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Habitat preferences of wild orchids in Bantimurung Bulusaraung National Park to model their suitable habitat in South Sulawesi, Indonesia

EKA MARTHA DELLA RAHAYU[1,♥], SAFRAN YUSRI[2]
[1]Research Center for Plant Conservation and Botanic Gardens (Bogor Botanic Gardens), National Agency for Research and Innovation. Jl. Ir. H. Djuanda No. 13, Bogor, 16022, West Java, Indonesia. Tel.: +62-251-8311362, ♥email: emdrahayu@gmail.com
[2]Terangi Foundation. Jl. Asyibaniah No. 106, Cipayung, Depok 16438, West Java, Indonesia

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Abstract. *Rahayu EMD, Yusri S. 2021. Habitat preferences of wild orchids in Bantimurung Bulusaraung National Park to model their suitable habitat in South Sulawesi, Indonesia. Biodiversitas 23: 43-54.* Wild orchids are mainly threatened by habitat degradation and over-exploitation. Orchid conservation requires information regarding its distribution and suitable habitat, and factors affecting it. This study aimed to investigate the distribution and habitat preferences of orchids in Bantimurung Bulusaraung National Park, Sulawesi, Indonesia, and to predict the habitat suitability map of orchids in South Sulawesi, Indonesia. The survey was conducted in Bantimurung Bulusaraung National Park to collect data on orchid occurrences along with microhabitat characteristics (altitude, light, temperature, substrate thickness, and vertical distribution). ERGo Datasets Landforms and Physiography, SRTM elevation, NDVI derived from LANDSAT 8 OLI were used in Google Earth Engine to obtain macrohabitat data. Microhabitat preference of environmental data was averaged for each variable and further explored with Canonical Correlation Analysis. Suitable habitat was modeled with Maxent using occurrences and environmental data. The survey found 26 epiphytic orchid species and 22 phorophyte species. Orchids were found at an altitude from 514 m to 933 m above sea level. Altitude is the most discriminant factor in determining orchids' distribution in the study area. The Maxent analysis showed that the suitable habitat of orchids comprises of 3,554.952 km^2 area which is mainly located in lowland rainforest with high topographic diversity, preferably warm slope, and ridges. Since lower slope and lowland areas are not protected, community-based conservation such as social forestry can become one of the alternative solutions for in situ conservation of orchids. For ex-situ conservation, integrated orchid conservation in botanic gardens should be prioritized.

Keywords: Conservation, habitat preferences, Orchidaceae, species distribution model

INTRODUCTION

The orchid family (Orchidaceae) is considered one of the most diverse taxa of flowering plants. Christenhusz and Byng (2016) estimated that the family has 736 genera and 28,000 species. The Global Biodiversity Information Facility so far has recorded 35,827 species and 4,430,528 occurrence records (GBIF 2021). The high diversity of orchids means that they have adapted to almost all climate conditions except in extreme environments, such as desert, arid and freezing regions. Orchids can be terrestrial, epiphytic, myco-heterotrophic, and lithophytic (Zhang et al. 2018). Orchids are particularly abundant in the wet tropics particularly in Southeast Asia.

Indonesia is known as the center of orchid diversity globally, with an estimation of more than 4,000 orchid species (Handoyo 2010). According to Thomas and Schuiteman (2002), there are 548 species of orchids in Sulawesi. Most orchids are cosmopolitan but there are few endemics, such as *Coelogyne celebensis* J.J.Sm., *Vanda aurea* (J.J. Sm.) L.M. Gardiner, *Dendrobium pseudoconanthum* J.J. Sm., *Paphiopedilum gigantifolium* Braem, M.L. Baker & C.O. Baker, *Paphiopedilum sangii* Braem, *Phalaenopsis celebensis* H.R. Sweet, *Phalaenopsis venosa* Shim & Fowlie, *Vanda devoogtii* J.J. Sm., and *Vanda jennae* P. O'Byrne & J.J. Verm., which can only be found in Sulawesi (GBIF 2021; POWO 2021).

Orchids are recognized as important ornamental plant commodities with an average trade value of cuts and buds (cut flowers and budding flowers) of US$ 483 million from 2007-2012 globally (De et al. 2014). Aside from being traded as ornamental plants, orchids are also utilized for medicinal, cosmetics and pharmaceuticals, and food purposes (Hinsley et al. 2018). Because of its high economic value, the population of many orchid species is pressured due to over-exploitation especially due to illegal collection in the wild for horticulture, food, or medicine. This, along with habitat destruction, intrinsic biological factors (symbiont requirements, complex reproduction mechanisms) and climate change, has threatened several orchids to extinction (Budiharta et al. 2011; Fay 2018). Social media analysis by Hinsley et al. (2018) shows that out of all posts containing plants for sale, 22-46% of these posts pertained to wild orchids. Harvesting orchids from the wild have been known to affect the decline of populations of native orchid in South China and the trade is considered to be unsustainable (Gale et al. 2019; Li et al. 2018).

The tropical forest, the main habitat for these species, is deforested at an alarming rate. Indonesia, for example, has lost 27.7 Mha of tree cover from 2001 to 2020 and released

19.0Gt of CO_2 emissions, with the top contributors being Riau, West Kalimantan, Central Kalimantan, East Kalimantan, and South Sumatera provinces (Hansen et al. 2013; Global Forest Watch 2021a). In Sulawesi, forest cover declined in the period of 1990-2018 with the largest forest cover loss was in North Sulawesi (23.29%) and the smallest occurred in South Sulawesi (13.57%) (Rijal et al. 2019a). Forest degradation makes orchids vulnerable to habitat fragmentation and modification (Jalal and Singh 201; Reina-Rodriguez et al. 2017). Therefore, in order to conserve these species, the identification of suitable habitat is necessary for prioritizing areas for habitat protection and reintroduction.

While small-scale microhabitat conditions can be recorded from field surveys, mapping the potential habitat for a species requires landscape-scale analysis. In doing so, there is increasing attention and knowledge on ecological niche modeling or species distribution modeling to map potentially suitable habitats of a particular species using a specific algorithm and species occurrence data. Maximum Entropy (Maxent) is the most used algorithm because it outperforms other presence-only modeling software and uses a small sample size (Deb et al. 2017). Maxent also produces outputs in the form of curves that predict species response toward a particular environmental variable (Phillips 2017). This study aimed to investigate the distribution and habitat preferences of orchids in Bantimurung Bulusaraung National Park, Sulawesi, Indonesia, and to predict habitat suitability map of orchids in South Sulawesi, Indonesia using Maxent.

