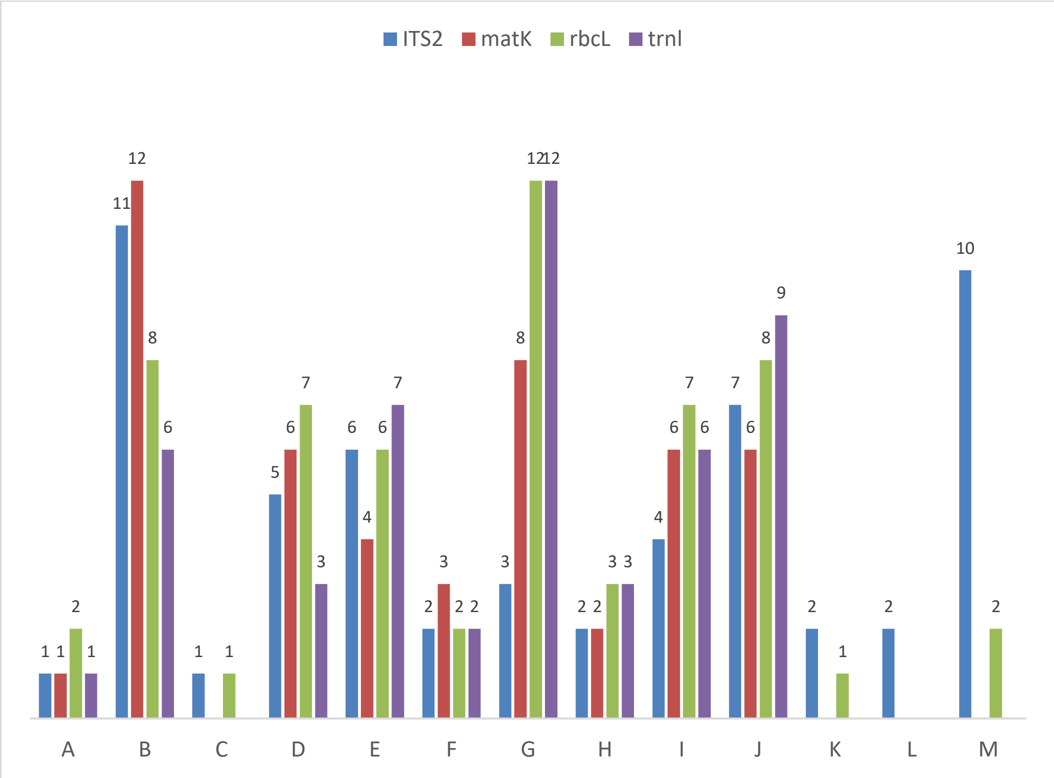

Figure 5.4. Summary of DNA Barcoding Use for Medicinal Plant Conservation in Indonesia; Letter represents the DNA barcoding contribution to DNA bank data and importance to conservation in order (A=new DNA barcoding and can strongly assist MP conservation, B=can strongly assist MP conservation, C=new DNA barcoding and can assist MP conservation, D=can assist MP conservation, E=new to DNA bank data and new DNA barcoding and may strongly assist MP conservation, F=new DNA barcoding and may strongly assist MP conservation, G=may strongly assist MP conservation, H=new to DNA bank data and new DNA barcoding and may assist MP conservation, I=new DNA barcoding and may assist MP conservation, J=may assist MP conservation, K=new to DNA bank data and new DNA barcoding, but sequences need to clarify further, L=new DNA barcoding, but sequences need to clarify further, M=sequences need to clarify further)

Figure 5.4 showed how the DNA barcoding to be useful for the conservation and use of Indonesian medicinal plants with regard to DNA bank – DNA barcoding data and identification ability. Sequences grouped in A-D can be given direct use to the conservation due to its correct identification to related medicinal plants. A-B criteria with its botanic forensic ability in casework of medicinal plants adulteration and illegal trading can be used in botanic forensic in terms of medicinal plants identification (Sass *et al.* 2007, Mahadani *et al.* 2013, Eurlings *et al.* 2013, Abubakar *et al.*, 2018), as the plants embraced are listed in the species that need to be conserved in the first place. There 19 families of Indonesian medicinal plants that consisted of 31 species were able to be identified accurately by DNA barcoding family. Major family of Indonesian medicinal plants that were successfully sequenced and correctly identified are Orchidaceae (13 sequences) and Apocynaceae (10 sequences). The MP species per criteria were served in Table Appendix 5.2.

5.4. Conclusion

Based on the study, no region is perfectly ideal for DNA barcoding. Nonetheless, according to its observed criteria, we recommend *matK* as the core DNA barcoding method for Indonesian medicinal plant identification. Also, due to its unique correct species identification, we recommend *ITS2* and *rbcL* alternatively or complementary to the core barcoding DNA. We contributed to conservation action of 33 species, especially to 21 species by offering the new botanic forensic tools that might prevent illegal trade and assuring the species identification of Indonesian medicinal plants, 3 of which are novel DNA barcoding to BOLD system.

CHAPTER 6. GENERAL DISCUSSION

6.1. Background

Medicinal plants, like other valuable plants, are part of biodiversity, and factors that threaten biodiversity subsequently threaten medicinal plants as well. Factors like population growth, deforestation, land conversion, and climate changes are all capable of contributing to biodiversity loss. Unlike deforestation and land conservation, both population growth and climate change occur gradually and slowly and could be dubbed an indirect contributor to biodiversity loss.

Medicinal plants have unique characteristics, especially because of knowledge basis and the diversity of origins. People that inhabit one particular village or a country may have a medicinal plant that is unique to their region and different from any other. For instance, China has TCM (Traditional China Medicine), India has Ayurveda, and of course, Indonesia has *Jamu*. Only specific parts of plants, and typically a small amount, are used to heal specific illnesses. For example, roots, leaves, or seeds are used to cure in the amounts of fist, 1-2 blade, and handful respectively. The use the medicinal plant depends on the illness, and can be either used directly (as a drink, or swallowed up or as a paste onto the skin) or used with prior processing (as drying, boiling, or turning it into ashes). In addition to curing illnesses, medicinal plants are also regularly used to maintain health. As a valuable plant, many people overharvest directly from its habitat and sell it at the market illegally, as many of them are wild plants, and propagation knowledge is unavailable or limited. Moreover, valuable plants are often exchanged with other species, creating a counterfeit version of the original.

In terms of the origins of medicinal plants, medicinal plants from Indonesia are unique in characteristics compared to medicinal plants from other countries. Indonesia, an archipelago country in South East Asia which is vast in size and has rich biodiversity and high population with rich ethnicity. Indonesia is home to three distinct biodiversity areas that span across a chain of thousands islands between Asia and Australia. More than 350 ethnicities possess different knowledge when it comes to the use of their medicinal plants. On the other hand, deforestation and land conversion occur very intensively for food, clothing, and houses, thus destroying the habitats of medicinal plants. Additionally, younger generations are less knowledgeable regarding the use of medicinal plants, and the resources needed to aid the transfer of knowledge between age groups are few and far between. It is a concern that the knowledge of these medicinal plants will be lost along with the presence of these plants.

6.2. Conservation strategy for Indonesian medicinal plants

Considering all the reasons mentioned above, a conservation strategy for Indonesian medicinal plants should be carried out in order to save them and guarantee sustainable, future use. However, due to limited resources and time, it would, unfortunately, be almost impossible to carry out conservation for all the medicinal plants in all areas of Indonesia. In this thesis, studies related conservation strategy were prepared as follows:

(1) Establishing a checklist and prioritising Indonesian medicinal plants

Almost 14K scientific names from the literature of medicinal plants were collated in an excel document. Any duplications were removed in excel and the rest was checked with a taxonomical tool for any typos, synonyms, and the accepted names. After defining the checklist of Indonesian medicinal plants from the proper literature, prioritisation of those species was based on criteria such as native status, rarity, part of the plant harvested, threat status, and legislations. Priority species names were matched against the Plants of the World Online (POWO, 2020). 233 priority medicinal plants have been decided. Establishing a checklist and prioritising Indonesian medicinal plants is the first step for comprehensive conservation.

(2) Conservation gap of priority Indonesian medicinal plants

Nearly 7000 plant occurrence points of priority Indonesian medicinal plants were collected from online resources, herbaria, and botanic gardens. According to species richness analysis, the area richest with medicinal plants has been identified specifically. According to the conservation gap analysis, some species are known to be under collected and need to be collected or propagated if there is already in *ex situ* site. Some *in situ* site and potential PA area that was passive conservation for Indonesian medicinal plants to be active conservation site have been identified. Conservation gap analysis is primarily done for resolving the conservation gaps in the field.

(3) Climate change analysis of priority Indonesian medicinal plants

Priority species were simulated in climate change analysis under future scenarios of RCP4.5 and RCP8.5 (year of 2050 and 2080). In 2050 and 2080, climate change was predicted to have effects on species richness and distribution area negatively, though some species are predicted to be benefited conversely. Some part in Papua, Java, and Sulawesi are predicted to have high reduction in species distribution area. Twenty medicinal plant species are identified to be target priority for Indonesia's conservation actions. In addition, areas benefited by climate change are suitable for species habitat and are recommended for a long term *in situ* conservation.

(4) DNA barcoding for supporting Indonesian medicinal plant conservation

61 medicinal plants of Indonesia were collected in order to get their DNA barcoding with four different regions of *ITS2*, *matK*, *rbcL*, and *trnL*. Those regions were analysed to discover which one was the most effective region for the DNA barcoding. Not all regions were able to provide the DNA barcoding due to failure in amplification or sequencing process. The new DNA barcoding created could help with the species identification correctly. Otherwise, at least DNA barcoding can be used as a clue for plant determination in genus or family level, from unknown species to known species. Here, we recommended *matK* as main DNA barcoding, with *ITS2* and *rbcL* as alternative or complement DNA barcoding. Additionally, we identified DNA barcoding sequences that are new for DNA bank and DNA barcoding data. The DNA barcoding technology is important in helping plant identification when the sample is in incomplete or damaged form. Also, this is mainly the laboratory leap regarding the conservation of Indonesian medicinal plants, especially in offering the new botanic forensic tools that might prevent illegal trade and ensure the species authentication of Indonesian medicinal plants.

6.3. Limitation of The Research

There is no way to create perfection in anything in this world, which is true for the resulting project. The plans may be not smoothly done. A lot of information should be collected, which, in some cases, was limited due to availability, accessibility, and time.

(1) Checklist and prioritisation

Many journals regarding medicinal plants list were collected. Many journals also reported the ethnobotanical studies in several Indonesian ethnicities. However, due to limited time and resources, only a few were selected. Information was selected from the literature that was estimated to have the most lists of Indonesian medicinal plants.

13,997 plant species were manually inputted from the selected literature. 8,178 species were not completed with their authors, as in the process, the name check did not include the author. Whereas there were homonyms in species taxon unit, that is the same name different author, which is commonly different species. We found *Dalbergia ferruginea* has more than two names that is *D. ferruginea* Roxb., *D. ferruginea* Glaz. (accepted name: *D. glaziovii* Harms), *D. ferruginea* Hochst. ex Benth (Accepted name: *D. horrida* (Dennst.) Mabb.), and *D. ferruginea* Hochst. ex Benth. (Accepted name: *D. horrida* (Dennst.) Mabb.). The name check process was assisted by http://tnrs.iplantcollaborative.org/TNRSapp.html. By chance, the machine led to *Dalbergia glaziovii* Harms as the accepted name. In some cases, where no notes of use of this species as a medicinal plant in Indonesia had been found, the earliest valid name was selected.

Non-binomial names or pre-binomial name, such as “Arbor nigra” (= black tree); “Folium tinctorium” = (leaf used as dye); “Olus album” (=white oi), and other names with author citation Rumphius/Rumph./Rump. were changed into their synonym names, according to Eisai (1986) and Eisai (1995). This change should be rechecked to the primary resources which is the Rumphius book itself and the translated version (Beekman, 2010).

Prioritisation was done based on available and accessible data. Not all species have complete data such as their medicinal record use and plant part use, which is why the important species might have been opted out from the selection due to incompleteness. The value of each medicinal plant would be perfect for the prioritisation, unfortunately, the data is unavailable except for the cultivated medicinal plants.

(2) Conservation gap analysis

Concerning priority species, out of 233 species, 12 species had no occurrence points, and 38 were under-collected with less than 5 occurrences. The analysis was carried out with limited data available.

(3) Climate change analysis

93 species were excluded from the analysis due to the limited occurrence data. They have zero or less than 10 occurrence points. The analysis was carried out with limited data available.

(4) DNA barcoding for Indonesian medicinal plants

The plan was to collect all the priority species, but in the end, due to time limitations, any available medicinal plants from botanical gardens were collected. Not all priority species are available in the garden. In addition, the required paperwork for phytosanitary that was incredibly important should be done after sample collection.

6.4. Recommendations: Future Research

(1) To update and enrich the checklist set with the recent ethnobotanical report or research from any ethnicities in Indonesia

(2) To promote the conservation of priority medicinal plants to the public through dissemination

(3) To conduct the threat assessment to Indonesian priority medicinal plants that have not been assessed by the IUCN

(4) To conduct fieldwork to gain the current status of Indonesian medicinal plants that have not been collected in *ex situ* sites, as well to collect them

(5) To enhance ethnobotany research in the area lacking medicinal plants found

6.5. Conclusions

From the work completed, the conservation action strategy of Indonesian medicinal plants including setting the checklist and priority list and inventory, conservation gap analysis, climate change analysis and DNA barcoding for Indonesian medicinal plants provided can give the foundation for further studies. Considering that Indonesian medicinal plants are valuable resources, the dissemination of knowledge and awareness of these findings have the power to enlighten the stakeholders of medicinal plants; be they pure users, farmers, traders, academics and researchers, locally or generally, in terms of how to conserve medicinal plants for sustainable use. For examples, people who use medicinal plants for livestock, especially small holdings farmers cultivating medicinal plants and might find that also conserving the plants is financially beneficial. In addition, the government, as a policymaker, hopefully, will be benefited in the first party.

Especially because the result can contribute to national conservation plans through the National Priority Program and the Convention on Biological Diversity on a global level. These findings help to achieve the Global Strategy for Plant Conservation 2011-2020 objectives and its targets: Objective I ("Plant diversity is well understood documented and recognized"), II ("Plant diversity is urgently and effectively conserved"), III ("Plant diversity is used in a sustainable and equitable manner"), IV ("Education and awareness about plant diversity, its role in sustainable livelihoods and importance for all life on earth is promoted"), and V ("The capacities and public engagement necessary to implement the strategy have been developed").

Furthermore, the list of medicinal plants with some of the ethnobotanical information provided in the appendix would provide knowledge for the wider range of people in addition to the related stakeholders on the richness of Indonesian medicinal plants, and how people can help to conserve them for sustainable use.

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APPENDICES

Table Appendix 2.1. Indonesian priority medicinal plant species.

