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Short Communication

An Update on the Habitat Suitability Model of *Dacrycarpus imbricatus* (Blume) de Laub. and Its Conservation Status in Bali, Indonesia

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ABSTRACT
Dacrycarpus imbricatus provides essential ecosystem functions and various potential uses. Therefore, studying this distribution and conservation status in Bali Islands is crucial. The Habitat Suitability Model (HSM) and Geospatial Conservation Assessment Tool (GeoCAT) were used to predict this distribution and conservation status. The results showed changes in the predicted habitat suitability in 2050. Climate change conditions will impact the preferential habitat of the current location. The analysis classifies *D. imbricatus* as an endangered (EN) species in Bali. The model does not consider anthropogenic factors which change the land use/land cover. Therefore, more severe conservation efforts in Bali are needed for this species.

Dacrycarpus is a gymnosperm genus belonging to the Podocarpaceae family that appeared in Gondwanaland in the Paleogene period, then it became more widely distributed across continents by cross-equatorial migration (Wu et al. 2019). The cross-equatorial migration involved the island formation in Indonesia as a bridge between the Northern and Southern hemispheres. One species of *Dacrycarpus* that is widely distributed in Indonesia is *Dacrycarpus imbricatus* (Blume) de Laub., also known as Java podocarpus or Malayan yellowwood. Presently, more broadly, this species is native to China, Malaysia, Thailand, Vietnam, Laos, Cambodia, Philippines, Papua New Guinea, and Indonesia, including on the island of Bali (POWO 2012). The distribution of *D. imbricatus* in Indonesia is spread from Sumatra, Java, Kalimantan, Sulawesi, Bali, NTB, NTT and Papua (Soerianegara & Lemmens 1993). *Dacrycarpus imbricatus* is commonly found in sub-montane to montane habitats at elevations of 800 -2,500 m asl. and can grow at elevations of 3,600 m asl. (Soerianegara & Lemmens 1993). *Dacrycarpus. imbricatus* is a typically a tall tree up to 50 m high with a trunk diameter of up to 2 m, a hard trunk, and a rough surface with lenticels spread across the trunk; in old trees, the bark peels off in the form of small thick slabs extending vertically (de Laubenfels 1988; Waskitaningtyas et al. 2018).

This species is used as a means of traditional ceremonies for the Hindu community in Bali (Sumantera 2004). Additionally, it has resin potential, and the wood is used for construction, furniture, and firewood. In traditional medicine, *D. imbricatus* leaves are used to treat bone fractures in North Sumatra (Silalahi et al. 2015). *Dacrycarpus imbricatus* tree may also be used in land rehabilitation following gold mining because it has a high survival capacity and is able to absorb lead (Dharmawan & Siregar 2014).

Dacrycarpus imbricatus is difficult to find in natural forests, although its official conservation status in the IUCN Red List is categorized as Least Concern (IUCN 2022). *Dacrycarpus imbricatus* is included in a experiencing vulnerability criteria in China (Su et al. 2010). The regeneration of *D. imbricatus* in one of the conservation forests on the island of Java has been poor due to presence of invasive plant species such as Kaliandar (*Caliandra* sp.) and Kirinyuh (*Chromolaena odorata* (L.) R.M.King & H.Rob.) (Waskitaningtyas et al. 2018). *Dacyrcarpus imbricatus* is often locally uncommon as reported for the species in Bromo Tengger Semeru National Park (Rahadiantoro et al. 2013) and in China (Li et al. 2014). Therefore, in many areas, appropriate and research-informed conservation strategies are needed in order to increase its population.

The patchy distribution of the species potentially increases its vulnerability at local scales, especially if major disturbances reduce the population size. Furthermore, *D. imbricatus* has a vital role in the ecosystem stability in mountain forests in several ways. Firstly, compared to angiosperm trees, the soil beneath the *D. imbricatus* has more abundant saprophytic fungi that correlated with high soil acid phosphatase activity (Kitayama et al. 2011). In other words, the existence of *D. imbricatus* was associated with enhanced efficiency of the phosphate acquisition from the soil and decomposing litter (Kitayama et al. 2011). In addition to its role in the nutrient cycling, *D. imbricatus* also contributes to forest stratification as being a shade-intolerant species, it is often an emergent or canopy tree reaching more than 40 m in height (Su et al. 2010). Forests with mature *D. imbricatus* typically have greater structural complexity which is associated with enhanced niche differentiation, which means such areas could provide suitable habitat for species with a particular microclimatic preference. Because of these important roles in the ecosystem, studies of *D. imbricatus* local distribution are warranted to improve our understanding of its habitat preference and potential threats.