MATERIALS AND METHODS

Study site and period

Species occurrences data was collected from September 26th to October 15th, 2017, in Balocci Resort, Bantimurung Bulusaraung National Park (BBNP) and its surrounding areas. The study area was mainly low land primary and secondary forest, with elevation ranging from 144-1600 m above sea level. Orchid occurrences and microhabitat variables were observed and recorded. The extent of the research is shown in Figure 1 and is not limited to BBNP administrative boundaries in order to avoid range constrictions and under prediction (Raes 2012).

Data collection and analysis of orchid microhabitat

Orchid occurrences were recorded along the track during the survey. Phorophytes (host plants) were observed carefully from the ground to make sure that no orchids were overlooked. The number of orchids and the phorophytes were recorded and living samples were collected and kept in Jompie Parepare Botanic Gardens and Bogor Botanic Gardens. Wild orchids were identified to the highest taxonomic rank possible using Comber (1990), Comber (2001), O'Byrne (2001), Handoyo (2010), and Handoyo and Prasetya (2012). The accepted name of orchid species referred to Plant of the World Online (POWO 2021). The geographic coordinates of each sample were recorded with a GNSS unit. Microhabitat characteristics, such as altitude, light, temperature, and substrate thickness were also recorded three times for each occurrence using corresponding measuring devices (altimeter, lux meter, thermometer). Vertical distribution of epiphytic orchids was recorded according to the zone division by Johansson (1974) (Figure 2).

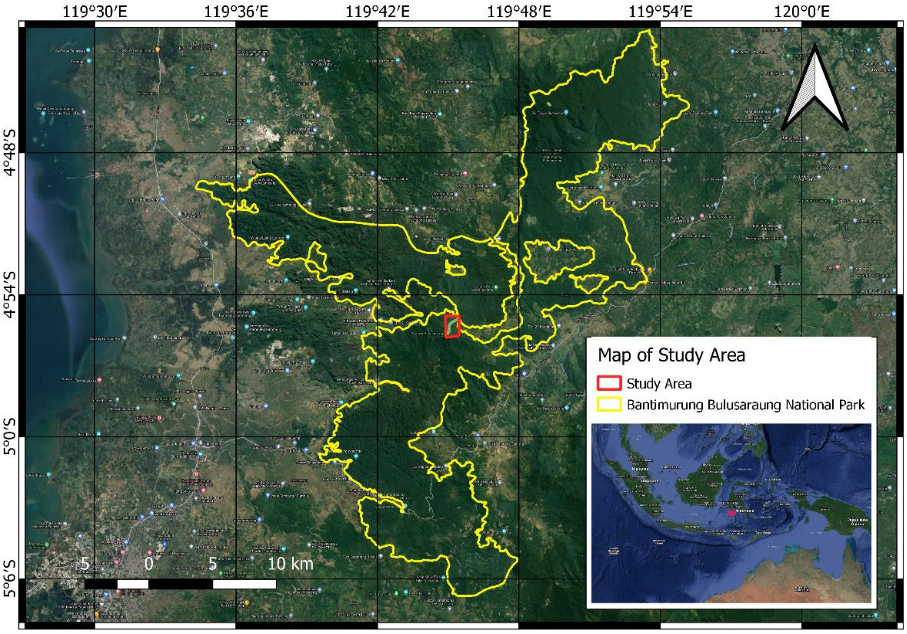

Figure 1. Map of research location in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia. Note that the long track is the wide line (green line) inside the study area (red box).

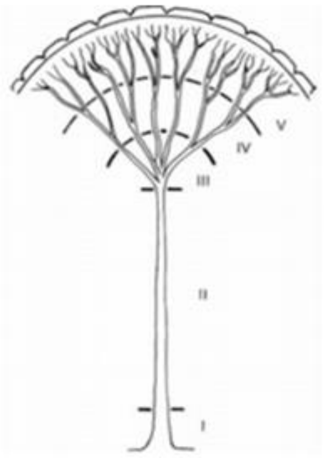

Figure 2. Division of the phorophyte according to Johansson (1974). Zone 1 is the bottom part (1/3) of the main stem, Zone 2 the upper part (2/3) of the main stem, Zone 3 is the bottom part of the branches, Zone 4 is the middle part of the branches, while Zone 5 is the outer part of the branches

Orchid and phorophytes diversity was explored through phorophytes relative frequency (%Ft), orchid relative abundance (%Fo), number of each phorophyte species, number of orchid species, amount of orchid plant, average of orchid species on each phorophyte species, average number of orchids on each phorophyte species as proposed by Yulia and Budiharta (2011).

Microhabitat preference of environmental data on each phorophyte was averaged for each variable and further explored with Canonical Correlation Analysis (CCA). Vertical distribution of epiphytic orchids on the phorophyte species was determined by mapping the vertical distribution of each epiphytic orchid species on the phorophyte, from the trunk to outer branches in five zones (zone 1, zone 2, zone 3, zone 4 and zone 5) and by calculating the average number of individuals of epiphytic orchids in each zone.

Data collection and analysis of habitat suitability model of orchids

Macrohabitat data with 30 m spatial resolution were obtained from Google Earth Engine (GEE) using the script for environmental data extraction from GEE by Yusri (2019). GEE is a cloud platform for planetary-scale geospatial analysis and visualization with a petabyte of recent and historical global data archives (Gorelick et al. 2017). Ecologically Relevant Geomorphology (ERGo) Datasets Landforms and Physiography (Topographic Diversity, CHILI/Continuous Heat-Insolation Load Index, Landforms), The Shuttle Radar Topography Mission (SRTM elevation), Normalized Difference Vegetation Index (NDVI) derived from LANDSAT 8 OLI were used and exported to GeoTiff (Theobald et al. 2015). Topographic diversity represents the variety and moisture conditions available (Theobald et al. 2015). The elevation dataset was obtained from SRTM digital elevation model.

SRTM mTPI (Multi-Scale Topographic Position Index) represents the relative position of a location compared to its surroundings derived from SRTM elevation. Therefore it will distinguish ridge from valley forms, the value ranges from negative (valleys) to positive (ridges) (Theobald et al. 2015). Slope (gradient) was calculated as the degree of elevation changes using modified Calculating Hillshade Script (GEE Developer 2018a). Landforms dataset is SRTM-derived landform classes, that include 15 classes, which are: peak/ridge (warm), peak/ridge, peak/ridge (cool), mountain/divide, cliff, upper slope (warm), upper slope, upper slope (cool), upper slope (flat), lower slope (warm), lower slope, lower slope (cool), lower slope (flat), valley, valley (narrow) (Theobald et al. 2015). An image collection of LANDSAT 8 OLI Surface Reflectance was collated using a spatial filter of the study site, and a temporal filter from January 1st, 2017 to December 31st, 2017. A cloud-free mosaic composite was created based on the script by GEE Developer (2018b). Normalized Difference Vegetation Index (NDVI) was then calculated using the following formula:

$$NDVI = (NIR - R) / (NIR + R) \text{ ... (Rouse et al. 1974)}$$

CHILI (Continuous Heat-Insolation Load Index) represents the effects of insolation and topographic shading on evapotranspiration, which ranges from 0 (very cool) to 255 (very warm) (Theobald et al. 2015). All environmental variables were exported with the same projection, 30 m pixel resolution, and spatial extent using QGIS. Using R, all rasters in TIFF format were converted to ASC.