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
1	*Avicennia marina* var. *rumphiana*	(Hallier f.) Bakh.	Acanth.	api-api (I)	K Sl M P	Sh	Wo	fever	A	P	6
2	*Barleria prionitis*	L.	Acanth.	jarong kembang landep (I)	J LSI Sl	Sh	Ro Le	NA	P (N)	A	6
3	*Hypoestes polythyrsa*	Miq.	Acanth.	trembuku (I)	LSI	He	St Ro Le	earache, cuts	A	A	6, 7, 5, 3
4	*Pseuderanthemum graciliflorum*	(Nees) Ridl.	Acanth.	kemoja hutan (M), Blue Twilight (En)	J	Sh	Ro	diabetes, tonic	A	A	6, 7
5	*Pangium edule*	Reinw.	Achari.	picung (I)	J LSI M P	Tr	WH	cough, body odor issue	P (N)	P	6, 7 13, 5 2
6	*Koordersiodendron pinnatum*	Merr.	Anacardi.	tabu hitam (I)	P	Tr	Sa	Folk medicine	P (N)	A	6
7	*Anaxagorea javanica*	Blume	Annon.	Akar angin (I)	Sm J K Sl	Sh	Ro Se Ba	Folk medicine	P (N)	A	7, 3
8	*Goniothalamus giganteus*	Hook.f. & Thomson	Annon.	penawar hitam (M)	Sm	Tr	Ba	back-ache	A	A	2
9	*Goniothalamus tapis*	Miq.	Annon.	unang-unang (I)	Sm	Sh	Ro Ba Le	scorpion stings antidote	A	P	6, 7 2
10	*Pimpinella pruatjan*	Molk.	Api.	purwaceng (I)	J	He	WH	genital disease	P (N)	A	6, 7, 5 2
11	*Alstonia iwahigensis*	Elmer	Apocyn.	pulai gunung (I)	K	Tr	Ro	cholera, childbirth care	A	A	2
12	*Alstonia scholaris*	(L.) R. Br.	Apocyn.	pulai (I)	Sm J K LSI Sl M P	Tr	Fl Le St	rheumatism, lumbago	P (N I)	P	6, 7, 8, 5 2

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
13	*Alyxia halmaheirae*	Miq.	Apocyn.	NA	Sl M	Sh	WH	childbirth care	A	A	2
14	*Alyxia reinwardtii*	Blume	Apocyn.	pulasari (I)	Sm J K LSI	Cl	WH	NA	P (N)	P	6, 7 2
15	*Alyxia rostrata*	(Markgr.) Markgr.	Apocyn.	komunang (I)	P	Cl	Ba	NA	A	A	2
16	*Hunteria zeylanica*	(Retz.) Gardner ex Thwaites	Apocyn.	gitan obat (I)	Sm	Sh	Ba Ro	NA	P (N)	A	6, 5, 7
17	*Myriopteron extensum*	(Wight & Arn.) K. Schum.	Apocyn.	wing-fruitvine (En)	J	Cl	Ro	diarrhoea, sore eyes	A	A	6
18	*Rauvolfia serpentina*	(L.) Benth. ex Kurz	Apocyn.	pule pandak (I)	J LSI	Sh	Ro St Le	asthma, colics	P (N)	P	6, 7, 5, 8 1
19	*Urceola laevigata*	(Juss.) D.J.Middleton & Livsh.	Apocyn.	gembor (I)	Sm J K LSI Sl	Sh	WH	aphrodisiac, cancer	P (N)	P	6, 7, 5 2
20	*Voacanga grandifolia*	(Miq.) Rolfe	Apocyn.	kalak kambin (I)	J LSI Sl M P	Sh	Le	cancer	P (N)	P	2
21	*Willughbeia tenuiflora*	Dyer ex Hook.f.	Apocyn.	Jitah (I)	Sm	Li	Ba St	rheumatism, stomach-ache	P (N)	A	5
22	*Alocasia cuprea*	K.Koch	Ar.	Taro (I)	K	He	St Ro Le	Folk medicine	P (N I)	P	6
23	*Agathis borneensis*	Warb.	Araucari.	bembueng (I)	Sm K	Tr	Wo	NA	P (N)	P	6
24	*Borassus flabellifer*	L.	Arec.	Lontar (I)	J LSI Sl	TrP	WH	aphrodisiac	P (N I)	P	6, 7, 5
25	*Caryota no*	Becc.	Arec.	sarai raja (I), Giant fishtail palm (En)	K	TrP	Wo	diuretic, tonic	P (N I)	P	6
26	*Eugeissona utilis*	Becc.	Arec.	bertan (I), Bornean sago palm (En)	K	TrP	Se Ro St	malarial	P (N)	P	6, 5

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
27	*Iguanura wallichiana*	(Mart.) Becc.	Arec.	mapau kalui (I)	Sm	TrP	Ro Le Se	NA	P (N)	P	6, 5
28	*Johannesteijsmannia altifrons*	(Rchb.f. & Zoll.) H.E.Moore	Arec.	belawan sang (I)	Sm K	Tr	Le	anaemia, stomach ache	P (N)	A	6, 5
29	*Phoenix paludosa*	Roxb.	Arec.	Korma rawa (I), Mangrove date palm (En)	Sm	TrP	Le Fr St	boils, sore eyes	P (N I)	P	6, 7
30	*Pigafetta filaris*	(Giseke) Becc.	Arec.	sagu laki-laki (I)	M P	Sh	Fr Wo	Folk medicine	P (N)	P	6, 5
31	*Saribus woodfordii*	(Ridl.) Bacon & W.J.Baker	Arec.	Boda (PNG), Nggela Fountain Palm (En)	P	TrP	St Wo	stomach issues	A	P	6
32	*Thottea tomentosa*	(Blume) Ding Hou	Aristoloc hi.	singa depa (I)	J	He	Le Rh St	cough, intestinal worms	P (N)	P	2
33	*Blumea arfakiana*	Martelli	Aster.	Kwipo (PNG)	P	Sh	Le Ro	NA	A	P	1
34	*Blumea arnakidophora*	Mattf.	Aster.	kambali (PNG)	P	Sh	LeRo	NA	A	A	1
35	*Balanophora fungosa subsp. Indica*	(Arn.) B.Hansen	Balanoph or.	perud puspa (I), fungus root (En)	Sm	Tr	WH	NA	A	A	6
36	*Oroxylum indicum*	(L.) Kurz	Bignoni.	pongporang (I)	Sm J LSI Sl	Tr	Ba Le	NA	P (N I)	P	6, 7, 5 2
37	*Mesua ferrea*	L.	Calophyll .	Penaga lilin (I)	LSI	Tr	Wo	snakebites, gonorrhoea	P (N)	P	6, 7, 5
38	*Gonocaryum gracile*	Miq.	Cardiopte rid.	tobung-tobung (I)	Sm	Sh	Fr Le Ro	stop bleeding, rheumatic	A	P	3
39	*Cibotium barometz*	(L.) J.Sm.	Ciboti.	Paku simpai (I)	Sm J P	Tr	Rh Ba	cholera	P (N)	P	7 12
40	*Garcinia amboinensis*	Spreng.	Clusi.	Kayu asam besar (I)	M	Tr	Ro Le	diarrhoea, wounds	A	A	6, 7, 5

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
41	*Terminalia bellirica*	(Gaertn.) Roxb.	Combret.	jaha kebo (I)	LSI	Tr	Fr	NA	P (N)	P	7, 5
42	*Rourea fulgens*	Planch.	Connar.	Semilat (M)	Sm	Sh	Le Ro	fever	A	A	6, 7
43	*Erycibe aenea*	Prain	Convolvul.	langsat hutan (M)	Sm	Li	Ro	sore muscles, headache, fever	A	A	3
44	*Trichosanthes ovigera*	Blume	Cucurbit.	areuy tiwuk (I), Japanese Snake Gourd (En)	J	Cl	Fr Tu	colic, asthma	A	P	6, 7, 5 1
45	*Cycas rumphii*	Miq.	Cycad.	Tandiang (I)	J K LSI Sl M P	TrP	Se Ba Le	cough, tuberculosis	P (N I)	P	6, 7, 5
46	*Fimbristylis falcata*	(Vahl) Kunth	Cyper.	malasibuias (P)	P	He	Rh	insect bites, cancer	P (I)	A	3
47	*Dicksonia blumei*	(Kunze) Moore	Dicksoni.	paku kidang (I)	Sm J LSI Sl	Sh	Le	a substitute for *Curcuma longa*	P (N)	P	7
48	*Dioscorea laurifolia*	Wall. ex Hook.f.	Dioscore.	Wild yam (En)	K	Cl	Tu	fever, colic	A	A	6, 7
49	*Dioscorea orbiculata*	Hook.f.	Dioscore.	Wild Yam (En)	Sm	Cl	Tu	sores, skin issues	A	A	6, 7
50	*Anisoptera costata*	Korth.	Dipterocarp.	Entenam (I)	Sm J K	Tr	Wo	colds, burns	P (N)	P	6, 5
51	*Anisoptera marginata*	Korth.	Dipterocarp.	Enthenam (I)	Sm K	Tr	Wo	emmenagogue	P (N)	P	6, 5
52	*Anisoptera megistocarpa*	Slooten	Dipterocarp.	beurmen (I)	Sm	Tr	Wo	sores on the legs	A	A	6, 7
53	*Dipterocarpus baudii*	Korth.	Dipterocarp.	Keruwing (I)	Sm	Tr	Wo	NA	A	P	6, 5
54	*Dipterocarpus gracilis*	Blume	Dipterocarp.	Keruwing bulu (I)	Sm J K	Tr	Wo	ulcerated wounds	P (N)	A	6, 5
55	*Dipterocarpus kunstleri*	King	Dipterocarp.	Keruwing bunga (I)	Sm K	Tr	Wo	scabies, fever	A	A	6, 5

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56	*Dipterocarpus retusus*	Blume	Dipterocarp.	Java Palahlar (I)	Sm J LSI	Tr	Wo	boils and pimples, infected ears	P (N)	P	6, 5
57	*Hopea celebica*	Burck	Dipterocarp.	Damar laut (I)		Tr	Wo	NA	P (N)	A	6, 5
58	*Hopea mengarawan*	Miq.	Dipterocarp.	damar mata kucing (I)	Sm K	Tr	Wo	dropsy	P (N)	A	5
59	*Hopea sangal*	Korth.	Dipterocarp.	Kedemut (I)	Sm J K LSI	Tr	Wo	infected nails,	P (N)	P	6, 5
60	*Parashorea lucida*	Kurz	Dipterocarp.	damar tyirik ayam (I)	Sm K	Tr	Wo	NA	P (N)	P	6, 5
61	*Shorea bracteolata*	Dyer	Dipterocarp.	bunyau (I)	Sm K	Tr	Wo	NA	P (N)	No information	5
62	*Shorea glauca*	King	Dipterocarp.	Simanto (I)	Sm	Tr	Wo	fever, sores	A	A	6, 5
63	*Shorea laevis*	Ridl.	Dipterocarp.	Kumus (I)	Sm K	Tr	Wo	stop bleeding	A	P	6, 5
64	*Shorea lepidota*	Blume	Dipterocarp.	Melebekan (I)	Sm	Tr	Wo	swellings	P (N)	A	6, 5
65	*Shorea macrophylla*	(de Vriese) P.S.Ashton	Dipterocarp.	Tengkawang telor (I)	K	Tr	Wo Fr	NA	A	A	6, 5
66	*Shorea palembanica*	Miq.	Dipterocarp.	tengkawang majau (I)	Sm K	Tr	Wo Fr	NA	P (N)	A	6
67	*Shorea selanica*	(Lam.) Blume	Dipterocarp.	Kayu bapa (I)	M	Tr	Wo	after childbirth care	P (N)	A	6, 5
68	*Shorea seminis*	Slooten	Dipterocarp.	tengkawang ayer (I)	K	Tr	Fr	NA	P (N)	P	6
69	*Shorea singkawang*	Burck	Dipterocarp.	Kalimantan Sengkawang (I)	Sm	Tr	Wo	NA	P (N)	P	6, 5
70	*Shorea splendida*	(de Vriese) P.S.Ashton	Dipterocarp.	Tengkawang pinang (I)	K	Tr	Wo Fr	childbirth	P (N)	A	6, 5

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71	*Shorea stenoptera*	Burck	Dipterocarp.	Tengkawang hungkul (I)	K	Tr	Fr Wo	flatulence, galactagogue	P (N)	A	6, 5
72	*Shorea sumatrana*	(Slooten) Desch	Dipterocarp.	Kedawang (I)	Sm J	Tr	Wo Fr	skin itchy	P (N)	A	6, 7, 5
73	*Shorea teysmanniana*	Dyer ex Brandis	Dipterocarp.	Sasak (I)	Sm	Tr	Wo	childbirth	P (N)	A	6, 5
74	*Vatica pauciflora*	Blume	Dipterocarp.	resak padang (I)	Sm	Tr	Wo Ba	NA	P (N)	A	6
75	*Vatica teysmanniana*	Burck	Dipterocarp.	resak paya (I)	Sm	Tr	Wo	tonic, aphrodisiac	A	A	5
76	*Homalanthus longistylus*	K.Schum. & Lauterb.	Euphorbi.	merom (PNG)	P	Tr	Sa Ba Sh	NA	A	A	3
77	*Macaranga griffithiana*	Müll.Arg.	Euphorbi.	mahang bulan (I), Griffith's Mahang (En)	Sm	Tr	Ro	febrifuge	A	P	3
78	*Cajanus goensis*	Dalzell	Fab.	NA	J	Sh	Le Ro Se	wounds, high blood pressure	A	A	6
79	*Dalbergia ferruginea*	Harms	Fab.	akar langsa (I)	K Sl M P	Sh	Wo	swellings	P (N)	A	3
80	*Dalbergia junghuhnii*	Benth.	Fab.	Akar urat-urat (M)	Sm J K Sl M	Sh	Le	NA	P (N)	A	3
81	*Dalbergia latifolia*	Roxb.	Fab.	Sana kling (I), Bombay blackwood (En)	J K LSI Sl	Tr	Wo	NA	P (N I)	P	6, 7, 5
82	*Dalbergia parviflora*	Roxb.	Fab.	Bulangan (I)	Sm K	Li	Wo	leucorrhoea, aphrodisiac	P (N)	A	6, 7, 5
83	*Dalbergia pinnata*	(Lour.)Prain	Fab.	areuy ki loma (I)	Sm J K LSI Sl M	Sh	Le Sts	dysentery and ringworm	A	A	6, 7, 5, 3
84	*Derris trifoliata*	Lour.	Fab.	areuy ki tonggeret (I)	Sm J K LSI Sl M P	Sh	Ro St Le	fever, head lice	A	A	6 1
85	*Entada spiralis*	Ridl.	Fab.	Akar sintok (I)	Sm	Sh	Se Ba	NA	A	P	7

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86	*Euchresta horsfieldii*	(Lesch.)Benn.	Fab.	palakiya (I)	Sm J LSI	Sh	Se	dysentery	P (N)	P	6, 7, 5, 3
87	*Intsia palembanica*	Miq.	Fab.	Merbau (I)	Sm K LSI Sl M P	Tr	Se Ba Le	NA	P (N)	A	6, 5
88	*Koompassia malaccensis*	Benth.	Fab.	Tualang ayam (I)	K	Tr	Wo	childbirth, rheumatism	P (N)	P	6, 5
89	*Parkia intermedia*	Hassk.	Fab.	petai (I)	Sm J K	Tr	Se	similar use to those of G. Macrophyllus	P (N)	A	6, 7, 5
90	*Parkia timoriana*	(DC.)Merr.	Fab.	Kedawong (I)	Sm J K LSI Sl M P	Tr	Se Le Ba	diarrhoea, mosquito repellent	P (N I)	P	6
91	*Phyllodium elegans*	(Lour.)Desv.	Fab.	NA	J	Sh	Ro Fl	headache, bruises	P (I)	A	2
92	*Sindora javanica*	(Koord. & Valeton)Backer	Fab.	Uku aka, Saprantu (I)	J	Tr	Wo	NA	A	A	6, 5
93	*Castanopsis argentea*	(Blume) A.DC.	Fag.	saninten (I)	Sm J K	Tr	Wo Ba Fr	asthma	P (N)	A	6, 5
94	*Castanopsis inermis*	(Lindl.) Benth. & Hook.f.	Fag.	berangan (I)	Sm	Tr	Se Ba	dropsy, dysentery	A	A	6, 7, 5
95	*Lithocarpus indutus*	(Blume) Rehder	Fag.	ataruwa (I)	J Sl	Tr	Wo Ba	snakebites, scorpions sting	P (N)	A	6, 5
96	*Lithocarpus platycarpus*	(Blume) Rehder	Fag.	Pasang (I)	J	Tr	NA	NA	A	A	6, 5
97	*Gentiana quadrifaria*	Blume	Gentian.	jukut cengcang (I)	J	He	Ro	stimulant, tonic	A	A	6
98	*Utania racemosa*	(Jack) Sugumaran	Gentian.	kopi hutan (I); False coffe tree (En)	Sm	Sh	Le Ba Ro Fl	NA	A	P	6, 7