Re-assessment of the conservation status of *D. imbricatus* at local scales, especially in Bali, has never been conducted previously. Population studies of *D. imbricatus* were conducted by Sutomo (2011) in Pohen Mountains, Bedugul, Bali. This current paper will be an update of Sutomo (2011), with additional emphasis on the use of Habitat Suitability Model (HSM) to predict its current and future potential distribution across Bali Island. Sutomo et al. (2018) also has mention Species Distribution Model (SDM, another term for HSM) of *D. imbricatus*. However, that SDM is applied to the whole Indonesian area for year 2050. In this current study, we focus only for Bali Island, comparing it distribution between current climatic conditions and a future climate change projection. In addition, this paper also assesses the current conservation status of *D. imbricatus* specifically in Bali Island, to fill this gap in the literature.

A desktop study regarding the distribution history of *D. imbricatus* in Bali Island was conducted in Global Biodiversity and Information Facility database (http://www.gbif.org/) (GBIF Secretariat 2021). The HSM was constructed and analysed using the BCCVL (Biodiversity and Climate Change Virtual Laboratory) (Huijbers et al. 2016) online application (http://www.bccvl.org.au/), this now has become eco-commons (ecocommons.org.au). The GBIF (Global Biodiversity and Information Facility) database which is available as one of the biodiversity databases in the BCCVL provides data on species occurrence (GBIF.org 2023). A current climate layers option available in the BCCVL which was chosen was from Worldclim (1950-2000) 10 arcmin (~20 km) data. The climatic layers chosen were namely in table 1.

Table 1. The climatic variables use in the model.

Layer data	Content data
B01	Annual Mean Temperature
B02	Mean Diurnal Range (Mean of monthly (max temp - min temp)
B03	Iso-thermality
B04	Temperature Seasonality
B07	Temperature Annual Range
B12	Annual Precipitation
B13	Precipitation of Wettest Month
B14	Precipitation of Driest Month
B15	Precipitation Seasonality

These layers were selected as they provided a wide range of different climate variables likely to be important in this region. The Generalized Linear Model approach was used to analyse the SDM, both for current climate projection as well as for climate change experiment projection in the BCCVL (Huijbers et al. 2016). For the climate change experiment projection, we used the RCP8.5 emission scenario (which assumes continued high future greenhouse gas emissions), with the circulation model is MIROC-ESM for the year 2050 (Huijbers et al. 2016; Sutomo & van Etten 2017). The forecast is represented as a grid cell's fitness on a scale of 0 to 1, with 0 indicating extremely low habitat suitability and 1 indicating very high suitability. The main SDM output is a map depicting the expected distribution of *D. imbricatus* based on the previously input baseline data. The anticipated distribution refers to the distribution of suitable habitat as determined by the model's environmental factors, rather than the actual existence of the species (Huijbers et al. 2016). The AUC (Area Under the Curve) of the ROC (Receiver-Operating Characteristics) curve was used to assess model strength. The value for ROC is the area under the curve (AUC). AUC score is interpreted as follow: a value above 0.9 is excellent, good 0.9 > AUC > 0.8, fair 0.8 > AUC > 0.7, poor 0.7 > AUC > 0.6 and fail 0.6 > AUC > 0.5 (Crego et al. 2014; Sutomo et al. 2021).