Orchid occurrences and environmental data were used as the input for Maxent version 3.4.1 (https://biodiversityinformatics.amnh.org/open_source/maxent/) to suitable model habitat of orchid species in BBNP and its surrounding areas (Phillips 2017). Default model parameters were used (a convergent threshold of 10-5, maximum iteration value of 500, and a regularization multiplier of 1) (Phillips and Dudik 2008). The threshold feature used was 10 percentile training presence. Models were run with three-fold cross-validation (Merow et al. 2013). The model evaluation was based on the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) (Phillips et al. 2017). The importance estimates of each data layer will be based on jackknife analysis and contributions towards model gain (Phillips 2017).

RESULTS AND DISCUSSION

Orchid diversity and microhabitat characteristics

There were 26 epiphytic orchid species and 22 phorophyte species (Table 1 and Table 3) in the surveyed area. The number of phorophyte species each hosting epiphytic orchid varied from 1-11 phorophyte species (Table 1). Some epiphytic orchid species occurred on a single phorophyte species, such as *Dendrobium crumenatum* Sw., *Flickingeria* sp., and *Liparis viridiflora* (Blume) Lindl. Other epiphytic orchid species occurred on multiple phorophyte species, such as *Pholidota imbricata* Hook. which grew on eleven phorophyte species, namely *Aleurites moluccanus* (L.) Willd., *Alstonia scholaris* (L.) R.Br., *Alstonia* sp., *Artocarpus integer* (Thunb.) Merr., *Dendrocnide* *stimulans* (L.f.) Chew, *Ficus benjamina* L., *Ficus* sp., *Knema* sp., *Mangifera indica* L., *Magnolia montana* (Blume) Figlar, and *Willughbeia coriacea* Wall. (Table 1). While *C. celebensis* was hosted by 7 phorophytes species, which are *A. moluccanus*, *Alstonia* sp., *A. integer*, *F. benjamina*, *Ficus* sp., *M. indica*, and *M. montana* (Table 1).

Table 1. Orchid and phorophytes species found at the surveyed area in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia

Code	Epiphytic orchids	No. of phorophyte species	Phorophyte species	Nt	No	%Ft	%Fo
X1	*Aerides leeana* Rchb.f.	4	*Gymnoscanthera* sp., *Mangifera indica* L., *Magnolia montana* (Blume) Figlar, *Saurauia* sp.	4	6	6.45%	1.78%
X2	*Aerides odorata* Lour.	6	*Alstonia scholaris* (L.) R.Br., *Dillenia* sp., *Ficus* sp., *Glochidion* sp., *Mangifera indica* L., *Magnolia montana* (Blume) Figlar	6	24	9.68%	7.10%
X3	*Bulbophyllum* sp.	2	*Dendrocnide stimulans* (L.f.) Chew, *Magnolia montana* (Blume) Figlar	2	5	3.23%	1.48%
X4	*Coelogyne celebensis* J.J.Sm.	7	*Aleurites moluccanus* (L.) Willd., *Alstonia* sp., *Artocarpus integer* (Thunb.) Merr., *Ficus benjamina* L., *Ficus* sp., *Mangifera indica* L., *Magnolia montana* (Blume) Figlar	7	13	11.29%	3.85%
X5	*Cymbidium finlaysonianum* Lindl.	4	*Dendrocnide stimulans* (L.f.) Chew, *Ficus* sp., *Mangifera indica* L., *Myristica elliptica* Wall. ex Hook.f. & Thomson	4	12	6.45%	3.55%
X6	*Dendrobium crumenatum* Sw.	1	*Alstonia scholaris* (L.) R.Br.	1	2	1.61%	0.59%
X7	*Dendrobium rantii* J.J.Sm.	5	*Aleurites moluccanus* (L.) Willd., *Alstonia scholaris* (L.) R.Br., *Alstonia* sp., *Ficus benjamina* L., *Litsea* sp.	5	8	8.06%	2.37%
X8	*Dendrobium sphenochilum* F.Muell. & Kraenzl.	2	*Ficus* sp., *Magnolia montana* (Blume) Figlar	2	3	3.23%	0.89%
X9	*Eria* sp.	2	*Ficus benjamina* L., *Magnolia montana* (Blume) Figlar	2	11	3.23%	3.25%
X10	*Flickingeria* sp.	1	*Ficus* sp.	1	1	1.61%	0.30%
X11	*Liparis condylobulbon* Rchb.f.	3	*Ficus benjamina* L., *Ficus* sp., *Saurauia* sp.	3	20	4.84%	5.92%
X12	*Liparis viridiflora* (Blume) Lindl.	1	*Biscophia* sp.	1	2	1.61%	0.59%
X13	*Luisia* sp.	2	*Alstonia scholaris* (L.) R.Br., *Magnolia montana* (Blume) Figlar	2	6	3.23%	1.78%
X14	*Luisia teretifolia* Gaudich.	2	*Alstonia scholaris* (L.) R.Br., *Artocarpus integer* (Thunb.) Merr.	2	5	3.23%	1.48%
X15	*Malleola* sp.	1	*Biscophia* sp.,	1	1	1.61%	0.30%
X16	*Oberonia costeriana* J.J.Sm.	6	*Alstonia* sp., *Artocarpus integer* (Thunb.) Merr., *Biscophia* sp., *Ficus* sp., *Magnolia montana* (Blume) Figlar, *Saurauia* sp.	6	99	9.68%	29.29 %
X17	*Phalaenopsis amabilis* (L.) Blume	1	*Myristica elliptica* Wall. ex Hook.f. & Thomson	1	2	1.61%	0.59%
X18	*Pholidota imbricata* Hook.	11	*Aleurites moluccanus* (L.) Willd., *Alstonia scholaris* (L.) R.Br., *Alstonia* sp., *Artocarpus integer* (Thunb.) Merr., *Dendrocnide stimulans* (L.f.) Chew, *Ficus benjamina* L., *Ficus* sp., *Knema* sp., *Mangifera indica* L., *Magnolia montana* (Blume) Figlar, *Willughbeia coriacea* Wall.	11	62	17.74%	18.34 %
X19	*Pholidota* sp.	1	*Dendrocnide stimulans* (L.f.) Chew ,	1	1	1.61%	0.30%
X20	*Pinalia moluccana* (Schltr. & J.J.Sm.) Schuit., Y.P.Ng & H.A.Pedersen	2	*Ficus* sp., *Magnolia montana* (Blume) Figlar	2	9	3.23%	2.66%
X21	*Pomatocalpa diffusum* Breda	1	*Ficus benjamina* L.	1	14	1.61%	4.14%
X22	*Pteroceras* sp.	3	*Ficus* sp., *Meliosma* sp., *Saurauia* sp.,	3	12	4.84%	3.55%
X23	*Robiquetia* sp.	1	*Ficus* sp.	1	1	1.61%	0.30%
X24	*Trichoglottis geminata* (Teijsm. & Binn.) J.J.Sm.	1	*Pterocarpus indicus* Willd.	1	1	1.61%	0.30%
X25	*Trichoglottis* sp.	7	*Alstonia* sp., *Ficus* sp., *Glochidion* sp., *Lagerstromia* sp., *Mangifera indica* L., *Myristica* sp., *Saurauia* sp.	7	8	11.29%	2.37%
X26	*Vanda miniata* (Lindl.) L.M.Gardiner	2	*Ficus* sp., *Glochidion* sp.,	2	10	3.23%	2.96%