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99	*Gnetum tenuifolium*	Ridl.	Gnet.	Dagum (I)	Sm	Li	Se Ro	NA	A	A	6, 7
100	*Gunnera macrophylla*	Blume	Gunner.	hariyang gede (I)	Sm J Sl P	He	Ro	NA	P (I)	P	6, 7, 5, 3
101	*Exbucklandia populnea*	(R.Br. ex Griff.) R.W.Br.	Hamameli d.	hapas-hapas (I)	Sm	Tr	Wo Ba Le	intestinal issues, tonics	A	A	6
102	*Galbulimima belgraveana*	(F.Muell.) Sprague	Himantan dr.	White magnolia (En)	P	Tr	Ba Le	sores	A	P	3
103	*Ixonanthes icosandra*	Jack	Ixonanth.	Kayu bulus (I)	Sm	Tr	Ba	cholera, menstruation disorders	P (N)	A	6
104	*Scutellaria javanica*	Jungh.	Lami.	kapunten (I)	Sm J LSI Sl M P	He	NA	dysentery, pneumonia	P (N)	A	1
105	*Vitex parviflora*	A.Juss.	Lami.	Kayu kula (I)	LSI Sl M	Tr	Le Ba	induce labour	P (I)	P	6, 7, 5
106	*Beilschmiedia madang*	Blume	Laur.	huru (I)	Sm J K	Tr	Wo	NA	A	P	6, 3
107	*Cinnamomum culilaban*	(L.) J. Presl	Laur.	kulitlawang (I)	M	Tr	Ba	NA	P (N)	A	6 14
108	*Cinnamomum sintoc*	Blume	Laur.	Huru Sintok (I)	Sm J K LSI	Tr	Ba	NA	P (N)	A	6, 7
109	*Cryptocarya massoy*	(Oken) Kosterm.	Laur.	ai kor (I)	P	Tr	Ba	boils	P (N)	A	6, 7
110	*Eusideroxylon zwageri*	Teijsm. & Binn.	Laur.	ulin (I)	Sm K	Tr	Fr	intestinal worms	P (N)	P	6, 7
111	*Strychnos ignatii*	P.J. Bergius	Logani.	pokru (I)	Sm J K	Li	Ro	women contraceptive	P (N)	P	6, 4
112	*Strychnos lucida*	R. Br.	Logani.	Bidaralaut (I), Slangen hout (En)	J LSI	Sh	WH	Folk medicine	P (N I)	P	6, 7, 5
113	*Woodfordia fruticosa*	(L.) Kurz	Lythr.	sidawayah (I).	J LSI	Sh	Fl Fr Se	Folk medicine	P (I)	P	5 14
114	*Grewia salutaris*	Span.	Malv.	Nila (I)	LSI	Sh	Wo Ba	NA	A	A	6, 7, 5

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115	*Helicteres isora*	L.	Malv.	Puteran (I)	M	Sh	Ba St Fr Le	diarrhoea, gonorrhoea	P (N)	P	6, 7, 5 14
116	*Hibiscus celebicus*	Koord.	Malv.	Kelembauan in talun (I)	Sl	Sh	Ba Le Ro	diarrhoea, gonorrhoea	A	A	6, 5
117	*Halopegia blumei*	(Körn.) K.Schum.	Marant.	Daun birarut (I)	J	He	Tu Le	dysentery, coughs	A	P	6, 5, 7
118	*Dissochaeta punctulata*	Hook.f. ex Triana	Melastomat.	akar meroyan busuk (M)	Sm	Li	Ro	NA	A	A	3
119	*Medinilla crispata*	Blume	Melastomat.	Tali morea (I)	M	Sh	Ro	Folk medicine	A	A	6, 7, 5
120	*Medinilla radicans*	Blume	Melastomat.	areuy manjel (I)	J	Sh	Ro	wounds	P (N)	A	6, 7, 5, 3
121	*Oxyspora bullata*	J.F.Maxwell	Melastomat.	Greater Allomorphia (En)	Sm	Sh	Le Ro	constipation	A	A	3
122	*Oxyspora exigua*	J.F.Maxwell	Melastomat.	keduduk hutan (I)	Sm	Sh	Le Ro	NA	A	A	6, 7
123	*Phyllagathis rotundifolia*	(Jack) Blume	Melastomat.	tapak gajah (M)	Sm	He	Ro Le	NA	P (N)	A	2
124	*Heynea trijuga*	Roxb. ex Sims	Meli.	mamak (I)	K	Tr	Le Ba Le Ro	NA	P (N)	A	6, 3
125	*Toona sureni*	(Blume) Merr.	Meli.	suren (I)	LSI P	Tr	Ba Le	diarrhoea,rheumatism	P (N)	A	5
126	*Stephania japonica*	(Thunb.) Miers	Menisperm.	areuy geureung (I)	LSI	He	Ro Le	fever	P (N I)	P	1
127	*Tinospora glabra*	(Burm.f.) Merr.	Menisperm.	pancasona (I)	LSI	Li	Le Ba	NA	P (N)	P	1
128	*Ficus chartacea*	(Wall. ex Kurz) Wall. ex King	Mor.	Speckle-leafed Fig (En)	K	Sh	Ba	wounds	A	P	6
129	*Ficus deltoidea*	Jack	Mor.	tabat barito (I)	Sm J K M	Sh	NA	wounds	P (N I)	A	6, 7 1
130	*Myrica javanica*	Blume	Myric.	Ki tete (I)	J	Sh	Ba Fr	skin diseases	A	A	6, 7, 5

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131	*Syzygium conglomeratum*	(Duthie) I.M.Turner	Myrt.	Jheling serai tatang (I)	Sm	Tr	Wo	NA	A	A	6, 5
132	*Syzygium rumphii*	(Merr.) Govaerts	Myrt.	Kayu merah (I)	M	Tr	Wo Ba	cough	A	A	6, 5
133	*Nepenthes ampullacea*	Jack	Nepenth.	kantong teko (I)		Cl	St	rheumatism	P (N)	A	6
134	*Nepenthes ampullaria*	Jack	Nepenth.	Ketakong (I)	Sm K M P	Cl	St Ro	infected eyes, headache	P (N)	P	6, 7
135	*Nepenthes boschiana*	Korth.	Nepenth.	NA	K	Cl	NA	diarrhoea, fevers	A	P	6, 7
136	*Nepenthes gracilis*	Korth.	Nepenth.	Periuk monyet (I)	Sm K Sl	Cl	NA	tuberculosis, cough	P (N)	P	6, 7
137	*Nepenthes mirabilis*	(Lour.) Druce	Nepenth.	Kantong semar rawa umum (I), common swamp pitcher-plant (En)	Sm J K LSI Sl M P	Cl	NA	NA	P (N)	P	6
138	*Nepenthes rafflesiana*	Jack	Nepenth.	Katakong menjangan (I)	Sm K	Cl	St	stomach-ache, eye inflammation	P (N)	A	6
139	*Nepenthes reinwardtiana*	Miq.	Nepenth.	Ketakong babi (I)	Sm K	Cl	St	NA	P (N)	P	6, 7
140	*Acriopsis liliifolia var. liliifolia*		Orchid.	ki plengpeng (I)	Sm J K LSI Sl M P	He	Ro Le	NA	P (N)	A	6, 7, 5, 3
141	*Apostasia nuda*	R.Br.	Orchid.	si sarsar bulung (I)	Sm J K	He	Ro Fr	NA	P (N)	P	6, 7, 5, 3
142	*Arundina graminifolia*	(D.Don) Hochr.	Orchid.	anggrek bambu (I)	Sm J K LSI Sl M P	He	NA	NA	P (N)	P	6, 7
143	*Calanthe triplicata*	(Willemet) Ames	Orchid.	anggrek natal (I)	Sm J K LSI Sl M P	He	NA	skin problems	P (N)	A	6

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144	*Cleisostoma scortechinii*	(Hook.f.) Garay	Orchid.	Scortechin's Cleisostoma (En)	Sm J K LSI	He	NA	childbirth, coughs	P (N)	A	6
145	*Corymborkis veratrifolia*	(Reinw.) Blume	Orchid.	white cinnamon orchid (En)	Sm J K LSI Sl M P	He	Le Ro	hepatitis, pneumonia	P (N)	P	3
146	*Cymbidium aloifolium*	(L.) Sw.	Orchid.	Cymbidium Daun Gaharu (I), The Aloe-Leafed Cymbidium (En)	Sm J	He	Le	tonic	P (N I)	P	3
147	*Dendrobium crumenatum*	Sw.	Orchid.	anggrak merpati (I)	Sm J K LSI Sl M P	He	Le Fr	boils	P (N I)	P	6, 7, 5 2
148	*Dendrobium faciferum*	J.J.Sm.	Orchid.	anggrek (I)	LSI Sl M	He	St	diuretic, rheumatism	P (N)	A	6, 5
149	*Dendrobium hymenanthum*	Rchb.f.	Orchid.	The Membranous Dendrobium (En)	K	He	NA	snake bites, rheumatism	A	A	6
150	*Dendrobium purpureum*	Roxb.	Orchid.	anggrek kesumba (I)	Sl M P	He	Le	skin issues	P (N I)	A	5 2
151	*Dendrobium salaccense*	(Blume) Lindl.	Orchid.	sakat harum (I)	Sm J K LSI	He	Le	childbirth, sores	P (N)	P	6, 7, 5
152	*Dendrobium utile*	J.J.Sm.	Orchid.	anggrek serat (I)	Sl M	He	St	fever, childbirth	P (N)	A	6, 5
153	*Erythrorchis altissima*	(Blume) Blume	Orchid.	Akar tulang (I)	Sm J K	He	NA	NA	P (N)	A	6
154	*Grammatophyllum scriptum*	(L.) Blume	Orchid.	anggrek boki (I)	M P	He	Se	poison antidote, cough	P (N)	A	6, 7, 5, 3
155	*Grammatophyllum speciosum*	Blume	Orchid.	anggrek tebu (I), Tiger orchid (En)	Sm J K Sl	He	St	sedative	P (N)	P	6, 3

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156	*Habenaria multipartita*	Blume ex Kraenzl.	Orchid.	uwi-uwi (I)	J LSI	He	Tu	antiseptic, disinfectant	A	A	6, 7, 5
157	*Habenaria rumphii*	(Brongn.) Lindl.	Orchid.	stiff rein orchid (En)	Sm J K Sl M P	He	Tu	NA	A	A	6, 5
158	*Hetaeria obliqua*	Blume	Orchid.	pokok tambak hutan (M), The Oblique Hetaeria (En)	Sm K	He	Le	liver issue, diabetes	P (N)	A	3
159	*Liparis condylobulbon*	Rchb.f.	Orchid.	tapered sphinx orchid (En)	Sm J K LSI Sl M P	He	NA	colic, scabies	P (N)	A	6, 7, 5, 3
160	*Liparis viridiflora*	(Blume) Lindl.	Orchid.	Green-Flowered Liparis (En)	Sm J K LSI Sl M P	He	NA	after childbirth, headache	P (N)	A	6
161	*Nervilia concolor*	(Blume) Schltr.	Orchid.	selembar sabulan (I), tall shield orchid (En)	Sm J K LSI Sl M P	He	WH	NA	P (N)	P	3
162	*Nervilia plicata*	(Andrews) Schltr.	Orchid.	selembar satahun (I), The Folded Nervilia (En)	Sm J K P	He	WH	malaria, fever	P (N)	P	3
163	*Oberonia lycopodioides*	(J.Koenig) Ormerod	Orchid.	sakat lidah buaya (M), The Lycopodium-Like Oberonia (En)	Sm J K Sl M	He	Le	tooth ache	P (N)	A	3
164	*Oberonia mucronata*	(D.Don) Ormerod & Seidenf.	Orchid.	The Mucronate Oberonia (En)	Sm J K Sl P	He	NA	liver issues	A	A	3
165	*Renanthera moluccana*	Blume	Orchid.	anggrek merah (I)	Sl M P	He	Le	NA	A	A	6, 7, 5, 4

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166	*Robiquetia spathulata*	(Blume) J.J.Sm.	Orchid.	The Sheath-Covered Spathe Robiquetia (En)	Sm J K Sl M	He	NA	antiseptic, disinfectant	P (N)	P	6
167	*Spathoglottis affinis*	de Vriese	Orchid.	The Similar Spathoglottis (En)	J K	He	NA	NA	P (N)	A	6
168	*Spathoglottis plicata*	Blume	Orchid.	Philippine Ground Orchid (En)	Sm J K LSI Sl M P	He	Le	cramped, headache	P (N)	P	6, 5
169	*Strongyleria pannea*	(Lindl.) Schuit., Y.P.Ng & H.A.Pedersen	Orchid.	kura kubong (M), The Flag Eria (En)	Sm K	He	NA	substitute for Piper betle	P (N)	A	3
170	*Tropidia curculigoides*	Lindl.	Orchid.	serugat (I), The Curculigo-Like Tropida (En)	Sm J K LSI Sl P	He	WH	boils	P (N)	A	3
171	*Vanda miniata*	(Lindl.) Gardiner, Lauren Maria	Orchid.	The Rust Red Ascocentrum (En)	Sm J	He	NA	eyesore, fever	A	P	6
172	*Vanilla abundiflora*	J.J.Sm.	Orchid.	vanila (I), Indonesian vanilla (En)	K	He	Fr	liver issue, toothache	P (N)	A	6, 7, 5, 4
173	*Vanilla griffithii*	Rchb.f.	Orchid.	akar penubal (I), Griffith's Vanilla (En)	Sm K	He	Fr Fl Sa	wounds, snakebite	P (N)	A	6, 7, 5
174	*Benstonea atrocarpa*	(Griff.) Callm. & Buerki	Pandan.	pandan mengkuang (I)	Sm	Sh	Le St Ro	childbirth care, tonic	A	A	6, 5
175	*Pandanus lais*	Kurz	Pandan.	pandan kowang (I)	Sm	Tr	Se Le Ba	skin issues, insects bites	A	A	6

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176	*Pandanus robinsonii*	Merr.	Pandan.	pandan pudak (I)	M	Sh	Le St Ro Ba	after childbirth care	A	A	6, 5
177	*Breynia pubescens*	Merr.	Phyllanth.	Gagilamo (I)	M	Sh	Ba	childbirth care, aphrodisiac	A	A	6, 7, 5
178	*Phyllanthus submollis*	K.Schum. & Lauterb.	Phyllanth.	hin (PNG)	P	Tr	Ba	high blood pressure, back pain	A	A	3
179	*Pinus merkusii*	Jungh. & de Vriese	Pin.	Sala (I)	Sm	Tr	Wo Ba	NA	P (N I)	P	6, 7, 5
180	*Piper attenuatum*	Buch.-Ham. ex Miq.	Piper.	Sirih dingin (I)	J	Cl	St Ba Le	wounds	A	P	6, 7, 5
181	*Piper caducibracteum*	C.DC.	Piper.	Sirih kandat (I)	M	Sh	Le Ba	NA	A	A	6, 7, 5
182	*Pontederia plantaginea*	Roxb.	Pontederi.	eceng padi (I)	J	He	Ro Se	stomach-ache	A	A	6
183	*Ardisia odontophylla*	Wall. ex A.DC.	Primul.	Pasal (I)	J	Sh	Ro Le	antiseptic, aromatherapy	A	P	6, 7, 5, 3
184	*Rafflesia arnoldi*	R.Br.	Rafflesi.	padma raksasa (I)	Sm K	Pa	Fl	NA	P (N)	A	6
185	*Rafflesia horsfieldii*	R.Br.	Rafflesi.	padma (I)	J	Pa	Fl	stomach ache	P (N)	A	6, 7, 5, 3
186	*Catunaregam spinosa*	(Retz.) Lam.	Rubi.	the mountain pomegranate (En)	J	Sh	Fr Ba Ro	NA	P (N)	A	6
187	*Mussaenda glabra*	Vahl	Rubi.	kingkilaban (I)	J	Sh	Sa Le Ro Fl	NA	A	A	6, 3
188	*Oldenlandia recurva*	(Korth.) Miq.	Rubi.	Akar kemenyan hantu (I)	K	He	Ro St Le	NA	A	A	6, 5
189	*Pavetta subvelutina*	Miq.	Rubi.	Jarum-jarum (I), White pavetta (En)	J	Sh	Le Ro St Ba Fr	NA	A	A	6

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
190	*Prismatomeris tetrandra subsp. malayana*	(Ridl.) J.T.Johanss.	Rubi.	mentulang (I)	K	Sh	Le Ro St	NA	A	A	6, 7
191	*Psychotria sylvatica*	Blume	Rubi.	halan (I)	J	Sh	Le Ba St Ro	NA	A	A	6
192	*Rennellia morindiformis*	(Korth.) Ridl.	Rubi.	akar bumi (M)	Sm	Sh	Ba	NA	A	A	3
193	*Uncaria homomalla*	Miq.	Rubi.	NA	Sm	Li	St Le Ba	NA	A	P	2
194	*Lunasia amara*	Blanco	Rut.	kemaitan (I)	LSI	Sh	Ro Fr St Sa	NA	P (N)	P	6, 7 2
195	*Melicope denhamii*	(Seem.) T.G.Hartley	Rut.	Kisampang (I)	P	Sh	Le Ba	NA	P (N)	A	6
196	*Micromelum minutum*	Wight & Arn.	Rut.	sesi (I)	LSI	Tr	Ro Sh Le	NA	P (N)	P	6, 7 2
197	*Murraya paniculata*	(L.) Jack	Rut.	Kemuning (I); Mock orang (En)	Sm LSI P	Sh	Le	NA	P (N)	P	6, 7, 8, 5 14
198	*Zanthoxylum avicennae*	(Lam.) DC.	Rut.	Adas kastela (I)	LSI	Sh	Le Fr Se St Ba	NA	A	A	6, 5
199	*Zanthoxylum nitidum*	(Roxb.) DC.	Rut.	Areuy beulit gede (I)	P	Sh	Ba Fr Le Ro	NA	A	A	6, 7, 5
200	*Santalum album*	L.	Santal.	Cendana (I), Sandalwood (En)	J LSI	Tr	HeW Fr Le	diseases and skin problems	P (N I)	P	6, 7, 5
201	*Dodonaea viscosa subsp. angustifolia*	(L.f.) J.G.West	Sapind.	cantigi (I)	LSI	Sh	Le Ba Fr	cholera, colic, cough	P (I)	A	6
202	*Palaquium hispidum*	H.J.Lam	Sapot.	Mayang serikit (En)	Sm K	Tr	Wo	NA	A	A	6, 5
203	*Kadsura scandens*	(Blume) Blume	Schisandr.	hunyur buut (I)	Sm J LSI	Li	Rh Le	painful joints	P (N)	A	6, 7