Based on the results of personal experiences and previous field surveys in previous years in Bali by Sutomo and team (Sutomo 2009, 2011; Sutomo et al. 2012), the locations of *D. imbricatus* were plotted in the GeoCAT to obtain information about AOO (Area of Occupancy) and EOO (Extent of Occurrence). Field exploration-derived geographic and biological data are significant sources of knowledge for EOO, AOO, and fragmentation. The area occupied by taxon in the more common EOO (IUCN 2022) is referred to as AOO. One of the most widely utilized parameters in IUCN Red List evaluations is species AOO. In assessing the IUCN Red List based on Criterion B, specific measurements of the geographic range of species (EOO) and AOO are utilized. The analysis' AOO is based on the IUCN's standards, with a grid cell width of 2 km (IUCN 2022). GeoCAT is used to determine AOO and EOO (Geospatial Conservation Assessment Tool). A web-based application tool called GeoCAT uses primary biological data to facilitate semi-automated IUCN Red List assessment and analysis. This free and open-source website tool enables quick geographic analysis to assist with Red List species self-evaluation (Bachman et al. 2011). https://www.kew.org/science/our-science/projects/geocat-geospatial-conservation-assessment-tool is the website address.

A desktop study of *D. imbricatus* based on the Global Biodiversity Information Facility (GBIF) databases shows an increase in its occurrences in Indonesia or the Nusantara Archipelago, from one to two occurrences in 1862-1888 around West Java, and then over the next two decades, another 11 occurrences ranging from west to east Java. In 1919, GBIF shows records of the species in Sumatra, Ambon and Papua Islands. Then it shows in Kalimantan and Sulawesi in 1928, and 1938 in Lombok and Buru. Only then in 1958, this species was recorded in Bali Island around the Bedugul Highlands based on preserved specimens from Royal Botanic Garden-Kew (GBIF Secretariat 2021). This increase is perhaps due to the increasing detection/survey efforts.

Results from HSM analysis show changes in the prediction of habitat suitability of *D. imbricatus* with Habitat Suitability Index (HSI) in Bali Island between the current condition to the year 2050 (Figure 1). Habitat Suitability Index (HSI) has range value from 0 to 1 where the higher index reflects the more suitable habitat and this is classified to ten classes (interval 0.1) of HSI. In the current climate projection (Figure 1A), *D. imbricatus* occurrences is predicted to be the most suitable in the eastern part of Bedugul with the index > 0.8. Whereas in the western part of Bedugul up to Pupuan, it has a index value IND of 0.5. The Batur Volcano and Kintamani areas in the Eastern part of the Island, it has HSI value of about similar to the HSI of the western part of the Bedugul. Bangli District is unsuitable for *D. imbricatus* with HSI only 0.2 based on the current climate projection. Based on future climate projection, the whole Bedugul area and Batur Volcano as well as near the Agung Volcano near Besakih becoming very suitable for the *D. imbricatus* to spread in these areas, with HSI of 0.8 or greater (Figure 1B).

Probability of species occurrence showed distinct relationships with several of the climate variables thus indicating they were important in influencing the suitability of *D. imbricatus* in the area, namely: Annual Mean Temperature (B01), Iso-thermality (B03), Temperature Seasonality (B04) and Precipitation of Wettest Month (B13) (Figure 2). *Dacrycarpus imbricatus* has an optimum suitability to inhabit areas which has mean annual temperature between 16 to 22°C with less seasonality in the temperature and with around 400 to 500 mm/month of precipitation in the wettest month. The results of the model performance evaluation are represented in the AUC value. Based on the AUC value, the *D. imbricatus* habitat suitability in Bali Island is modelled as 'very good' because it is in the value range 0.9–1 (Figure 3). Prediction model of habitat suitability for *D. imbricatus* could have significantly affecting its conservation efforts. Ex-situ conservation can be better conducted in sites which has high