Notes: Nt: number of phorophytes for each orchid species; No: number of plants for each orchid species; %Ft: phorophytes relative frequency; %Fo: relative abundance for each orchid species

Table 2. Environmental parameters were recorded on each orchid occurrence at the surveyed area in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia

Parameter	Min	Mean	Standard Deviation	Max
Altitude (m)	514	774.59	145.38	933
Light (lux)	322	3498.44	2078.66	9800
Humidity (%)	49.4	64.30	6.24	83.5
Temperature (°C)	25.4	29.98	1.97	33.2

Table 3. Phorophyte species were found at the surveyed area in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia

Phorophyte species	Jt	Js	Ji	Js/Jt	Ji/Jt
Aleurites moluccanus	2	3	3	1.5	1.5
Alstonia scholaris	5	6	25	1.2	5
Alstonia sp.	4	5	42	1.25	10.5
Artocarpus integer	1	4	19	4	19
Biscophia sp.	2	3	5	1.5	2.5
Dendrocnide stimulans	3	4	7	1.33	2.33
Dillenia sp.	1	1	3	1	3
Ficus benjamina L.	3	6	23	2	7.67
Ficus sp.	11	13	93	1.18	8.45
Glochidion sp.	1	3	7	3	7
Gymnoscanthera sp.	1	1	1	1	1
Knema sp.	1	1	1	1	1
Lagerstromia sp.	1	1	1	1	1
Litsea sp.	1	1	1	1	1
Magnolia montana	5	10	46	2	9.2
Mangifera indica	4	6	15	1.5	3.75
Meliosma sp.	2	1	9	0.5	4.5
Myristica elliptica	1	2	3	2	3
Myristica sp.	1	1	1	1	1
Pterocarpus indicus	1	1	1	1	1
Saurauia sp.	10	5	30	0.5	3
Willughbeia coriacea	1	1	2	1	2

Notes: Jt: number of each phorophyte species, Js: number of orchid species, Ji: amount of orchid plant, Js/Jt: average of orchid species on each phorophyte species, Ji/Jt: average number of epiphytic orchid on each phorophyte species

The results of this study were similar to other studies showed that the number of phorophyte species where epiphytic orchids occur varied from a single to multiple phorophyte species (Nurfadilah, 2015; Hernández-Pérez et al. 2018). Nurfadilah (2015) reported that in Coban Trisula, Malang, Indonesia, *Appendicula elegans* Rchb.f occurred on one phorophyte species, while the orchid *Parapteroceras odoratissimum* (J.J.Sm.) J.J. Wood was found on 5 phorophyte species. In Southern Mountain of Mexico, Hernández-Pérez et al. (2018) also showed that, *Oncidium unguiculatum* Lindl. was only recorded on *Quercus laurina* Bonpl., whereas *Artorima erubescens* (Lindl.) Dressler & G.E. Pollard was found on 7 host species.

Oberonia costeriana J.J.Sm. is small to medium-sized, with acute leaves held in a fan and has many-flowered inflorescences (Figure 3.A). Nirwana et al. (2018) also found this species abundantly in Tompobulu Village (Balocci Resort, Bantimurung Bulusaraung National Park). The *Oberonia* genus has amongst the smallest flowers of orchids, from just about 1 mm to about 10 mm in maximum diameter (Geiger and Kocyan 2018). The wide dispersal ability of the species in this genus is likely due to the smallest seeds of any orchid. Therefore, significant wind dispersal is to be expected (Geiger 2019). *P. imbricata* is a sympodial orchid that has continuous lateral growth of the stems through rhizome, which is an effective vegetative reproduction to grow a large number of individuals. *P. imbricata* has flexuous rachis carrying up to 50 fragrant flowers (Bijmoer et al. 2021; Figure 3.B). A large number of *P. imbricata* flowers and seed increase the chance for the fruit set to produce large population. All of these characters support the high abundance of *P. imbricata* at the study site. One of the orchids, *C. celebensis* (Figure 3.C) has a high conservation value since it is endemic to Sulawesi (GBIF 2021; POWO 2021). Eight of orchid species (*Aerides leeana* Rchb.f., *Aerides odorata* Lour., *Vanda miniata* (Lindl.) L.M. Gardiner, *C. celebensis*, *Cymbidium finlaysonianum* Lindl., *Dendrobium rantii* J.J.Sm., *Phalaenopsis amabilis* (L.) Blume, and *P. imbricata* have high ornamental value.

Based on Table 2, orchids were found in altitude from 514 m to 933 m above sea level. They also prefer low to medium light intensity with a minimum of 322 lux to 9800, with an average of 3498.44 ± 2078.66 lux. Orchids also prefer high humidity areas, with relative humidity ranging from 49.4% to 83.5% with an average of 64.3 ± 6.24%. They also grew in warm areas with temperatures ranging from 25.4°C to 29.98°C, with a mean of 29.98 ± 1.97°C. Overall, orchids in the study area grew in areas where the condition is warm and humid, consistent with the findings of Timsina et al. (2016) and Kusumastuti et al. (2021).

Further relationships between orchid occurrences and environmental variables were explored using Canonical Correspondence Analysis (CCA) as presented in Figure 4. According to the result of CCA, there are at least three clusters of orchids (Figure 4). The first cluster indicated that the occurrence of some orchids is affected by humidity, including *Luisia teretifolia* (X14) and *Robiquetia* sp. (X23). While the other orchids are grouped within the second cluster whose distribution doesn't associate with any of the variables.