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
204	*Eurycoma apiculata*	A.W.Benn.	Simaroub.	pasak bumi (I)	Sm	Tr	Ro	dysentery, stomach-ache	A	P	1
205	*Eurycoma longifolia*	Jack	Simaroub.	Pasak bumi (I)	Sm K	Sh	Ro Ba Le	ague, bruises	P (N)	P	6, 7, 5 1
206	*Soulamea amara*	Lam.	Simaroub.	buwa hati (I)	P	Sh	Ro Fr Le	aphrodisiac	P (N)	P	6, 7, 5 2
207	*Smilax zeylanica*	L.	Smilac.	kayu cina hutan (I)	J	Li	Ro	fever, snake bites	P (N)	P	1
208	*Gomphandra quadrifida*	(Blume) Sleumer	Stemonur.	kayu barik-barik(I)	Sm	Sh	Ro Le	diarrhoea, gonorrhoea	A	P	3
209	*Symplocos cochinchinensis*	(Lour.) S. Moore	Symploc.	kayu dyurang (I)	J LSI P	Sh	Le Ba	aphrodisiac, diuretic	P (N)	A	6
210	*Symplocos odoratissima*	Choisy ex Zoll.	Symploc.	ki seriawan (I)	Sm J LSI	Sh	WH	NA	P (N)	P	6, 7, 5, 4
211	*Taxus wallichiana*	Zucc.	Tax.	tampinur batu (I)	Sm Sl	Tr	Se St Ba Le	NA	P (N)	P	3
212	*Aquilaria cumingiana*	(Decne.) Ridl.	Thymelae .	giba kolano (I)	K M	Sh	Ba Ro	diabetes, cough	A	A	3
213	*Aquilaria hirta*	Ridl.	Thymelae .	karas (I)	Sm	Tr	Ba	Folk medicine	P (N)	A	7
214	*Aquilaria malaccensis*	Lam.	Thymelae .	Alim (I), Eagle wood tree (En)	Sm K	Tr	Ba	cough, snakebite	P (N)	P	6, 5
215	*Gonystylus bancanus*	(Miq.) Kurz	Thymelae .	ramin (I)	Sm K	Tr	NA	sore breasts of nursing mothers	P (N)	A	7, 5
216	*Gonystylus macrophyllus*	(Miq.) Airy Shaw	Thymelae .	pinang bai (I)	Sm J K Sl M P	Tr	Wo	tonic, diarrhoea	P (N)	A	6
217	*Maoutia diversifolia*	(Miq.) Wedd.	Urtic.	beubeunteuran (I)	J	Sh	Ba	NA	A	A	85ei41 i, 7, 5
218	*Nothocnide repanda*	(Blume) Blume	Urtic.	leuksa (I)	LSI	Li	Le St Ba	diarrhoea, malaria	P (N)	P	7, 3
219	*Pipturus asper*	Wedd.	Urtic.	dalunot (P)	M	Sh	Ba	febrifuge, headache	A	P	2

No.	Scientific name	Author	Family	Auxilary name	Dist.	Plant habit	Plant part*	Uses	*Ex situ*	DNA Barc.	Ref.
220	*Poikilospermum amboinense*	Zipp. & Miq.	Urtic.	tali ayer (M)	M	Li	Ro St Le Ba	tonic, dysentery	A	A	6
221	*Ampelocissus arachnoidea*	(Hausskn.) Planch.	Vit.	oyod air (I)	J	Li	Ro Fr	tonic, fever	A	A	6, 7, 3
222	*Ampelocissus cinnamomea*	(Wall. ex M.A.Lawson) Planch.	Vit.	Bulung kerta (I)	Sm	Li	Le Ro	NA	A	A	6, 7
223	*Ampelocissus polythyrsa*	(Miq.) Gagnep.	Vit.	akar lemar (I)	Sm	Li	Ro	NA	A	A	6
224	*Leea aequata*	L.	Vit.	ginggiyang (I)	LSI	Sh	Ro Tu St Sh	fever, hair care	P (N)	A	6, 7, 5 2
225	*Amomum sumatranum*	(Valeton) Skornick. & Hlavatá	Zingiber.	Puwar tenangan (I)	Sm	He	Sa	NA	A	A	6, 7, 5 14
226	*Curcuma aeruginosa*	Roxb.	Zingiber.	temu hitam (I)	J	He	Rh	NA	P (N)	P	6, 7 10, 5 1
227	*Curcuma aurantiaca*	Zijp	Zingiber.	koneng kalamasu (I)	J	He	Rh Fl	jaundice, dropsy	A	P	5, 6, 7 1
228	*Curcuma colorata*	Valeton	Zingiber.	temu hitam (I)	J	He	Le Rh	diarrhoea, malaria	P (N)	P	6, 7, 5
229	*Curcuma euchroma*	Valeton	Zingiber.	kunir kebo (I)	J	He	Rh	skin diseases	A	A	6, 7, 5 1
230	*Curcuma petiolata*	Roxb.	Zingiber.	temu badur (I)	J	He	Rh	diuretic, rheumatism	A	P	6, 7, 5 1
231	*Kaempferia angustifolia*	Roscoe	Zingiber.	kunci menir (I)	Sm	He	Rh Le	stomach-ache	P (N)	P	6
232	*Kaempferia undulata*	Wender.	Zingiber.	kunci kunot (I)	J	He	Ro Tu Rh	tonic, snakebites	A	A	6
233	*Wurfbainia uliginosa*	(J.Koenig) Giseke	Zingiber.	tepus merah (M)	Sm	He	Se Rh Fr	toothache, anthelmintic	A	P	6, 7

Notes: Auxilary name I: Indonesia, En: English, M: Malaysia, PNG: Papua New Guinea, NA: No Information; Distribution J: Java, K: Kalimantan, LSI: the Lesser Sunda Islands, Sm: Sumatera, Sl: Sulawesi, M: Maluku, P: Papua; Plant habit Cl: climber, He: herb, Li: liana, Sh: shrub, Tr: tree, Pa: Parasite, TrP: tree like-palm; Used plant part*: all uses, medicinal uses and others; Ba: bark, Wo: wood, Rh: Rhizome, Tu: Tuber, Ro: root, Le: leaves, Sa: sap, St: stem, Fr: fruit, Fl: flower, Se: Seed, WH: Whole plants. NA: No Information; *Ex situ* conservation/DNA barcoding P: Present, A: Absent, N: National, I: International; References 1: de Padua *et al.* (1999) 2: van Valkenburg and Bunyapraphatsara (2002), 3: Lemmens and Bunyapraphatsara (2003), 4: de Guzman and Siemonsma (1999), 5: Heyne (1992), 6: Eisai (1986), 7: Eisai (1995), 8-13: Dalimartha (1999 2000 2003 2006 2008 2009) 14: IBSAP (Indonesia Biodiversity Strategy and Action Plan) based on Rifai *et al.* (1992) and Zuhud *et al.* (2001) in The National Development Planning Agency (2003).

Table Appendix 2.2. Indonesian medicinal plants with threat status (IUCN), whether they are listed in CITES Appendix II and national legislations.

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
1	*Avicennia marina var. rumphiana*	(Hallier f.) Bakh.	Acanth.		VU							Duke *et al.* 2010
2	*Pangium edule*	Reinw.	Achari.								√	
3	*Anaxagorea javanica*	Blume	Annon.								√	
4	*Pimpinella pruatjan*	Molk.	Api.								√	
5	*Alstonia scholaris*	(L.) R. Br.	Apocyn.								√	LC (World Conservation Monitoring Centre 1998a)
6	*Alyxia halmaheirae*	Miq.	Apocyn.								√	
7	*Alyxia reinwardtii*	Blume	Apocyn.								√	
8	*Rauvolfia serpentina*	(L.) Benth. ex Kurz	Apocyn.	II							√	
9	*Urceola laevigata*	(Juss.) D.J.Middleton & Livsh.	Apocyn.								√	
10	*Voacanga grandifolia*	(Miq.) Rolfe	Apocyn.								√	
11	*Agathis borneensis*	Warb.	Araucari.		EN			√	√			Farjon 2013a
12	*Borassus flabellifer*	L.	Arec.		EN							Rakotoarinivo, Dransfield 2012
13	*Caryota no*	Becc.	Arec.			√		√	√	√		LC (Johnson 1998)
14	*Eugeissona utilis*	Becc.	Arec.			√						
15	*Johannesteijsmannia altifrons*	(Rchb.f. & Zoll.) H.E.Moore	Arec.			√		√	√	√	√	
16	*Phoenix paludosa*	Roxb.	Arec.			√						NT (Ellison *et al.* 2010)
17	*Pigafetta filaris*	(Giseke) Becc.	Arec.			√		√	√	√		
18	*Saribus woodfordii*	(Ridl.) Bacon & W.J.Baker	Arec.		VU							World Conservation

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
												Monitoring Centre 1998e
19	*Oroxylum indicum*	(L.) Kurz	Bignoni.								√	
20	*Mesua ferrea*	L.	Calophyll.								√	
21	*Cibotium barometz*	(L.) J.Sm.	Ciboti.	II		√					√	
22	*Terminalia bellirica*	(Gaertn.) Roxb.	Combret.								√	
23	*Cycas rumphii*	Miq.	Cycad.	II								NT (Hill 2010)
24	*Dicksonia blumei*	(Kunze) Moore	Dicksoni.				√					
25	*Anisoptera costata*	Korth.	Dipterocarp.		EN							Nguyen 2017
26	*Anisoptera marginata*	Korth.	Dipterocarp.		EN							Ashton 1998a
27	*Anisoptera megistocarpa*	Slooten	Dipterocarp.		CR							Ashton 1998k
28	*Dipterocarpus baudii*	Korth.	Dipterocarp.		VU							Ly *et al.* 2017c
29	*Dipterocarpus gracilis*	Blume	Dipterocarp.		VU							Ly *et al.* 2017b
30	*Dipterocarpus kunstleri*	King	Dipterocarp.		CR							Ashton 1998b
31	*Dipterocarpus retusus*	Blume	Dipterocarp.		EN							Ly *et al.* 2017d
32	*Hopea celebica*	Burck	Dipterocarp.		EN							Ashton 1998c
33	*Hopea mengarawan*	Miq.	Dipterocarp.		CR							Ashton 2018
34	*Hopea sangal*	Korth.	Dipterocarp.		VU							Pooma *et al.* 2017a
35	*Parashorea lucida*	Kurz	Dipterocarp.		CR							Ashton 1998d
36	*Shorea bracteolata*	Dyer	Dipterocarp.		EN							Newman, Pooma 2017
37	*Shorea glauca*	King	Dipterocarp.		EN							Newman, Pooma 2017a
38	*Shorea laevis*	Ridl.	Dipterocarp.		VU							Pooma *et al.* 2017b
39	*Shorea lepidota*	Blume	Dipterocarp.		CR	√						Ashton 1998e
40	*Shorea macrophylla*	(de Vriese) P.S.Ashton	Dipterocarp.			√						LC (Randi *et al.* 2019a)

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
41	*Shorea palembanica*	Miq.	Dipterocarp.		CR	√						Ashton 1998f
42	*Shorea selanica*	(Lam.) Blume	Dipterocarp.		CR	√						Ashton 1998g
43	*Shorea seminis*	Slooten	Dipterocarp.		CR	√						Ashton 1998h
44	*Shorea singkawang*	Burck	Dipterocarp.		VU	√						Pooma, Newman 2017a
45	*Shorea splendida*	(de Vriese) P.S.Ashton	Dipterocarp.		EN	√						Randi *et al.* 2019b
46	*Shorea stenoptera*	Burck	Dipterocarp.		EN	√						Randi *et al.* 2019c
47	*Shorea sumatrana*	(Slooten) Desch	Dipterocarp.		EN							Pooma, Newman 2017b
48	*Shorea teysmanniana*	Dyer ex Brandis	Dipterocarp.		EN							Ashton 1998i
49	*Vatica teysmanniana*	Burck	Dipterocarp.		CR							Ashton 1998j
50	*Dalbergia ferruginea*	Roxb.	Fab.	II								
51	*Dalbergia junghuhnii*	Benth.	Fab.	II								
52	*Dalbergia latifolia*	Roxb.	Fab.	II	VU							Asian Regional Workshop (Conservation & Sustainable Management of Trees, Viet Nam, August 1996) 1998a.
53	*Dalbergia parviflora*	Roxb.	Fab.	II								LC (Chadburn 2012)
54	*Dalbergia pinnata*	(Lour.)Prain	Fab.	II								
55	*Derris trifoliata*	Lour.	Fab.	II								
56	*Euchresta horsfieldii*	(Lesch.)Benn.	Fab.								√	
57	*Intsia palembanica*	Miq.	Fab.					√	√			
58	*Koompassia malaccensis*	Benth.	Fab.					√	√			LC (Asian Regional Workshop

No.	Species	Author	Family	CITES App.	IUCN	National Legislations L1	L2	L3	L4	L5	L6	References
												(Conservation & Sustainable Management of Trees, Viet Nam, August 1996) 1998c)
59	*Parkia intermedia*	Hassk.	Fab.								√	
60	*Parkia timoriana*	(DC.)Merr.	Fab.								√	LC (Harvey-Brown 2019)
61	*Sindora javanica*	(Koord. & Valeton)Backer	Fab.		VU							World Conservation Monitoring Centre 1998f
62	*Castanopsis argentea*	(Blume) A.DC.	Fag.		EN		√	√	√	√		Barstow, Kartawinata 2018
63	*Lithocarpus indutus*	(Blume) Rehder	Fag.		VU							World Conservation Monitoring Centre 1998c
64	*Lithocarpus platycarpus*	(Blume) Rehder	Fag.		EN							World Conservation Monitoring Centre 1998d
65	*Gunnera macrophylla*	Blume	Gunner.								√	
66	*Scutellaria javanica*	Jungh.	Lami.								√	
67	*Vitex parviflora*	A.Juss.	Lami.		VU							World Conservation Monitoring Centre 1998g
68	*Beilschmiedia madang*	Blume	Laur.					√	√			LC (de Kok 2019a)
69	*Cinnamomum culilaban*	(L.) J. Presl	Laur.								√	

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
70	*Cinnamomum sintoc*	Blume	Laur.								√	LC (de Kok 2019b)
71	*Eusideroxylon zwageri*	Teijsm. & Binn.	Laur.		VU			√	√			Asian Regional Workshop (Conservation & Sustainable Management of Trees, Viet Nam, August 1996) 1998b
72	*Strychnos ignatii*	P.J. Bergius	Logani.								√	
73	*Strychnos lucida*	R. Br.	Logani.								√	LC (BGCI, IUCN SSC Global Tree Specialist Group 2018)
74	*Woodfordia fruticosa*	(L.) Kurz	Lythr.								√	LC (CAMP Workshops on Medicinal Plants, India (January 1997) 1998)
75	*Helicteres isora*	L.	Malv.								√	
76	*Ficus deltoidea*	Jack	Mor.								√	
77	*Syzygium conglomeratum*	(Duthie) I.M.Turner	Myrt.		VU							Kochummen 1998
78	*Nepenthes ampullacea*	Jack	Nepenth.	II								
79	*Nepenthes ampullaria*	Jack	Nepenth.	II								LC (Clarke 2018b)
80	*Nepenthes boschiana*	Korth.	Nepenth.	II	EN	√	√	√	√	√		Schnell *et al.* 2000
81	*Nepenthes gracilis*	Korth.	Nepenth.	II								LC (Clarke 2018a)
82	*Nepenthes mirabilis*	(Lour.) Druce	Nepenth.	II								LC (Clarke 2014)