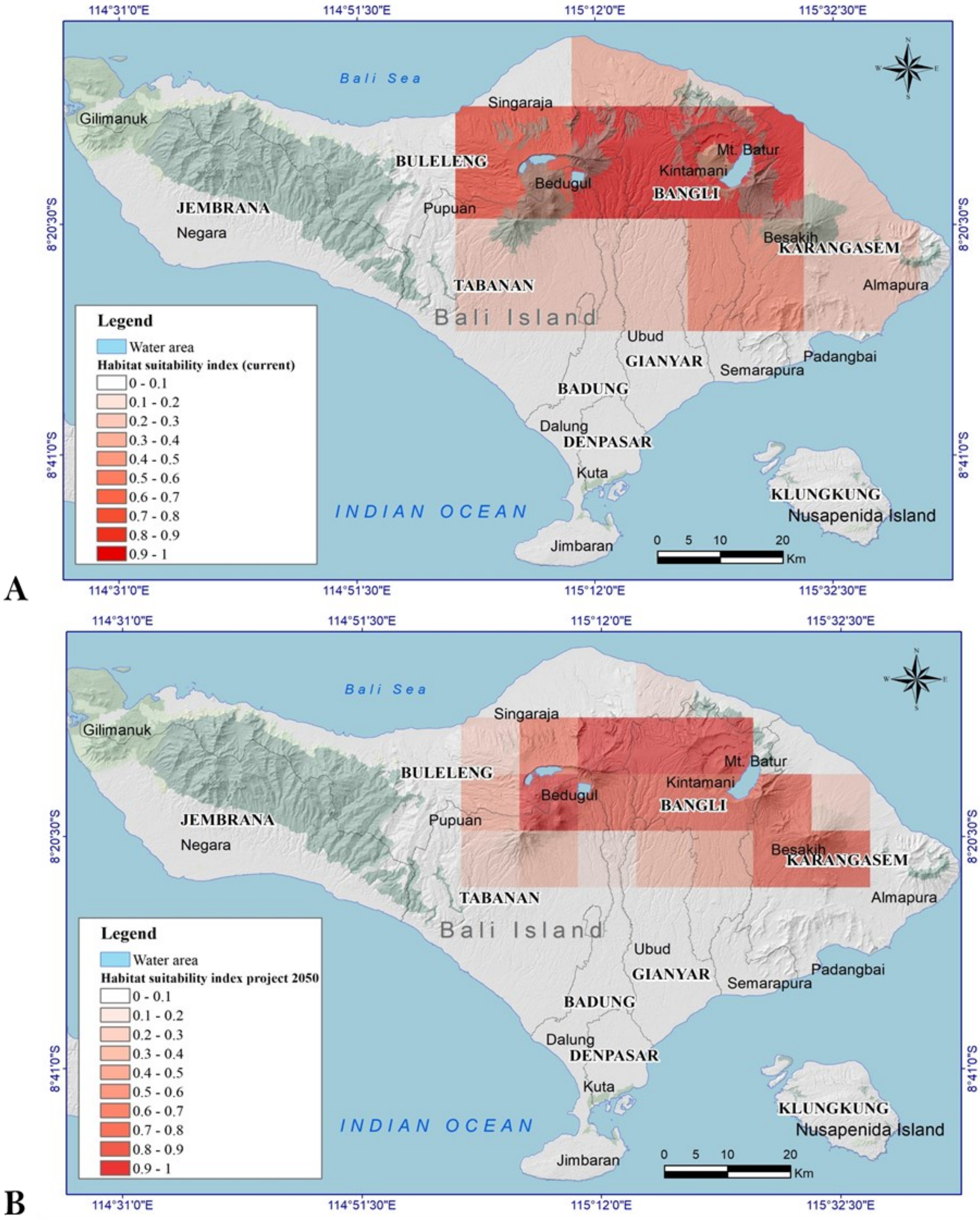

Figure 1. Habitat suitability model of *Dacrycarpus imbricatus* as resulted from the BCCVL web apps (bccvl.org.au). A: Current climate projection model; B: Climate change projection model in year 2050 based on RCP8.5 future emission scenario.

suitability index. Various stakeholders such as local government, botanical garden can use this as policy brief in better managing the conservation for *D. imbricatus*.

The estimated Extent of Occurrence (EOO) (Figure 4) *of D. imbricatus* in Bali is 680 km^2 according to the spatial analyses using GeoCAT. *Dacrycarpus imbricatus* is classified as endangered (EN) based on this estimation of EOO (Criteria B1). Based on the estimated Area of Occupancy (AOO; Category B2) of 120 km^2 (Figure 4), the species in Bali satisfies the requirement for "Endangered" (AOO less than 500 km^2) (IUCN 2022). As a result, it is regarded to be in grave danger of extinction in the wild (EW) especially in Bali.