Ficus sp. and *M. montana* not only had a large individual number of epiphytic orchids, but also had the highest species richness of epiphytic orchids (Table 3). Thirteen orchid species had been recorded growing on the phorophyte *Ficus* sp., while 10 species of orchids were found on *M. montana*. Other phorophytes such as *Dillenia* sp., *Gymnoscanthera* sp., *Knema* sp., *Lagerstroemia* sp., *Litsea* sp., *Meliosma* sp., *Myristica* sp., *Pterocarpus* *indicus* Willd., and *Willughbeia coriacea* Wall. only hosted one orchid species. This is due to Sulawesi having 83 *Ficus* species with various forms of growth including hemiepiphytes (strangulation), large woody plants, climber, trees, and bushes (Yusuf 2011).

Ficus spp. found in the study location were tall trees which increase the surface area that also increase the possibility of holding epiphytes since host size (height and diameter) and branching architecture impact epiphytic orchid diversity (Zhao et al. 2015; Rasmussen and Rasmussen 2018; Hendrayana et al. 2021). *Magnolia montana* is also a medium to a tall tree that is common to lowland and lower montane forests throughout Sumatera, Peninsular Malaysia, Borneo, and Java (Tropical Plants Database 2021; MyBIS 2021). Aside from surface area, tall trees also provide various microhabitat conditions which can shelter various orchid species with different habitat preferences (Zhao et al. 2015; Hernández-Pérez et al. 2018; Zotarelli et al. 2019; Timsina et al. 2021). Both *Ficus* spp. and *M. montana* found in the study area had large diameter sizes. Therefore, they were considered as old trees, allowing them to accumulate orchids compared to smaller and younger trees (Adhikari et al. 2017; Ding et al. 2016; Huda and Wilcock 2011).

This study showed that epiphytic orchids could grow in all zones, from zone 1 to zone 5 (Table 4). Based on the result, zone 1 was the less preferred by orchids followed by zone 2 where only *O. costeriana* and *Pteroceras* sp. were found. On the other hand, zone 5 harbored the most orchids, followed by zone 3 and 4. This pattern was also found in Coban Trisula, East Java, Indonesia (Nurfadilah 2015); previous observation in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia (Rahayu and Utami 2019); Mount Togo, Togo (Sodjinou et al. 2019); and Bawean Island Nature Reserve, Indonesia (Trimanto and Danarto 2020).

Figure 3.A. *Oberonia costeriana* J.J.Sm., B. *Pholidota imbricata* Hook., C. *Coelogyne celebensis* J.J.Sm.

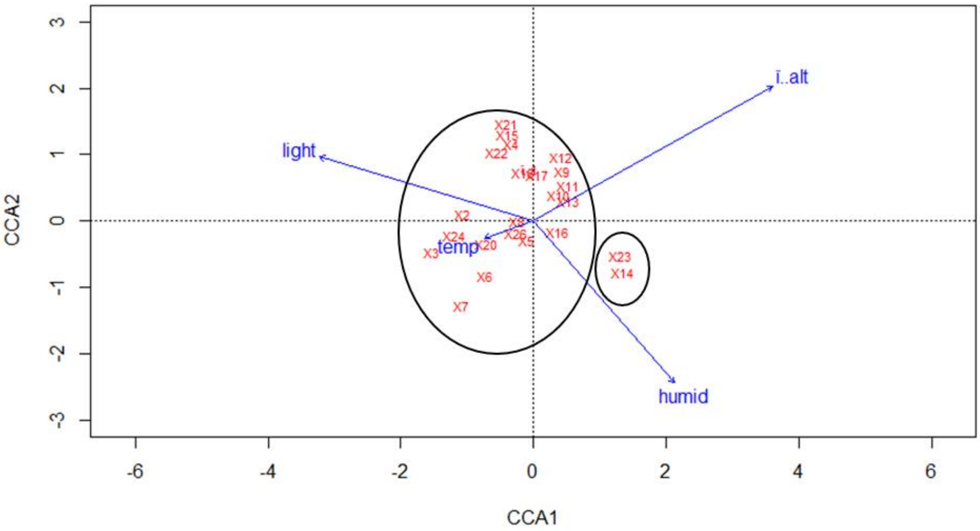

Figure 4. Canonical Correspondence Analysis (CCA) between orchid species and four factors (alt: Altitude, light: Light intensity, temp: Temperature, and humid: Humidity). The X1 to X26 represent the 26 species present in the study area as stated in Table 1.

The high diversity in mid-canopy area might be the result of large surface area, accumulation of substrates in the main fork site, and the intermediate levels of light and moisture (Zhao et al. 2015). The positioning of these epiphytic orchids on the phorophyte is conditioned by several factors such as temperature, luminous intensity, humidity, the thickness of the layer of the bryophytes, and slopes of the branches of the trees (Sodjinou et al. 2019). Zones 3, 4, and 5 are area that offers a wide variety of micro-habitats because the branches favor a humus deposit and moisture substrate that would promote the development of epiphytes (Sodjinou et al. 2019; Trimanto and Danarto 2020). Higher orchids density within said zones can also become the result of seed entrapment on the base of the main fork site and sufficient sunlight, humidity, water and nutrients (Hernández-Pérez et al. 2018; Rahayu and Utami 2019).

The most abundant orchid, *O. costeriana* was found to have the widest vertical distribution ranging from zone 1, 3, 4, and 5 (Table 4). Hiola et al. (2015) found that *O. costeriana* that grew at Resort Mallawa Taman Nasional Bantimurung Bulusaraung lived in open places. While *P. imbricata* was found in zone 2 to zone 5. *P. imbricata* lived in moderate shading (Handoyo 2010). The ability of *O. costeriana* and *P. imbricata* to occupy a large area and different zones supported population growth resulting in the abundance of the orchids.

Ecological niche modeling and macro-habitat characteristics

The model Area Under the Curve (AUC) of the wild orchid distribution model has an average value of 0.908 and a standard deviation of 0.009 (Figure 5). The high AUC value in this study suggests that the model has high discrimination at which orchid is probably present or absent (Hosmer and Lemeshow 2000; Phillips and Dudik 2008). Using the 10-percentile training presence threshold, regions with habitat suitability values for the lowest 10% of occurrence records were removed, resulting in a binary classification on the wild orchid habitat (Phillips and Dudik 2008; Redon and Luque 2010). The analysis showed that suitable orchid habitat in South Sulawesi Province covers an area of 3,554.95 km^2 that overlaps with the forested area. The comparison of the continuous distribution with the discrete distribution can be seen in Figure 6.