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
83	*Nepenthes rafflesiana*	Jack	Nepenth.	II								LC (Clarke 2018d)
84	*Nepenthes reinwardtiana*	Miq.	Nepenth.	II								LC (Clarke 2018e)
85	*Acriopsis liliifolia var. liliifolia*		Orchid.	II								
86	*Apostasia nuda*	R.Br.	Orchid.	II								
87	*Arundina graminifolia*	(D.Don) Hochr.	Orchid.	II								
88	*Calanthe triplicata*	(Willemet) Ames	Orchid.	II								
89	*Cleisostoma scortechinii*	(Hook.f.) Garay	Orchid.	II								
90	*Corymborkis veratrifolia*	(Reinw.) Blume	Orchid.	II								
91	*Cymbidium aloifolium*	(L.) Sw.	Orchid.	II								
92	*Dendrobium crumenatum*	Sw.	Orchid.	II								
93	*Dendrobium faciferum*	J.J.Sm.	Orchid.	II								
94	*Dendrobium hymenanthum*	Rchb.f.	Orchid.	II								
95	*Dendrobium purpureum*	Roxb.	Orchid.	II							√	
96	*Dendrobium salaccense*	(Blume) Lindl.	Orchid.	II								
97	*Dendrobium utile*	J.J.Sm.	Orchid.	II								
98	*Erythrorchis altissima*	(Blume) Blume	Orchid.	II								LC (Brummitt 2013)
99	*Grammatophyllum scriptum*	(L.) Blume	Orchid.	II								
100	*Grammatophyllum speciosum*	Blume	Orchid.	II		√						
101	*Habenaria multipartita*	Blume ex Kraenzl.	Orchid.	II								
102	*Habenaria rumphii*	(Brongn.) Lindl.	Orchid.	II								
103	*Hetaeria obliqua*	Blume	Orchid.	II								
104	*Liparis condylobulbon*	Rchb.f.	Orchid.	II								
105	*Liparis viridiflora*	(Blume) Lindl.	Orchid.	II								
106	*Nervilia concolor*	(Blume) Schltr.	Orchid.	II								
107	*Nervilia plicata*	(Andrews) Schltr.	Orchid.	II								

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
108	*Oberonia lycopodioides*	(J.Koenig) Ormerod	Orchid.	II								
109	*Oberonia mucronata*	(D.Don) Ormerod & Seidenf.	Orchid.	II								
110	*Renanthera moluccana*	Blume	Orchid.	II							√	
111	*Robiquetia spathulata*	(Blume) J.J.Sm.	Orchid.	II								
112	*Spathoglottis affinis*	de Vriese	Orchid.	II								
113	*Spathoglottis plicata*	Blume	Orchid.	II								
114	*Strongyleria pannea*	(Lindl.) Schuit., Y.P.Ng & H.A.Pedersen	Orchid.	II								
115	*Tropidia curculigoides*	Lindl.	Orchid.	II								
116	*Vanda miniata*	(Lindl.) Gardiner, Lauren Maria	Orchid.	II		√						
117	*Vanilla abundiflora*	J.J.Sm.	Orchid.	II								
118	*Vanilla griffithii*	Rchb.f.	Orchid.	II								
119	*Pinus merkusii*	Jungh. & de Vriese	Pin.		VU							Farjon 2013b
120	*Rafflesia arnoldi*	R.Br.	Rafflesi.			√	√	√	√	√		
121	*Rafflesia horsfieldii*	R.Br.	Rafflesi.			√	√	√	√	√	√	
122	*Lunasia amara*	Blanco	Rut.								√	LC (BGCI, IUCN SSC Global Tree Specialist Group 2019)
123	*Murraya paniculata*	(L.) Jack	Rut.								√	
124	*Santalum album*	L.	Santal.		VU							Arunkumar *et al.* 2019
125	*Palaquium hispidum*	H.J.Lam	Sapot.		VU							Olander, Wilkie 2018
126	*Kadsura scandens*	(Blume) Blume	Schisandr.								√	
127	*Eurycoma longifolia*	Jack	Simaroub.								√	
128	*Symplocos odoratissima*	Choisy ex Zoll.	Symploc.								√	

No.	Species	Author	Family	CITES App.	IUCN	National Legislations						References
						L1	L2	L3	L4	L5	L6	
129	*Taxus wallichiana*	Zucc.	Tax.	II	EN							Thomas, Farjon 2011
130	*Aquilaria cumingiana*	(Decne.) Ridl.	Thymelae.	II	VU							Harvey-Brown 2018a
131	*Aquilaria hirta*	Ridl.	Thymelae.	II	VU							Harvey-Brown 2018b
132	*Aquilaria malaccensis*	Lam.	Thymelae.	II	CR							Harvey-Brown 2018c
133	*Gonystylus bancanus*	(Miq.) Kurz	Thymelae.	II	CR							Barstow 2018a
134	*Gonystylus macrophyllus*	(Miq.) Airy Shaw	Thymelae.	II								LC (Barstow 2018b)
135	*Amomum sumatranum*	(Valeton) Skornick. & Hlavatá	Zingiber.								√	DD (Romand-Monnier 2013)
136	*Curcuma petiolata*	Roxb.	Zingiber.								√	DD (Ardiyani 2019)
137	*Kaempferia angustifolia*	Roscoe	Zingiber.								√	

Notes: L1: Government Regulation No.7/1999; L2: Decree of Forestry Ministry No 57/MENHUT-II/2008; L3: Forestry Ministry No. P.20/MENLHK/SETJEN/KUM.1/6/2018; L4: P No 92/MENLHK/SETJEN/KUM1/8/2018; L5: P No 106/MENLHK/SETJEN/KUM1/12/2018; L6: IBSAP (Indonesia Biodiversity Strategy and Action Plan) based on Rifai *et al.* (1992) and Zuhud *et al.* (2001) *in* The National Development Planning Agency (2003); IUCN: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD)

Table Appendix 3. Priority medicinal plant species included in gap analysis 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
	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

Table Appendix 4.1. Species used for the climate changes analysis and maxent result for its validity

No.	Species and Author	Family	Presence points	Sources	Test AUC	AUC Stdev.	ASD15	Valid SDM
1	*Acriopsis liliifolia* var. *liliifolia*	Orchid.	102	BO	0.64	0.11	0.41	No
2	*Agathis borneensis* Warb.	Araucari.	119	GBIF, IBG, NAT	0.8	0.06	0.03	Yes
3	*Alstonia iwahigensis* Elmer	Apocyn.	33	BO, GBIF, NAT, RBG K	0.84	0.07	0.01	Yes
4	*Alstonia scholaris* (L.) R. Br.	Apocyn.	111	BO	0.76	0.09	0.70	Yes
5	*Alyxia halmaheirae* Miq.	Apocyn.	18	BO, GBIF, NAT	0.72	-0.8	3.61	No
6	*Alyxia reinwardtii* Blume	Apocyn.	90	BO, GBIF	0.83	0.08	0.05	Yes
7	*Alyxia rostrata* (Markgr.) Markgr.	Apocyn.	22	BO, GBIF, NAT	0.7	-1	0.07	No
8	*Ampelocissus arachnoidea* (Hausskn.) Planch.	Vit.	45	NAT	0.9	0.05	0	Yes
9	*Ampelocissus polythyrsa* (Miq.) Gagnep.	Vit.	29	BO, GBIF, NAT	0.58	0.13	2.96	No
10	*Anaxagorea javanica* Blume	Annon.	32	BO	0.79	0.09	0.84	Yes
11	*Anisoptera costata* Korth.	Dipterocarp.	27	GBIF, IBG	0.79	-0.12	1.03	Yes
12	*Anisoptera marginata* Korth.	Dipterocarp.	31	GBIF, IBG	0.77	0.11	1.24	Yes
13	*Apostasia nuda* R.Br.	Orchid.	27	GBIF	0.73	0.1	0.63	Yes
14	*Aquilaria cumingiana* (Decne.) Ridl.	Thymelae.	17	BO, GBIF, NAT	0.68	-0.66	17.10	No
15	*Aquilaria malaccensis* Lam.	Thymelae.	28	GBIF, IBG	0.78	-0.02	0.07	Yes
16	*Ardisia odontophylla* Wall. ex A.DC.	Primul.	12	BO	0.87	-1	0.06	No
17	*Arundina graminifolia* (D.Don) Hochr.	Orchid.	58	GBIF	0.81	0.08	0	Yes
18	*Barleria prionitis* L.	Acanth.	39	NAT	0.9	0.03	0.72	Yes
19	*Beilschmiedia madang* (Blume) Blume	Laur.	61	GBIF, NAT	0.69	0.1	2.28	No
20	*Blumea arfakiana* Martelli	Aster.	18	BO, GBIF, NAT, RBG K	0.6	-0.8	0.17	No
21	*Borassus flabellifer* L.	Arec.	15	GBIF	0.99	-1	0	No
22	*Calanthe triplicata* (Willemet) Ames	Orchid.	34	GBIF	0.65	0.13	1.08	No
23	*Castanopsis argentea* (Blume) A.DC.	Fag.	51	GBIF, NAT	0.87	0.07	0.26	Yes
24	*Catunaregam spinosa* (Thunb.) Tirveng.	Rubi.	10	GBIF, NAT	0.78	-1	0.79	No
25	*Cibotium barometz* (L.) J.Sm.	Ciboti.	41	GBIF, IBG	0.64	0.12	0.81	No

26	*Cinnamomum culilaban* (L.) J.Presl	Laur.	15	GBIF, IBG, NAT	0.77	-1	5.01	No
27	*Cinnamomum sintoc* Blume	Laur.	30	GBIF	0.84	0.1	0.25	Yes
28	*Cryptocarya massoy* (Oken) Kosterm.	Laur.	24	GBIF, NAT	0.45	-0.67	8.11	No
29	*Curcuma aurantiaca* Zijp	Zingiber.	15	GBIF	0.78	-0.66	0.60	No
30	*Curcuma petiolata* Roxb.	Zingiber.	12	BO, GBIF, NAT	0.82	-1	1.65	No
31	*Cycas rumphii* Miq.	Cycad.	39	GBIF, IBG	0.78	-0.03	2.46	Yes
32	*Dalbergia ferruginea* Roxb.	Fab.	17	GBIF	0.71	-0.78	15.46	No
33	*Dalbergia latifolia* Roxb.	Fab.	29	GBIF, IBG	0.81	-0.88	0.43	No
34	*Dalbergia parviflora* Roxb.	Fab.	13	GBIF, IBG	0.52	-0.89	18.14	No
35	*Dalbergia pinnata* (Lour.) Prain	Fab.	94	BO, GBIF	0.82	0.08	0.17	Yes
36	*Dendrobium crumenatum* Sw.	Orchid.	23	GBIF	0.63	-0.66	0.01	No
37	*Dendrobium purpureum* Roxb.	Orchid.	33	BO, GBIF	0.8	0.11	1.42	Yes
38	*Dendrobium salaccense* (Blume) Lindl.	Orchid.	24	GBIF	0.85	-0.46	6.81	No
39	*Derris trifoliata* Lour.	Fab.	74	GBIF	0.7	0.1	0.72	No
40	*Dicksonia blumei* (Kunze) T.Moore	Dicksoni.	39	GBIF	0.94	0.03	0.02	Yes
41	*Dipterocarpus baudii* Korth.	Dipterocarp.	30	GBIF	0.82	0.08	2.37	Yes
42	*Dipterocarpus gracilis* Blume	Dipterocarp.	42	GBIF, IBG, NAT	0.71	0.11	0.98	Yes
43	*Dipterocarpus kunstleri* King	Dipterocarp.	21	GBIF	0.7	-1	0.03	No
44	*Dipterocarpus retusus* Blume	Dipterocarp.	20	GBIF	0.78	-0.45	1.53	No
45	*Dodonaea viscosa* subsp. *angustifolia* (L.f.) J.G.West	Sapind.	21	GBIF	0.83	-0.36	14.68	No
46	*Euchresta horsfieldii* (Lesch.)Benn.	Fab.	39	GBIF, NAT	0.91	0.06	0.33	Yes
47	*Eurycoma longifolia* Jack	Simaroub.	37	BO	0.75	0.06	0.21	Yes
48	*Eusideroxylon zwageri* Teijsm. & Binn.	Laur.	61	GBIF, IBG, NAT	0.71	0.12	0.39	Yes
49	*Ficus deltoidea* Jack	Mor.	33	BO	0.69	0.09	0.36	No
50	*Galbulimima belgraveana* (F.Muell.) Sprague	Himantandr.	20	BO, GBIF	0.84	-0.35	25.92	No
51	*Gentiana quadrifaria* Blume	Gentian.	42	BO, GBIF, NAT	0.93	0.05	0.30	Yes
52	*Gomphandra quadrifida* (Blume) Sleumer	Stemonur.	20	NAT	0.63	-0.03	2.85	No
53	*Goniothalamus giganteus* Hook.f. & Thomson	Annon.	19	BO, NAT	0.57	-0.78	0.74	No
54	*Goniothalamus tapis* Miq.	Annon.	24	BO, GBIF, NAT	0.48	0.02	7.99	No

55	*Gonocaryum gracile* Miq.	Cardiop terid.	13	GBIF, NAT	0.48	-0.89	6.72	No
56	*Gonystylus bancanus* (Miq.) Kurz	Thymel ae.	33	GBIF	0.79	0.07	0.19	Yes
57	*Gonystylus macrophyllus* (Miq.) Airy Shaw	Thymel ae.	15	GBIF	0.59	-0.78	13.58	No
58	*Grammatophyllum scriptum* (L.) Blume	Orchid.	28	BO	0.65	0.12	0.84	No
59	*Grammatophyllum speciosum* Blume	Orchid.	43	BO, GBIF, IBG	0.78	0.1	2.79	Yes
60	*Gunnera macrophylla* Blume	Gunner.	27	BO	0.95	-0.27	0.40	No
61	*Habenaria multipartita* Blume ex Kraenzl.	Orchid.	20	GBIF	0.93	-0.47	0.65	No
62	*Habenaria rumphii* (Brongn.) Lindl.	Orchid.	20	GBIF	0.6	-1	0.11	No
63	*Helicteres isora* L.	Malv.	20	GBIF, IBG	0.89	-1	5.86	No
64	*Hopea celebica* Burck	Diptero carp.	21	GBIF, IBG	0.81	-0.87	32.40	No
65	*Hopea mengarawan* Miq.	Diptero carp.	27	GBIF, IBG	0.69	0.11	0.03	No
66	*Hopea sangal* Korth.	Diptero carp.	29	GBIF, IBG	0.61	0.1	2.37	No
67	*Hypoestes polythyrsa* Miq.	Acanth.	21	NAT	0.82	-0.15	0.42	No
68	*Intsia palembanica* Miq.	Fab.	13	GBIF, NAT	0.8	-0.69	12.05	No
69	*Ixonanthes icosandra* Jack	Ixonant h.	11	BOLD , NAT	0.76	-0.9	42.28	No
70	*Kadsura scandens* (Blume) Blume	Schisan dr.	26	BO, GBIF	0.95	-0.18	1.95	No
71	*Kaempferia angustifolia* Roscoe	Zingibe r.	16	BO, GBIF, NAT	0.94	-1	0.40	No
72	*Koompassia malaccensis* Maingay	Fab.	24	GBIF	0.91	-0.58	0.03	No
73	*Koordersiodendron pinnatum* (Blanco) Merr.	Anacar di.	22	GBIF	0.68	-0.15	13.16	No
74	*Leea aequata* L.	Vit.	67	IBG, NAT	0.67	0.1	0	No
75	*Liparis condylobulbon* Rchb.f.	Orchid.	10	BO, GBIF	0.44	-1	0.28	No
76	*Liparis viridiflora* (Blume) Lindl.	Orchid.	11	GBIF	0.79	-1	0.15	No
77	*Lithocarpus indutus* (Blume) Rehder	Fag.	15	GBIF	0.87	-0.88	2.10	No
78	*Lithocarpus platycarpus* (Blume) Rehder	Fag.	10	GBIF	0.99	-1	17,11 1.11	No
79	*Lunasia amara* Blanco	Rut.	115	BO	0.79	0.09	1.37	Yes
80	*Macaranga griffithiana* Müll.Arg.	Euphor bi.	22	BO	0.83	0.06	0.17	Yes
81	*Maoutia diversifolia* (Miq.) Wedd.	Urtic.	10	NAT	0.87	-1	0	No
82	*Medinilla radicans* Blume	Melasto mat.	17	BO	0.93	-0.36	13.36	No
83	*Melicope denhamii* (Seem.) T.G.Hartley	Rut.	30	GBIF	0.68	0.01	11.48	No
84	*Mesua ferrea* L.	Caloph yll.	19	GBIF	0.85	-0.79	0.23	No
85	*Micromelum minutum* (G.Forst.) Wight & Arn.	Rut.	79	IBG, NAT	0.68	0.08	0.61	No

86	*Murraya paniculata* (L.) Jack	Rut.	94	GBIF, IBG	0.81	0.07	0.01	Yes
87	*Mussaenda glabra* Vahl	Rubi.	33	NAT	0.86	0.05	0.64	Yes
88	*Nepenthes ampullaria* Jack	Nepenth.	24	GBIF	0.71	-0.79	10.71	No
89	*Nepenthes gracilis* Korth.	Nepenth.	23	GBIF	0.66	0.01	6.92	No
90	*Nepenthes mirabilis* (Lour.) Druce	Nepenth.	25	GBIF	0.59	-0.56	15.44	No
91	*Nepenthes rafflesiana* Jack	Nepenth.	15	GBIF	0.66	-0.45	1.03	No
92	*Nepenthes reinwardtiana* Miq.	Nepenth.	32	GBIF	0.75	0.1	0.18	Yes
93	*Nervilia concolor* (Blume) Schltr.	Orchid.	21	NAT	0.79	-0.48	1.74	No
94	*Nervilia plicata* (Andrews) Schltr.	Orchid.	22	BO, NAT	0.84	0.05	1.44	Yes
95	*Nothocnide repanda* (Blume) Blume	Urtic.	38	NAT	0.67	0.1	1.21	No
96	*Oroxylum indicum* (L.) Kurz	Bignoni.	82	BO, GBIF	0.8	0.08	0.95	Yes
97	*Pangium edule* Reinw.	Achari.	19	GBIF	0.69	-0.9	0.48	No
98	*Parashorea lucida* (Miq) Kurz	Dipterocarp.	14	IBG, NAT	0.59	-1	10.27	No
99	*Parkia intermedia* Hassk.	Fab.	13	GBIF	0.87	-1	1.03	No
100	*Parkia timoriana* (DC.) Merr.	Fab.	59	GBIF, NAT	0.75	0.11	0.18	Yes
101	*Phyllagathis rotundifolia* (Jack) Blume	Melastomat.	10	GBIF	0.89	-1	0.43	No
102	*Phyllodium elegans* (Lour.)Desv.	Fab.	12	GENESIS	0.64	-1	4.37	No
103	*Pigafetta filaris* (Giseke) Becc.	Arec.	10	GBIF	0.63	-1	0.50	No
104	*Pimpinella pruatjan* Molk.	Api.	35	BO	1	-0.5	0	No
105	*Pinus merkusii* Jungh. & de Vriese	Pin.	28	GBIF, IBG	0.83	0.08	1.10	Yes
106	*Pontederia plantaginea* Roxb.	Pontederi.	10	NAT	0.63	-1	160.01	No
107	*Rafflesia arnoldi* R.Br.	Rafflesi.	12	GBIF	0.71	-0.77	1.87	No
108	*Rafflesia horsfieldii* R.Br.	Rafflesi.	33	BO, GBIF, IBG, NAT	0.84	-0.46	1.76	No
109	*Rauvolfia serpentina* (L.) Benth. ex Kurz	Apocyn.	62	BO, GBIF, IBG	0.94	0.03	0.10	Yes
110	*Renanthera moluccana* Blume	Orchid.	10	BO, GBIF, NAT	0.85	-1	59.76	No
111	*Santalum album* L.	Santal.	25	GBIF, IBG	0.86	-0.13	1.36	Yes
112	*Scutellaria javanica* Jungh.	Lami.	40	BO, RGBE	0.93	0.03	0.07	Yes
113	*Shorea bracteolata* Dyer	Dipterocarp.	10	NAT	0.89	-1	4.99	No
114	*Shorea lepidota* (Korth) Blume	Dipterocarp.	17	GBIF, NAT	0.81	-0.58	0.50	No
115	*Shorea macrophylla* (de Vriese) P.S.Ashton	Dipterocarp.	10	GBIF	0.7	-1	42.76	No

116	*Shorea palembanica* Miq.	Diptero carp.	21	GBIF	0.75	-0.12	3.20	Yes
117	Shorea selanica (Lam) Blume	Diptero carp.	26	GBIF, IBG	0.9	-1	6.06	No
118	Shorea seminis (de Vriese) Slooten	Diptero carp.	52	GBIF, IBG, NAT	0.76	0.09	0.13	Yes
119	Shorea singkawang (Miq.) Burck	Diptero carp.	18	GBIF	0.64	-1	6.15	No
120	Shorea stenoptera Burck	Diptero carp.	21	GBIF, IBG	0.79	-0.8	1.10	No
121	Shorea teysmanniana Dyer ex Brandis	Diptero carp.	10	GBIF, IBG	0.88	-1	9.23	No
122	*Sindora javanica* (Koord & Valeton)Backer	Fab.	12	GBIF, NAT	0.91	-1	4.50	No
123	*Smilax zeylanica* L	Smilac.	16	NAT	0.72	-0.66	0.01	No
124	*Spathoglottis plicata* Blume	Orchid.	115	GBIF, IBG	0.75	0.07	1.30	Yes
125	*Stephania japonica* (Thunb) Miers	Menisp erm.	15	NAT	0.75	-0.77	0.06	No
126	*Strychnos ignatii* Bergius	Logani.	21	BO	0.66	-0.13	1.93	No
127	*Strychnos lucida* RBr	Logani.	15	BO, GBIF, RBG K	0.95	-1	0	No
128	*Symplocos cochinchinensis* var. *sessifolia* (Blume) Noot	Symplo c.	13	GBIF	0.57	-0.78	0	No
129	*Symplocos odoratissima* (Blume) Choisy ex Zoll	Symplo c.	23	BO, GBIF	0.57	-0.47	0	No
130	*Taxus wallichiana* Zucc	Tax.	12	GBIF	0.93	-0.8	0.10	No
131	*Terminalia bellirica* (Gaertn.) Roxb.	Combre t.	12	GBIF	0.7	-0.88	0.35	No
132	*Toona sureni* (Blume) Merr	Meli.	13	NAT	0.96	-1	1.92	No
133	*Tropidia curculigoides* Lindl	Orchid.	20	BO, GBIF	0.82	-0.47	1.84	No
134	*Urceola laevigata* (Juss.) D.J.Middleton & Livsh.	Apocyn .	84	BO	0.84	0.08	0.15	Yes
135	*Utania racemosa* (Jack) Sugumaran	Gentian .	152	GBIF, IBG, NAT	0.59	0.07	0.75	No
136	*Vitex parviflora* AJuss	Lami.	23	GBIF	0.95	-0.69	2.30	No
137	*Voacanga grandifolia* (Miq) Rolfe	Apocyn .	75	BO	0.91	0.03	0.41	Yes
138	*Woodfordia fruticosa* (L) Kurz	Lythr.	10	GBIF	0.94	-1	11.33	No
139	*Zanthoxylum avicennae* (Lam) D.C.	Rut.	14	GBIF, NAT	0.86	-0.79	6.93	No

Table Appendix 4.2. Impacts of climate change on the predicted distribution areas of priority medicinal plants in Indonesia for two emission scenarios (RCP4.5 and RCP8.5) for 2050 and 2080

No.	Species (IUCN, 2020)	PH*	Major cont. var.	Presence grids (≈10 km x 10 km)					RCP4.5 2050			RCP4.5 2080			RCP8.5 2050			RCP8.5 2080		
				Current	RCP4.5 2050	RCP4.5 2080	RCP8.5 2050	RCP8.5 2080	%L/G	Thr. Lev.	T	%L/G	Thr. Lev.	T	%L/G	Thr. Lev.	T	%L/G	Thr. Lev.	T
1	*Agathis borneensis* (EN)	Tr	bio_14; aspect; bio_4	22614	12935	11406	11908	8228	-42.80	VU	-2.25	-49.56		-2.61	-47.34	VU	-2.49	-63.62	EN	-3.38
2	*Alstonia iwahigensis*	Tr	slope; bio_16; bio_4	15198	7032	4867	7362	4618	-53.73	EN	-1.87	-67.98		-2.37	-51.56	EN	-1.79	-69.61	EN	-2.43
3	*Alstonia scholaris*	Tr	s_oc; alt; t_teb	22776	22451	21571	22632	21358	-1.43		-0.08	-5.29		-0.28	-0.63		-0.03	-6.23		-0.33
4	*Alyxia reinwardtii*	Cl	bio_4; t_oc; alt	16797	18332	17614	18698	17568	9.14		0.35	4.86		0.19	11.32		0.44	4.59		0.18
5	*Ampelocissus arachnoidea*	Li	bio_4; bio_14; bio_13	14227	25791	32883	28076	33918	81.28		2.64	131.13		4.18	97.34		3.14	138.41		4.41
6	*Anaxagorea javanica*	Sh	bio_14; s_teb; bio_4	23572	16374	13807	16327	14152	-30.54	VU	-1.68	-41.43		-2.29	-30.74	VU	-1.69	-39.96	VU	-2.20
7	*Anisoptera costata* (EN)	Tr	bio_17; s_oc; bio_4	17350	9140	6837	7915	5304	-47.32	VU	-1.88	-60.59		-2.43	-54.38	EN	-2.17	-69.43	EN	-2.79
8	*Anisoptera marginata* (EN)	Tr	alt; bio_14; slope	25560	25664	25431	25535	24098	0.41		0.02	-0.50		-0.03	-0.10		-0.01	-5.72		-0.34
9	*Apostasia nuda*	He	slope; alt; bio_4	27929	29833	25223	28551	23770	6.82		0.45	-9.69		-0.64	2.23		0.15	-14.89		-0.99
10	*Aquilaria malaccensis* (CR)	Tr	s_oc; alt; s_teb	25415	18219	15735	17537	13561	-28.31		-1.68	-38.09		-2.28	-31.00	VU	-1.85	-46.64	VU	-2.80
11	*Arundina graminifolia*	He	bio_14; t_teb; alt	20570	22150	23531	20980	19368	7.68		0.37	14.39		0.68	1.99		0.10	-5.84		-0.28

12	*Barleria prionitis*	Sh	t_teb; bio_4; bio_14	8314	8170	8786	8564	8894	-1.73		-0.03	5.68		0.11	3.01		0.06	6.98		0.13
13	*Castanopsis argentea* (EN)	Tr	alt; bio_17; bio_4	15139	14039	12649	11790	8927	-7.27		-0.25	-16.45		-0.57	-22.12		-0.77	-41.03	VU	-1.44
14	*Cinnamomum sintoc*	Tr	alt; bio_19; bio_14	12239	11683	11193	11478	8735	-4.54		-0.13	-8.55		-0.24	-6.22		-0.17	-28.63		-0.80
15	*Cycas rumphii*	TrP	slope; bio_18; s_oc	15633	15125	14596	14498	13972	-3.25		-0.12	-6.63		-0.24	-7.26		-0.26	-10.62		-0.38
16	*Dalbergia pinnata*	Sh	bio_16; bio_4; slope	19215	26446	28455	26680	28963	37.63		1.67	48.09		2.12	38.85		1.72	50.73		2.23
17	*Dendrobium purpureum*	He	alt; bio_4; bio_18	12120	12643	13678	13308	13885	4.32		0.12	12.85		0.35	9.80		0.27	14.56		0.40
18	*Dicksonia blumei*	Sh	alt; s_oc; bio_19	2110	2094	1965	1919	1728	-0.76		-	-6.87	EN	-0.03	-9.05		-0.04	-18.10		-0.08
19	*Dipterocarpus baudii* (VU)	Tr	bio_4; s_oc; bio_18	21962	16018	11675	14235	9474	-27.06		-1.38	-46.84		-2.41	-35.18	VU	-1.80	-56.86	EN	-2.94
20	*Dipterocarpus gracilis* (VU)	Tr	alt; bio_4; bio_17	29290	26790	25756	26688	22484	-8.54		-0.59	-12.07		-0.84	-8.88		-0.61	-23.24		-1.62
21	*Euchresta horsfieldii*	Sh	alt; bio_14; s_ph	2331	1858	1629	1562	1163	-20.29		-0.10	-30.12	EN	-0.16	-32.99	VU	-0.17	-50.11	EN	-0.26
22	*Eurycoma longifolia*	Sh	bio_19; bio_4; bio_14	24955	12788	9704	12317	9169	-48.76	VU	-2.84	-61.11		-3.59	-50.64	EN	-2.96	-63.26	EN	-3.72
23	*Eusideroxylon zwageri* (VU)	Tr	bio_4; alt; t_teb	31140	13952	9881	14660	8931	-55.20	EN	-4.07	-68.27		-5.09	-52.92	EN	-3.90	-71.32	EN	-5.33
24	*Gentiana quadrifaria*	He	bio_19; alt; t_teb	4112	4502	4483	4034	3916	9.48		0.09	9.02	VU	0.08	-1.90		-0.02	-4.77		-0.04
25	*Gonystylus bancanus* (CR)	Tr	alt; bio_19; bio_14	25468	26712	25400	23793	25671	4.88		0.29	-0.27		-0.02	-6.58		-0.39	0.80		0.05

26	*Grammatophyllum speciosum*	He	bio_16; aspect; alt	24059	27052	29130	27158	29427	12.44		0.70	21.08		1.18	12.88		0.72	22.31		1.24
27	*Lunasia amara*	Sh	bio_18; alt; s_oc	16689	15384	14735	15816	13444	-7.82		-0.30	-11.71		-0.45	-5.23		-0.20	-19.44		-0.75
28	*Macaranga griffithiana*	Tr	alt; slope; s_oc	17557	12426	9948	11920	9875	-29.22		-1.18	-43.34		-1.76	-32.11	VU	-1.30	-43.75	VU	-1.77
29	*Murraya paniculata*	Sh	bio_14; bio_4; bio_13	21685	21624	23962	21692	21846	-0.28		-0.01	10.50		0.53	0.03		-	0.74		0.04
30	*Mussaenda glabra*	Sh	bio_13; alt; bio_4	9460	13500	14712	13796	13220	42.71		0.91	55.52		1.18	45.84		0.98	39.75		0.85
31	*Nepenthes reinwardtiana*	Cl	bio_4; s_oc; alt	29372	16357	13287	17738	12282	-44.31	VU	-3.07	-54.76		-3.82	-39.61	VU	-2.74	-58.18	EN	-4.07
32	*Nervilia plicata*	He	bio_14; slope; bio_16	7202	9997	12782	10263	12085	38.81		0.63	77.48		1.24	42.50		0.69	67.80		1.09
33	*Oroxylum indicum*	Tr	bio_13; bio_4; bio_14	21672	32519	33915	32653	34533	50.05		2.51	56.49		2.83	50.67		2.54	59.34		2.97
34	*Parkia timoriana*	Tr	bio_13; s_teb; s_oc	20307	22496	23632	24013	22363	10.78		0.51	16.37		0.77	18.25		0.85	10.12		0.48
35	*Pinus merkusii*	Tr	slope; s_oc; bio_17	11334	8020	6357	6885	4469	-29.24		-0.75	-43.91	VU	-1.13	-39.25	VU	-1.01	-60.57	EN	-1.57
36	*Rauvolfia serpentina*	Sh	bio_14; s_ph; bio_4	6542	7368	7595	6979	7568	12.63		0.18	16.10		0.24	6.68		0.10	15.68		0.23
37	*Santalum album* (VU)	Tr	t_teb; bio_19; bio_14	4627	4542	4727	4731	4773	-1.84		-0.02	2.16	EN	0.02	2.25		0.02	3.16		0.03
38	*Scutellaria javanica*	He	alt; s_teb; bio_14	2896	2741	2565	2659	2332	-5.35		-0.03	-11.43	EN	-0.07	-8.18		-0.05	-19.48		-0.13