Based on the contribution of environmental variables on the model (Table 5), elevation gave the highest contribution (44%), followed by topographic diversity (23%) and landforms (13.4%). While those three variables also have high permutation importance (50.9% for elevation, 13.4% for topographic diversity, and 15.1% for landforms). NDVI was the second-highest value for permutation of importance (16.8%).

Based on the jackknife analysis (Figure 7), topographic diversity gave the highest gain when used alone for modeling and it also decreased the most gain when not used. Elevation also gave significant gain when used alone. Therefore, topographic diversity and elevation are the most determinant factors on the distribution of wild orchids in the study area (Baldwin 2009). NDVI was the second-highest value for permutation of importance (16.8%) even though the contribution towards model gain was only 2.7%. The use of this variable in niche modeling of plant species is currently contested, because some authors argue it should not be used due to its correlation with plant productivity, while others argue it's a measure of ecosystem functioning (Leitão and Santos 2019). In this study, NDVI was used as the proxy for canopy closure and based on the permutation of importance, it can improve the model's predictive power, as proposed by Amaral (2007).

Table 4. Orchids occurrence in phorophytes' zone at the surveyed area in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia

Orchid species	**Total number of orchids found**				
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
Aerides leeana	0	3	0	2	1
Aerides odorata	0	0	10	11	3
Bulbophyllum sp.	0	0	1	2	2
Coelogyne celebensis	0	2	1	5	5
Cymbidium finlaysonianum	0	0	3	7	2
Dendrobium crumenatum	0	0	0	0	2
Dendrobium rantii	0	0	7	1	0
Dendrobium sphenochilum	0	0	0	1	2
Eria sp.	0	0	0	1	10
Flickingeria sp.	0	0	0	1	0
Liparis condylobulbon	0	11	9	0	0
Liparis viridiflora	0	0	2	0	0
Luisia sp.	0	0	0	4	2
Luisia teretifolia	0	0	2	2	1
Malleola sp.	0	1	0	0	0
Oberonia costeriana	1	0	10	5	83
Phalaenopsis amabilis	0	0	0	2	0
Pholidota imbricata	0	11	17	21	13
Pholidota sp.	0	0	0	1	0
Pinalia moluccana (	0	0	0	4	5
Pomatocalpa diffusum Bred	0	0	12	2	0
Pteroceras sp.	2	5	3	2	0
Robiquetia sp.	0	0	0	1	0
Trichoglottis geminata	0	0	0	0	1
Trichoglottis sp.	0	1	4	3	0
Vanda miniata	0	0	2	4	4
Total	3	34	83	82	136

Table 5. Contribution of environmental variables on the model gain and their permutation of importance. Note that elevation and topographic diversity are the most important variable having the highest contribution and importance.

Variable	**Percent contribution**	**Permutation importance**
SRTM Elevation	44.4	50.9
SRTM Topographic Diversity	23	13.4
SRTM Landforms	13.4	15.1
SRTM MTPI	8.9	1.1
SRTM CHILI	6.2	1.6
LANDSAT 8 OLI NDVI	2.7	16.8
SRTM Slope	1.3	1.2

Another model output is the response curves of wild orchids toward environmental variables (Figure 8). An upward trend in the curve shows a positive association and vice versa, with the magnitude, indicating relationship strength (Baldwin 2009). For elevation, wild orchids showed a high positive relationship with elevation until 500 m of altitude. Higher than this value, the probability of finding orchids decreased slowly. Based on the landform, wild orchid preferred warm lower slope and warm peak/ridge. This is due to most orchids found in the study area are orchids preferring warm temperatures, such as *O. costeriana* and *P. imbricata* (O'Byrne 2001; Handoyo 2010).

Wild orchid also responded positively towards NDVI and peaked at 0.8, even though after reaching that value, the probability decreased dramatically. This means orchids require moderate canopy cover. Orchids in the study area showed a mild increase toward the slope, but a mild decrease happened when reaching 25°. Wild orchids responded positively to CHILI, where they tended to increase toward warmer CHILI. For MTPI, wild orchids preferred negative values up to 150, where lower than this, the probability decreased significantly. A negative value in MTPI means the area is a valley, or lower than its surrounding. Wild orchids also responded positively to topographic diversity, but the probability decreased when reaching 0.7.

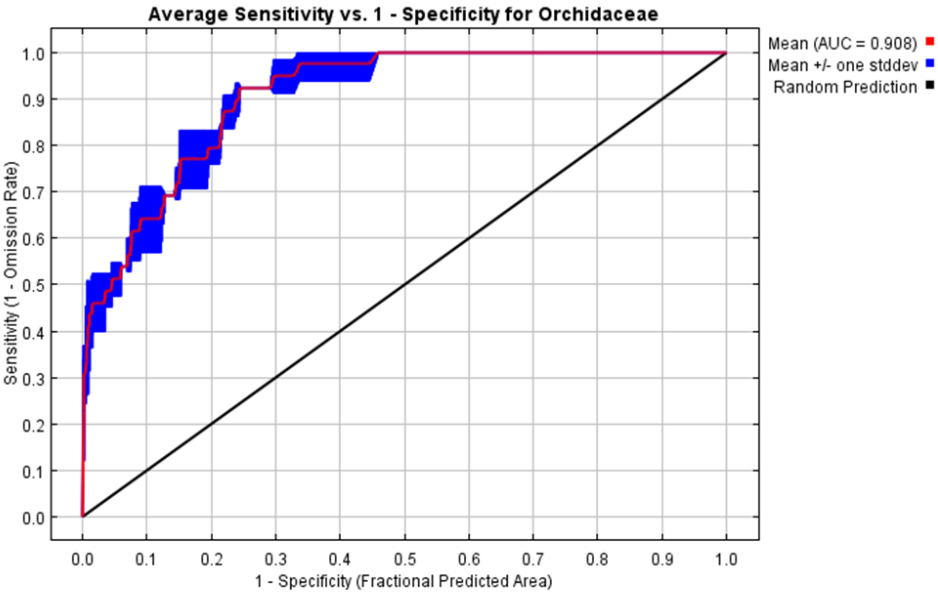

Figure 5. Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) for wild orchids model in the study site, showing high average AUC from three replicates, with a low standard deviation