39	*Shorea palembanica* (CR)	Tr	bio_19; slope; bio_4	24095	22746	21954	23368	21467	-5.60		-0.31	-8.89		-0.50	-3.02		-0.17	-10.91		-0.61
40	*Shorea seminis* (CR)	Tr	bio_4; bio_14; alt	27328	19738	18732	19914	17256	-27.77		-1.78	-31.45		-2.02	-27.13		-1.74	-36.86	VU	-2.38
41	*Spathoglottis plicata*	He	slope; s_teb; t_teb	22407	29087	31359	30647	33030	29.81		1.55	39.95		2.07	36.77		1.91	47.41		2.44
42	*Urceola laevigata*	Sh	bio_14; s_ph; bio_13	12634	15273	16935	15576	15724	20.89		0.60	34.04		0.97	23.29		0.67	24.46		0.70
43	*Voacanga grandifolia*	Sh	bio_14; s_ph; s_teb	10124	10039	10738	10254	10213	-0.84		-0.02	6.06		0.14	1.28		0.03	0.88		0.02

Notes: PH (Cahyaningsih *et al.*, 2021b): Plant Habit. Cl: climber, He: herb, Li: liana, Sh: shrub, Tr: tree, TrP: tree like-palm; Environmental variables. alt: Altitude, metres above sea level, aspect: Orientation (in degrees) of the land surface, bio_13: Rainfall during the wettest month, bio_14: Rainfall during the driest month, bio_16: Rainfall during the wettest quarter (three rainiest months), bio_17: Rainfall during the driest quarter (three driest months), bio_18: Rainfall during the hottest quarter (three hottest months), bio_19: Rainfall during the coldest quarter (three coldest months), bio_4: Temperature seasonality (standard deviation*100), s_oc: Content of organic carbon in subsoil, s_ph: pH in subsoil in soil-water solution, s_teb: Total exchangeable bases in subsoil, slope: Gradient (in degrees) of the land surface, t_oc: Organic carbon content in surface soil, t_teb: Total exchangeable bases in surface soil; Pr. Grid: Presence grid (approximately equal 10 km x 10 km); %L/G: %Loss/Gain, Extinct (EX) if 100% presence grid loss, Critically endangered (CR) if more than 80% presence grid loss, Endangered (EN) if more than 50% to 80% presence grid loss, and Vulnerable (V) if more than 30% to 50% presence grid loss (IUCN 2001); Thr. Lev: Threat Level; T: Turnover Rate

Table Appendix 5.1. Summary of DNA barcoding result with related information per species

No.	Species*	Author	Fam.	N/I	Important Sp.	Sp. no. per genus	Region	Max Score	Total Score	Query cover	E Value	Per. Ident	Best matched species	Sum.	Notes
1	*Justicia gendarussa*	Burm.f.	Acanth.	N	No	921	*ITS2*	562	562	0.73	5.00E-156	0.9968	*Justicia gendarussa*	c	
							matK	1330	1330	0.96	0	0.9986	*Justicia gendarussa*	c	
							rbcL	1055	1055	0.97	0	1	*Justicia gendarussa*	c	
							trnL	1487	1487	0.92	0	0.9975	*Justicia gendarussa*	c	
2	*Staurogyne elongata*	(Nees) Kuntze	Acanth.	N	No	148	*ITS2*	597	597	0.89	1.00E-166	0.9526	*Ophiorrhiziphyllon macrobotryum*	a**	
							matK	1273	1273	0.97	0	0.9821	*Staurogyne concinnula*	a*	
							rbcL	939	939	0.91	0	0.9923	*Staurogyne concinnula*	a*	
							trnL	1013	1427	0.99	0	0.9732	*Staurogyne trinitensis*	a*	
3	*Pangium edule*	Reinw.	Achari.	N	Yes (P)	1	*ITS2*	163	163	0.15	1.00E-35	0.9286	*Celastraceae* sp.	i	
							matK	1387	1387	1	0	0.9974	*Pangium edule*	c	
							rbcL	972	972	0.91	0	1	*Pangium edule*	c	
							trnL	1158	1741	0.98	0	0.982	*Ryparosa kurrangii*	a*	
4	*Spondias malayana*	Kosterm.	Anacardi.	N	No	19	*ITS2*	636	636	1	3.00E-178	0.9332	*Spondias tuberosa*	a*	
5	*Toxicodendron succedaneum*	(L.) Kuntze	Anacardi.	I	No	27	*ITS2*	660	660	0.75	0	1	*Toxicodendron succedaneum*	c	
							matK	1452	1452	0.99	0	1	*Toxicodendron succedaneum*	c	
							rbcL	1038	1038	0.97	0	1	*Toxicodendron succedaneum*	c	
							trnL	1598	1598	1	0	1	*Toxicodendron succedaneum*	c	1/7 is a*
6	*Ancistrocladus tectorius*	(Lour.) Merr.	Ancistroclad.	N	No	21	*ITS2*	774	774	1	0	0.9953	*Ancistrocladus benomensis*	c	1/3 is a*
							matK	1387	1387	1	0	0.9987	*Ancistrocladus heyneanus*	a*	
							rbcL	1053	1053	1	0	1	*Ancistrocladus tectorius*	c	
							trnL	1663	1663	1	0	0.9903	*Ancistrocladus tectorius*	c	
7	*Anaxagorea javanica*	Blume	Annon.	N	Yes (P)	25	*matK*	1502	1502	0.97	0	0.9928	*Anaxagorea luzonensis*	a*	

							rbcL	1013	1013	0.94	0	1	*Anaxagorea luzonensis*	a*	
							trnL	1423	1423	1	0	1	*Anaxagorea javanica*	c	
							ITS2	237	237	0.38	3.00E-58	0.9474	*Acer palmatum*	i	
8	*Dasymaschalon dasymaschalum*	(Blume) I.M.Turner	Annon.	N	No	27	*matK*	1382	1382	1	0	0.9947	*Dasymaschalon clusiflorum*	a*	
							rbcL	1020	1020	0.97	0	1	*Desmos dasymaschalus*	c	
							trnL	1565	1565	0.95	0	0.9965	*Dasymaschalon megalanthum*	a*	
							ITS2	763	763	0.98	0	0.9976	*Alstonia scholaris*	a*	
							matK	1386	1386	1	0	0.9987	*Alstonia macrophylla*	c	
9	*Alstonia macrophylla*	Wall. Ex. G.Don	Apocyn.	N	No		*rbcL*	857	857	1	0	0.9876	*Alstonia scholaris*	c	13/14 is a* with the same coverage
						44	*trnL*	1557	1557	1	0	0.9908	*Alstonia scholaris*	a*	
							ITS2	457	457	0.62	3.00E-124	0.9772	*Alstonia scholaris*	c	
10	*Alstonia scholaris*	(L.) R. Br.	Apocyn.	N	Yes (P)		*matK*	1380	1380	1	0	0.9987	*Alstonia yunnanensis*	c	1/9 a is a* with same coverage
							rbcL	1051	1051	1	0	0.9983	*Alstonia scholaris*	c	
							trnL	1589	1589	1	0	0.9977	*Alstonia scholaris*	c	1/2 is a*
							ITS2	614	614	0.8	1.00E-171	0.9912	*Alyxia reinwardtii*	c	
							matK	1317	1317	0.95	0	0.9972	*Alyxia reinwardtii*	c	
11	*Alyxia reinwardtii*	Blume	Apocyn.	N	Yes (P)	106	*rbcL*	1020	1020	0.96	0	1	*Alyxia reinwardtii*	c	1/2 is a* with higher coverage
							trnL	1524	1524	0.98	0	0.9929	*Alyxia grandis*	a*	
							ITS2	507	507	0.63	3.00E-139	1	*Hoya glabra*	a*	
12	*Hoya diversifolia*	Blume	Apocyn.	N	No	521	*matK*	1347	1347	1	0	1	*Hoya vitellinoides*	a*	
							rbcL	1051	1051	0.99	0	1	*Hoya pottsii*	a*	

							trnL	1539	1539	0.98	0	0.9988	*Hoya* sp.	a*
13	*Rauvolfia serpentina*	(L.) Benth. ex Kurz	Apocyn.	N	Yes (II)	74	*ITS2*	617	617	0.73	1.00E-172	1	*Rauvolfia serpentina*	c
							matK	1380	1380	0.99	0	1	*Rauvolfia serpentina*	c
							rbcL	1057	1057	0.99	0	1	*Rauvolfia serpentina*	c
							trnL	1395	1395	0.89	0	0.9873	*Rauvolfia serpentina*	c
14	*Aglaonema commutatum*	Schott	Ar.	N	No	22	*ITS2*	501	805	0.59	2.00E-137	0.9964	*Thunbergia coccinea*	i
							matK	1384	1384	1	0	0.9974	*Aglaonema crispum*	a*
							rbcL	1022	1022	0.97	0	1	*Aglaonema commutatum*	c
							trnL	1650	1650	1	0	0.9989	*Aglaonema crispum*	a*
15	*Trevesia burckii*	R.Br.	Arali.	N	No	8	*ITS2*	745	745	0.95	0	0.988	*Trevesia palmata*	a*
							matK	1393	1393	1	0	1	*Trevesia palmata*	a*
							rbcL	1048	1048	0.98	0	0.9982	*Brassaiopsis gracilis*	a*
							trnL	1668	1668	0.99	0	0.9989	*Brassaiopsis ciliata*	a*
16	*Cibotium barometz*	(L.) J.Sm.	Ciboti.	N	Yes (II)	10	*ITS2*	348	858	0.75	3.00E-91	0.9896	*Cucumis sativus*	i
							rbcL	965	965	0.94	0	0.9872	*Cyathea chinensis*	a**
17	*Decalobanthus mammosus*	(Lour.) A.R.Simoes & Staples	Convolvul.	I	No	13	*rbcL*	1031	1031	0.97	0	0.9982	*Merremia peltata*	a*
18	*Erycibe malaccensis*	C.B.Clarke	Convolvul.	N	No	70	*ITS2*	466	466	0.95	5.00E-127	0.8631	*Erycibe obtusifolia*	a*
							matK	1389	1389	1	0	1	*Erycibe cochinchinensis*	a*
							rbcL	1033	1033	0.96	0	1	*Erycibe* sp.	a*
							trnL	1347	1347	0.93	0	0.9881	*Erycibe coccinea*	a*
19	*Rhododendron macgregoriae*	F.Muell.	Eric.	N	Yes (E)	1057	*ITS2*	723	723	1	0	0.9658	*Rhododendron groenlandicum*	a*
							matK	1369	1369	1	0	0.9908	*Rhododendron javanicum*	a*
							rbcL	1027	1027	0.98	0	0.9912	*Rhododendron simsii*	a*
							trnL	1629	1629	0.96	0	0.9955	*Rhododendron javanicum*	a*

20	*Acalypha grandis*	Benth.	Euphorbi.	N	No	428	*ITS2*	272	272	0.35	1.00E-68	0.9808	*Acer tataricum* subsp. *theiferum*	i	
							rbcL	1062	1062	0.99	0	1	*Acalypha grisebachiana*	a*	
							trnL	1729	1729	1	0	0.9886	*Acalypha hispida*	a*	
21	*Euphorbia tirucalli*	L.	Euphorbi.	I	Yes (II)	1976	*ITS2*	617	617	0.71	1.00E-172	1	*Euphorbia tirucalli*	c	1/12 I with higher coverage
							rbcL	1046	1046	0.98	0	1	*Euphorbia rauhii*	a*	
22	*Millettia sericea*	(Vent.) Benth.	Fab.	N	No	187	*ITS2*	712	712	0.94	0	0.9571	*Millettia pulchra*	a*	
							matK	1332	1332	0.97	0	0.988	*Millettia pulchra*	a*	
							rbcL	1042	1042	0.97	0	0.9982	*Dahlstedtia pinnata*	a*	
							trnL	1543	1543	1	0	0.9819	*Millettia pinnata*	a*	
23	*Parkia timoriana*	(DC.)Merr.	Fab.	N	No	40	*ITS2*	593	593	0.71	2.00E-165	0.9909	*Parkia timoriana*	c	
							matK	1376	1376	0.98	0	0.996	*Parkia biglandulosa*	a*	
							rbcL	1000	1000	0.95	0	0.9927	*Magnoliophyta* sp.	i	
							trnL	1814	1814	0.99	0	0.999	*Parkia biglandulosa*	a*	
24	*Phanera fulva*	(Korth.) Benth.	Fab.	N	Yes (E)	90	*ITS2*	475	475	0.68	7.00E-130	0.9477	*Bauhinia* sp.	a*	
							rbcL	1016	1016	0.96	0	0.9982	*Embryophyte environmental*	i	
							trnL	1404	1404	0.78	0	0.9974	*Phanera vahlii*	a**	
25	*Orthosiphon aristatus*	(Blume) Miq.	Lami.	N	No	44	*ITS2*	562	562	0.69	5.00E-156	1	*Orthosiphon aristatus*	c	
							rbcL	1042	1042	0.98	0	1	*Clerodendranthus spicatus*	a**	
26	*Premna serratifolia*	L.	Lami.	N	No	131	*ITS2*	422	422	0.99	9.00E-114	0.8495	*Premna microphylla*	a*	
							rbcL	1040	1040	0.97	0	1	*Premna serratifolia*	c	2/3 is a* with higher and lower coverage
27	*Vitex glabrata*	Gaertn.	Lami.	N	No	203	*ITS2*	651	651	0.91	0	0.9558	*Vitex carvalhoi*	a*	
							matK	1587	1587	1	0	0.9988	*Vitex glabrata*	c	

							rbcL	1050	1050	1	0	0.9982	*Vitex doniana*	a*	
							trnL	1411	1411	0.94	0	0.9923	*Vitex triflora*	a*	
							matK	1375	1375	0.99	0	0.9987	*Cinnamomum camphora*	a*	
28	*Cinnamomum rhynchophyllum*	Miq.	Laur.	N	No	241	*rbcL*	1055	1055	1	0	1	Cinnamomum dubium	a*	
							trnL	1587	1587	1	0	1	Cinnamomum pittosporoides	a*	
							ITS2	616	616	0.78	4.00E-172	1	*Ficus deltoidea*	c	
29	*Ficus deltoidea*	Jack	Mor.	N	Yes (P)	874	*matK*	1380	1380	1	0	0.996	*Ficus cf.*	a*	
							rbcL	1051	1051	0.98	0	0.9983	*Ficus benjamina*	a*	
							trnL	1664	1664	0.99	0	0.9967	*Ficus carica*	a*	
							ITS2	185	185	0.17	2.00E-42	0.9231	*Rhodohypoxis milloides*	i	
30	*Myristica succedanea*	Blume	Myristic.	N	Yes (E)	175	*matK*	1476	1476	0.92	0	0.9988	*Myristica fragrans*	a*	
							rbcL	1057	1057	1	0	1	*Horsfieldia amygdalina*	a*	4/11 is a**
							trnL	1371	1371	0.83	0	0.9987	*Myristica iners*	a*	
							matK	1375	1375	0.99	0	0.9973	*Nepenthes mapuluensis*	a*	
31	*Nepenthes ampullaria*	Jack	Nepenth.	N	Yes (P, II)		*rbcL*	1042	1042	1	0	1	*Nepenthes mirabilis*	a*	
							trnL	1648	1648	1	0	0.9956	*Nepenthes mirabilis*	a*	
							matK	1371	1371	1	0	0.9973	*Nepenthes gracilis*	c	
32	*Nepenthes gracilis*	Korth.	Nepenth.	N	Yes (P, II)		*rbcL*	1046	1046	1	0	1	*Nepenthes mirabilis*	a*	
							trnL	961	961	0.57	0	0.9962	*Nepenthes ampullaria*	a*	
						165	*ITS2*	857	857	1	0	0.9979	*Nepenthes reinwardtiana*	a*	
33	*Nepenthes mirabilis*	(Lour.) Druce	Nepenth.	N	Yes (P, II)		*matK*	1371	1371	1	0	0.9973	*Nepenthes mapuluensis*	a*	
							rbcL	1038	1038	1	0	0.9965	*Nepenthes graciliflora*	a*	
							trnL	959	959	0.57	0	0.9943	*Nepenthes sanguinea*	a*	
34	*Nepenthes reinwardtiana*	Miq.	Nepenth.	N	Yes (P, E, II)		*ITS2*	861	861	1	0	0.9979	*Nepenthes reinwardtiana*	c	
							matK	1376	1376	1	0	0.996	*Nepenthes reinwardtiana*	c	

							rbcL	1042	1042	0.98	0	0.9965	*Nepenthes mirabilis*	a*	
							trnL	948	948	0.57	0	0.9924	*Nepenthes alba*	a*	
35	*Acriopsis liliifolia* var. *liliifolia*	(J.Koenig) Ormerod	Orchid.	N	Yes (P, II)	10	*ITS2*	394	394	0.94	2.00E-105	0.8428	*Cymbidium ensifolium*	a**	
							matK	1408	1408	1	0	0.9987	*Acriopsis* sp.	a*	
							rbcL	911	911	1	0	0.9824	*Acriopsis* sp.	a*	
							trnL	824	1591	0.91	0	0.9265	*Cymbidium erythraeum*	a**	
36	*Cymbidium aloifolium*	(L.) Sw.	Orchid.	N	Yes (P, II)		*ITS2*	468	468	0.61	1.00E-127	0.9884	*Cymbidium aloifolium*	c	
							matK	1386	1386	1	0	0.9987	*Cymbidium aloifolium*	c	1/5 is a*
						74	*rbcL*	1048	1048	0.98	0	0.9982	*Cymbidium aloifolium*	c	1/4 is a*
							trnL	989	989	0.79	0	0.953	*Cymbidium wadae*	a*	
37	*Cymbidium ensifolium*	(L.) Sw.	Orchid.	I	Yes (II)		*ITS2*	387	387	0.66	4.00E-103	0.9072	*Cymbidium goeringii*	a*	
							matK	1293	1293	0.99	0	0.9889	*Cymbidium longibracteatum*	a*	
38	*Dendrobium crumenatum*	Sw.	Orchid.	N	Yes (P, II)		*ITS2*	577	577	0.7	2.00E-160	0.9968	*Dendrobium crumenatum*	c	
							matK	1400	1400	0.99	0	0.9961	*Dendrobium crumenatum*	c	
							rbcL	1038	1038	0.97	0	0.9982	*Dendrobium pseudotenellum*	a*	
39	*Dendrobium purpureum*	Roxb.	Orchid.	N	Yes (P, E, II)		*ITS2*	481	537	0.86	2.00E-131	0.9005	*Dendrobium calcaratum*	a*	
							matK	1360	1360	1	0	0.9947	*Dendrobium faciferum*	a*	
						1547	*rbcL*	1042	1042	0.98	0	0.9965	*Dendrobium aggregatum*	a*	
							trnL	562	998	0.98	8.00E-156	0.9814	*Dendrobium chrysanthum*	a*	
40	*Dendrobium salaccense*	(Blume) Lindl.	Orchid.	N	Yes (P, II)		*ITS2*	627	627	0.79	2.00E-175	0.9914	Dendrobium haemoglossum	a*	
							matK	1382	1382	0.99	0	0.9987	*Dendrobium salaccense*	c	
							rbcL	1031	1031	1	0	1	*Dendrobium salaccense*	c	2/3 is a*
							trnL	1328	1328	0.81	0	0.9959	*Dendrobium salaccense*	c	