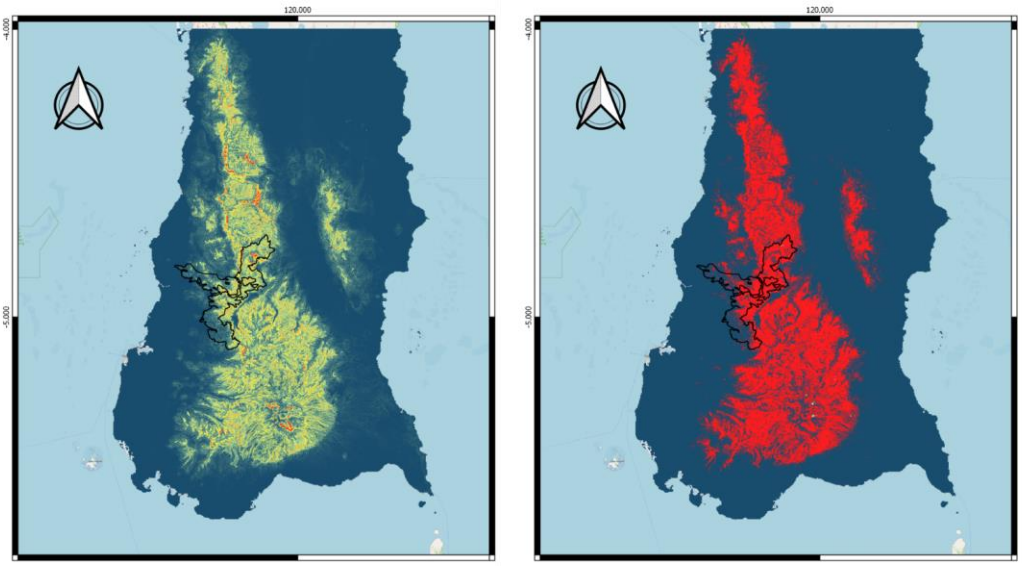

Figure 6. Continuous probability distribution model (*left*) and discrete distribution model (*right*). Notice in the left image that the yellow to red gradient shows the probability from low to high. On the right image suitable habitat is shown in red

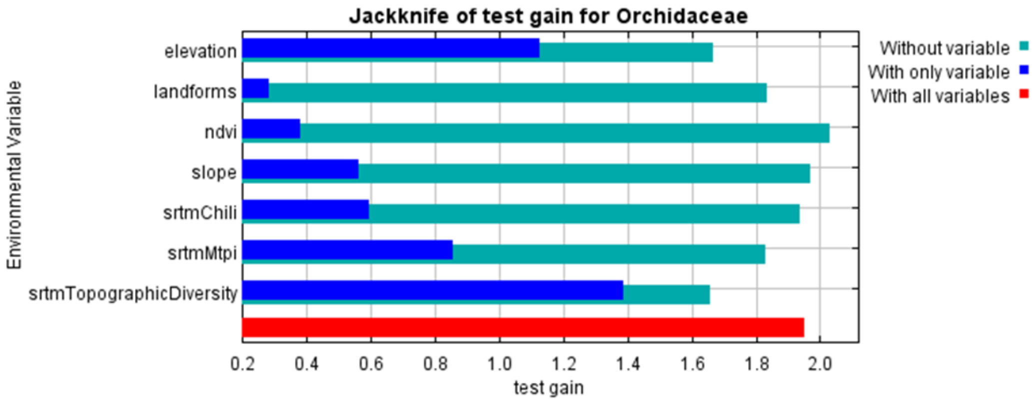

Figure 7. Jackknife of regularized test gain for the wild orchid model

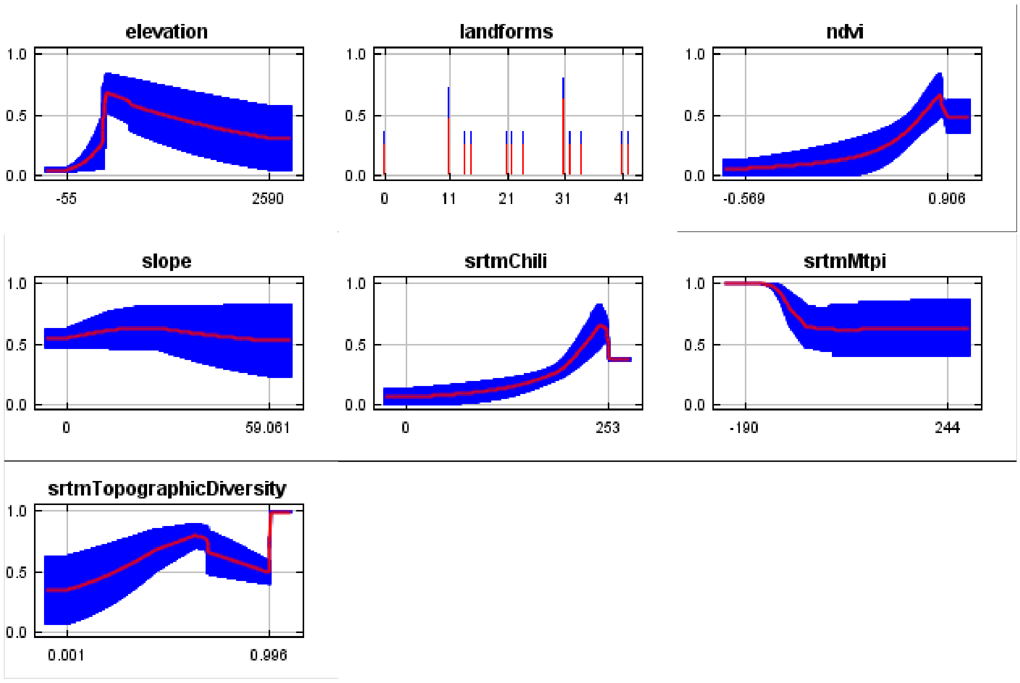

Figure 8. The curve of wild orchids' response to environmental variables

In this study, Maxent was able to predict suitable habitat/ecological niches using a low sample size for a large area in BBNP, South Sulawesi, Indonesia. A similar application was also conducted in research of other biotas, such as corals (Yusri et al. 2019), Cornelian cherries (Cao et al. 2016), and Cycad-ferns (Wang et al. 2012). Previously, Maxent has also been used for predicting orchids distribution; such as in Crete and Zante Island, Greece (Martinis et al. 2018; Tsiftsis 2011), Czech Republic (Štípková et al. 2017), dry forest in Columbia (Reina-Rodriguez et al. 2017), and Goa, India (Jalal and Singh 2017; Jalal 2019) with generally produced good result. Identifying the suitable habitat of orchids can assist in the development of orchid conservation strategy by focusing research efforts on the highest probability area, area selection for conservation and restoration, and directing future research questions (Wang et al. 2015). However, these studies mainly used bioclimatic variables from the Worldclim with 1 km of spatial resolution (Hijmans et al. 2005). While it is good for broad-scale analysis, Trivedi et al. (2008) found its coarse spatial resolution means it cannot capture local habitat variability and, in their case, is biased against the cold, high-altitude habitats of montane plants. To our knowledge, our study is the first attempt in modeling orchid suitable habitat in Indonesia that is using Worldclim, instead, we used moderate resolution (from 90 m to 30 m spatial resolution) remotely-sensed images and digital elevation models, to come up with 30 m resolution of wild orchid habitat distribution with good result. Our finding is similar to Chavez et al. (2018) that LANDSAT bands and elevation can be used to improve spatial resolution and prediction of distribution models. Elevation also gave the highest contribution towards model gain, and Wang et al. (2015) also found its importance in modeling *Spiranthes cernua* (L.) Rich., an endemic orchid to Central Texas, US.

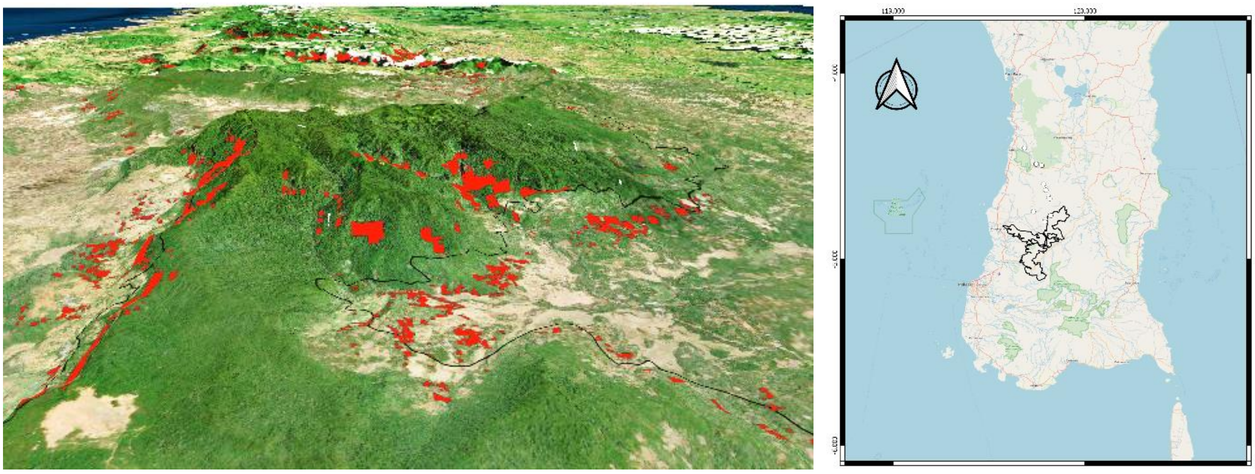

Figure 9. A three-dimensional view of area in Bantimurung Bulusaraung National Park, South Sulawesi, Indonesia with the highest probability for orchid habitat (red box). Red color shows the highest probability

Based on the results, the 3,554.952 km^2 predicted wild orchid habitat in the study area mainly located in lowland rainforest area with high topographic diversity. Wild orchids found also prefer warm slopes and ridges, and a certain degree of greenness. The topographic diversity variable shows how much variety and moisture condition is available, so the higher the variety, the higher orchid diversity can be supported (Theobald et al. 2015). This finding is similar to Jalal (2019), that undulating mountains with semi-evergreen forest in the Western Ghats, India, provide suitable habitats for endemic orchids.

In Figure 9, the highest probability for orchid habitat can be seen on lower slopes and ridges around 500 m, suggesting that it is influenced by the mid-domain effect (MDE) that was also found in orchids of Yunnan, China (Zhang et al. 2015). MDE predicts that species richness reaches a peak near the midpoint of a mountain or ridges (Rahbek 1995). The distribution might also change due to global warming, as altitudinal displacement might happen to orchid species (Reina-Rodriguez 2017).

Implication for conservation

Deforestation is the most prevalent threat for orchids (Jalal 2019; Li et al. 2018), moreover in Indonesia (Budiharta et al. 2011). Generally, Sulawesi experiences an early stage of large-scale deforestation (Rijal et al. 2019a). From 2001-2020, South Sulawesi alone lost 318 Kha of tree cover, emitting 196Mt of CO_2 with Luwu Timur District having the most tree cover loss at 92.4 Kha compared to a provincial average of 13.2 Kha (Global Forest Watch 2021b). Deforestation in urban areas is mainly due to development, while in rural areas is mainly due to agriculture and logging (Rijal et al. 2019b).

Our finding that orchids' preference habitat on warm ridges and slope poses a problem for conservation since the highest levels of protection are usually at the peaks and hills while the lowest protection was at the lower slope (Theobald et al. 2015). In our case, peaks and hills have already been protected in the BBNP, while the lower slope and lowland area are situated in the buffer zone. This problem also happens in China, and Zhang et al. (2015) suggested that new orchid reserves should be designated to protect the most suitable area. While implementing this suggestion is somewhat problematic, Indonesia does have other effective area-based conservation measures (OECM), such as social forestry, that have been indicated to be developed in Pare-Pare, Barru, Pangkajene, Bone, Maros, Sinjai, Bantaeng, and Janeponto (MOEF 2019). Local communities in the buffer zones can be facilitated to propagate high-value orchids in order to secure sustainable use and livelihood.

Aside from in situ, ex-situ conservation of Sulawesi’s orchid should also be prioritized, especially by supporting local and national botanic gardens to implement integrated orchid conservation. According to Swartz and Dixon (2009), integrated orchid conservation include five outputs, which are education and conservation prioritization, identification and management of threatening processes, long-term ex situ germplasm storage, research and development (conservation genetics, pollination ecology, mycorrhizal ecology), and horticulture and living collections. Currently, integrated orchid conservation in Indonesia is growing. As an example, one of the local botanic gardens is Jompie Parepare Botanic Gardens which currently has a botanical collection of 37 species out of 548 orchid species from Sulawesi (Rahayu 2018). At the national level, Bogor Botanic Gardens (BBG) manages to provide three outputs out of five required, which include education and conservation prioritization, long-term ex situ germplasm storage, and horticulture and living collections (Rahayu in press). Therefore, supporting these botanic gardens will ensure the success of the ex-situ conservation of orchids.

The result of our study showed that wild orchids in South Sulawesi prefer a warm and humid environment with some canopy cover. Therefore, altitude is indicated as the most prominent factor in determining orchids' distribution in the study area. The orchid habitat comprises 3,554.952

km2 is that mainly located in lowland rainforest areas with high topographic diversity, preferably warm slopes and ridges. Since lower slope and lowland areas are not protected, community-based conservation such as social forestry can become one of the alternative solutions for in situ conservation. Integrated orchid conservation in the botanic garden should be prioritized for ex-situ conservation.

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