							ITS2	809	38152	1	0	1	*Raphanus raphanistrum* subsp. *landra*	i	
41	*Grammatophyllum speciosum*	Blume	Orchid.	N	Yes (P, II)	13	*matK*	1378	1378	0.99	0	0.996	*Grammatophyllum papuanum*	a*	
							rbcL	1037	1037	0.97	0	0.9947	*Cymbidium faberi*	a**	
							trnL	568	1103	0.93	2.00E-157	0.9905	*Cymbidium serratum*	a**	
							ITS2	828	828	1	0	1	*Cucumis sativus*	i	
42	*Nervilia concolor*	(Blume) Schltr.	Orchid.	N	Yes (P, II)		*rbcL*	1062	1062	0.99	0	1	*Nepenthes mirabilis*	i	
							trnL	1585	1585	1	0	0.9834	*Nervilia mekongensis*	a*	
						77	*ITS2*	721	721	0.88	0	0.9741	*Syzygium megacarpum*	i	
							matK	1413	1413	0.97	0	0.9987	*Nervilia plicata*	c	
43	*Nervilia plicata*	(Andrews) Schltr.	Orchid.	N	Yes (P, II)		*rbcL*	1005	1005	0.94	0	1	*Nervilia plicata*	c	1/4 is a* with higher coverage
							trnL	1663	1663	0.99	0	0.9967	*Nervilia plicata*	c	
							ITS2	398	398	0.88	1.00E-106	0.8765	*Oberonia caulescens*	a*	
44	*Oberonia lycopodioides*	(J.Koenig) Ormerod	Orchid.	N	Yes (P, II)	305	*matK*	1205	1205	0.93	0	0.9732	*Oberonia mucronata*	a*	
							rbcL	922	922	1	0	0.9921	*Ancistrochilus* sp.	a**	
							trnL	592	1078	0.91	2.00E-164	0.8734	*Liparis loeselii*	a**	
							ITS2	431	431	0.59	2.00E-116	0.959	*Mycaranthes pannea*	c	
45	*Strongyleria pannea*	(Lindl.) Schuit., Y.P.Ng & H.A.Pedersen	Orchid.	N	Yes (P, II)	4	*matK*	1375	1375	1	0	0.996	*Mycaranthes pannea*	c	
							rbcL	1055	1055	1	0	0.9965	*Mycaranthes pannea*	c	
							ITS2	433	433	0.99	4.00E-117	0.8552	*Populus nigra*	i	
46	*Galearia filiformis*	(Blume) Boerl.	Pand.	N	Yes (E)	5	*matK*	1393	1393	1	0	1	*Galearia filiformis*	c	
							rbcL	1042	1042	0.98	0	1	*Galearia filiformis*	c	
							trnL	1744	1744	1	0	0.9969	*Galearia filiformis*	c	
47	*Benstonea affinis*	(Kurz) Callm. & Buerki	Pandan.	N	No	61	*ITS2*	124	124	0.24	6.00E-24	0.8611	*Magnolia henryi*	i	

							matK	1397	1397	0.91	0	0.9935	*Pandanus oblatus*	a*	
							rbcL	1057	1057	1	0	1	*Pandanus adinobotrys*	a*	
							trnL	1705	1705	1	0	0.9989	*Pandanus baptistii*	a*	
48	*Phyllanthus oxyphyllus*	Miq.	Phyllanth.	N	No	1016	*ITS2*	621	621	0.74	9.00E-174	0.9971	*Phyllanthus oxyphyllus*	c	1/2 is a* with higher coverage
							matK	1375	1375	1	0	0.9973	*Phyllanthus oxyphyllus*	c	
							rbcL	1059	1059	1	0	1	*Phyllanthus emblica*	a*	
							trnL	989	989	0.58	0	0.9945	*Phyllanthus emblica*	a*	
49	*Ardisia complanata*	Wall.	Primul.	N	No		*ITS2*	667	667	0.78	0	0.9973	*Ardisia dasyrhizomatica*	a*	
							matK	1574	1574	1	0	0.9931	*Ardisia mamillata*	a*	
							rbcL	1031	1031	0.99	0	0.9965	*Ardisia crenata*	a*	
							trnL	1483	1483	1	0	0.9951	*Ardisia dasyrhizomatica*	a*	
50	*Ardisia crenata*	Sims	Primul.	I	No	719	*ITS2*	617	617	0.74	1.00E-172	0.997	*Ardisia villosa*	a*	
							matK	1404	1404	0.88	0	0.9987	*Ardisia crenata*	c	
							rbcL	1048	1048	1	0	1	*Ardisia cornudentata* subsp. *morrisonensis*	c	1/2 is a*
							trnL	1476	1476	0.99	0	0.9988	*Ardisia affinis*	a*	
51	*Ventilago madraspatana*	Boerl.	Rhamn.	N	No	41	*ITS2*	206	316	0.45	1.00E-48	0.9444	*Hibiscus panduriformis*	i	
							matK	1347	1347	0.96	0	0.9973	*Ventilago leiocarpa*	a*	
							rbcL	1022	1022	0.96	0	0.9947	*Ventilago leiocarpa*	a*	
							trnL	1574	1574	1	0	0.9722	*Ventilago kurzii*	a*	
52	*Psychotria montana*	Blume	Rubi.	N	No	1531	*ITS2*	398	398	1	8.00E-107	0.9744	*Psychotria camerunensis*	a*	
							matK	1376	1376	0.99	0	0.996	*Psychotria asiatica*	a*	
							rbcL	1029	1029	0.96	0	1	*Psychotria adenophylla*	a*	
							trnL	1504	1504	0.96	0	0.9826	*Psychotria asiatica*	a*	
53	*Lunasia amara*	Blanco	Rut.	N	Yes (P)	1	*ITS2*	579	579	0.74	6.00E-161	0.9654	*Lunasia amara*	c	

							matK	1243	1243	0.88	0	0.9971	*Lunasia amara*	c
							rbcL	1026	1026	0.97	0	0.9947	*Flindersia brayleyana*	a**
							trnL	1668	1668	0.95	0	0.9946	*Lunasia amara*	c
							ITS2	787	787	1	0	0.9823	*Melicope pteleifolia*	a*
54	*Melicope lunu-ankenda*	(Gaertn.) T.G. Hartley	Rut.	N	No	241	*matK*	1408	1408	1	0	0.9987	*Melicope pteleifolia*	a*
							rbcL	1031	1031	0.98	0	0.9965	*Melicope pteleifolia*	a*
							trnL	1168	1168	1	0	0.9953	*Melicope grisea*	a*
							ITS2	558	558	0.69	7.00E-155	0.9967	*Kadsura scandens*	c
55	*Kadsura scandens*	(Blume) Blume	Schisandr.	N	Yes (P)	17	*matK*	1376	1376	1	0	0.9947	*Kadsura philippinensis*	a*
							rbcL	1050	1050	0.99	0	1	*Kadsura cf.*	a*
							trnL	1635	1635	0.99	0	0.986	*Kadsura matsudae*	a*
56	*Smilax calophylla*	Wall. ex A.DC.	Smilac.	N	No		*ITS2*	821	821	1	0	0.9933	*Phaseolus vulgaris*	I
							rbcL	1048	1048	0.98	0	0.9982	*Smilax cocculoides*	a*
						262	*ITS2*	274	274	0.35	3.00E-69	0.9809	*Acer tataricum* subsp. *theiferum*	i
57	*Smilax zeylanica*	L.	Smilac.	N	Yes (P)		*matK*	1371	1371	1	0	1	*Smilax ovalifolia*	a*
							rbcL	1044	1044	0.98	0	1	*Smilax ocreata*	a*
							ITS2	702	702	0.82	0	0.9948	*Aquilaria microcarpa*	a*
58	*Aquilaria hirta*	Ridl.	Thymelae.	N	Yes (P, Vu)	21	*matK*	1402	1402	1	0	0.9974	*Aquilaria malaccensis*	a*
							rbcL	1057	1057	0.99	0	1	*Rauvolfia serpentina*	c
							trnL	987	987	0.67	0	0.9945	*Aquilaria microcarpa*	a*
							ITS2	616	616	0.79	4.00E-172	0.9884	*Sundamomum hastilabium*	a**
59	*Amomum hochreutineri*	Valeton	Zingiber.	N	Yes (E)	102	*rbcL*	1044	1044	0.98	0	1	*Amomum villosum* var. *xanthioides*	a*
							trnL	1568	1568	0.98	0	0.9931	*Amomum fulviceps*	a*
60	*Etlingera solaris*	(Blume) R.M.Sm.	Zingiber.	N	Yes (E, Vu)	143	*ITS2*	656	656	0.89	0	0.9764	*Hornstedtia conica*	a**
							rbcL	1053	1053	0.99	0	1	*Alpinia arundelliana*	a**

							trnL	1622	1622	0.99	0	0.9955	*Etlingera yunnanensis*	a**
61	*Meistera aculeata*	(Roxb.) Skornick. & M.F. Newman	Zingiber.	N	No	41	*ITS2*	592	592	0.72	7.00E-165	1	*Amomum aculeatum*	c
							rbcL	1020	1020	0.96	0	1	*Amomum dallachyi*	a*

Note: Result summary: c=correct, a*: ambiguous or correct in genus level, a**: ambiguous or correct in family level, i=incorrect; Important Species: P for priority (see chapter 2), E for Endemic, Vu for Vulnerable (IUCN Red list), and II for CITES Appendix II; N/I N=Native, I=Introduced

Table Appendix 5.2. Summary DNA Barcoding Region Use for MP Conservation in Indonesia

DNA Barcoding Use for MP Conservation in Indonesia	*ITS2*	*matK*	*rbcL*	*trnL*
new DNA barcoding and can strongly assist MP conservation	1	1	2	1
Anaxagorea javanica				1
Aquilaria hirta			1	
Strongyleria pannea	1	1	1	
can strongly assist MP conservation	11	12	8	6
Alstonia scholaris	1	1	1	1
Alyxia reinwardtii	1	1	1	
Cymbidium aloifolium	1	1	1	
Dendrobium crumenatum	1	1		
Dendrobium salaccense		1	1	1
Euphorbia tirucalli	1			
Ficus deltoidea	1			
Galearia filiformis		1	1	1
Kadsura scandens	1			
Lunasia amara	1	1		1
Nepenthes gracilis		1		
Nepenthes reinwardtiana	1	1		
Nervilia plicata		1	1	1
Pangium edule		1	1	
Parkia timoriana	1			
Rauvolfia serpentina	1	1	1	1
new DNA barcoding and can assist MP conservation	1		1	
Aglaonema commutatum			1	
Meistera aculeata	1			
can assist MP conservation	5	6	7	3
Alstonia macrophylla		1	1	
Ancistrocladus tectorius	1		1	1

Ardisia crenata		1	1	
Dasymaschalon dasymaschalum			1	
Justicia gendarussa	1	1	1	1
Orthosiphon aristatus	1			
Phyllanthus oxyphyllus	1	1		
Premna serratifolia			1	
Toxicodendron succedaneum	1	1	1	1
Vitex glabrata		1		
new to DNA bank data and new DNA barcoding and may strongly assist MP conservation	6	4	6	7
Amomum hochreutineri	1		1	1
Dendrobium purpureum	1	1	1	1
Etlingera solaris	1		1	1
Myristica succedanea		1	1	1
Oberonia lycopodioides	1	1	1	1
Phanera fulva	1			1
Rhododendron macgregoriae	1	1	1	1
new DNA barcoding and may strongly assist MP conservation	2	3	2	2
Acriopsis liliifolia var. liliifolia	1	1	1	1
Anaxagorea javanica		1	1	
Aquilaria hirta	1	1		1
may strongly assist MP conservation	3	8	12	12
Alyxia reinwardtii				1
Cibotium barometz			1	
Cymbidium aloifolium				1
Cymbidium ensifolium	1	1		
Dendrobium crumenatum			1	
Dendrobium salaccense	1			
Euphorbia tirucalli			1	
Ficus deltoidea		1	1	1

Grammatophyllum speciosum		1	1	1
Kadsura scandens		1	1	1
Lunasia amara			1	
Nepenthes ampullaria		1	1	1
Nepenthes gracilis			1	1
Nepenthes mirabilis	1	1	1	1
Nepenthes reinwardtiana			1	1
Nervilia concolor				1
Pangium edule				1
Parkia timoriana		1		1
Smilax zeylanica		1	1	
new to DNA bank data and new DNA barcoding and may assist MP conservation	2	2	3	3
Acalypha grandis			1	1
Ardisia complanata	1	1	1	1
Erycibe malaccensis	1	1	1	1
new DNA barcoding and may assist MP conservation	4	6	7	6
Aglaonema commutatum		1		1
Cinnamomum rhynchophyllum		1	1	1
Decalobanthus mammosus			1	
Hoya diversifolia	1	1	1	1
Meistera aculeata			1	
Melicope lunu-ankenda	1	1	1	1
Psychotria montana	1	1	1	1
Spondias malayana	1			
Ventilago madraspatana		1	1	1
may assist MP conservation	7	6	8	9
Alstonia macrophylla	1			1
Ancistrocladus tectorius		1		
Ardisia crenata	1			1

Benstonea affinis		1	1	1
Dasymaschalon dasymaschalum		1		1
Millettia sericea	1	1	1	1
Orthosiphon aristatus			1	
Phyllanthus oxyphyllus			1	1
Premna serratifolia	1			
Smilax calophylla			1	
Staurogyne elongata	1	1	1	1
Trevesia burckii	1	1	1	1
Vitex glabrata	1		1	1
new to DNA bank data and new DNA barcoding, but sequences need to clarify further	2		1	
Acalypha grandis	1			
Myristica succedanea	1			
Phanera fulva			1	
new DNA barcoding, but sequences need to clarify further	2			
Aglaonema commutatum	1			
Ventilago madraspatana	1			
sequences need to clarify further	10		2	
Benstonea affinis	1			
Cibotium barometz	1			
Dasymaschalon dasymaschalum	1			
Galearia filiformis	1			
Grammatophyllum speciosum	1			
Nervilia concolor	1		1	
Nervilia plicata	1			
Pangium edule	1			
Parkia timoriana			1	
Smilax calophylla	1			
Smilax zeylanica	1			