Conservation efforts of *D. imbricatus* has been conducted by the Bali Botanical Garden (BBG). Bali Botanic Garden as ex-situ conservation institution has living collection planted in the garden, herbarium speci-

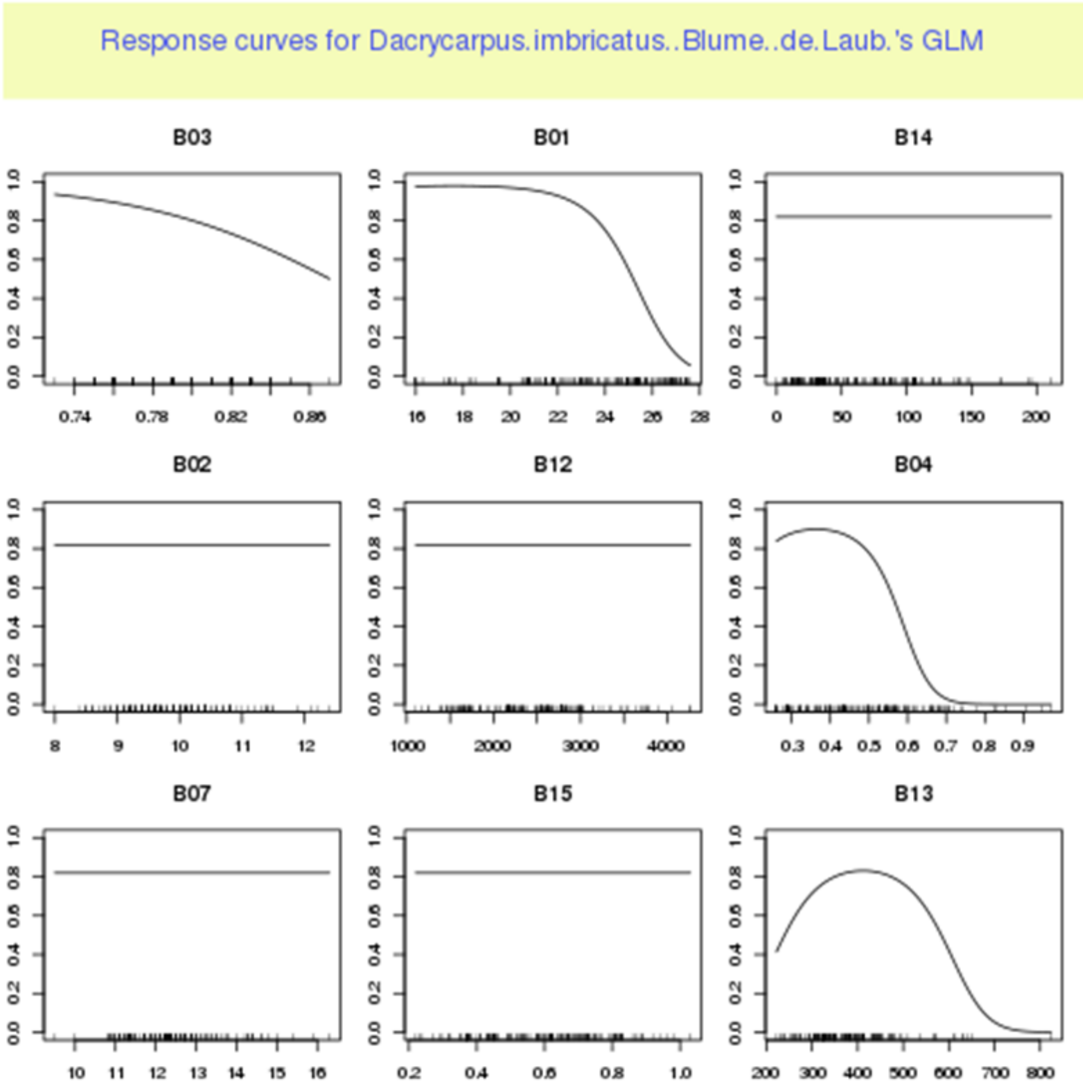

Figure 2. Species response curve of *D. imbricatus* toward environmental factors that were used in this study. X axis refers to the environmental factors and Y axis refers to occurrence index of the species. Annual Mean Temperature (B01); Mean Diurnal Range (Mean of monthly (max temp - min temp) (B02); Iso-thermality (B03); Temperature Seasonality (B04); Temperature Annual Range (B07); Annual Precipitation (B12); Precipitation of Wettest Month (B13); Precipitation of Driest Month (B14); Precipitation Seasonality (B15).

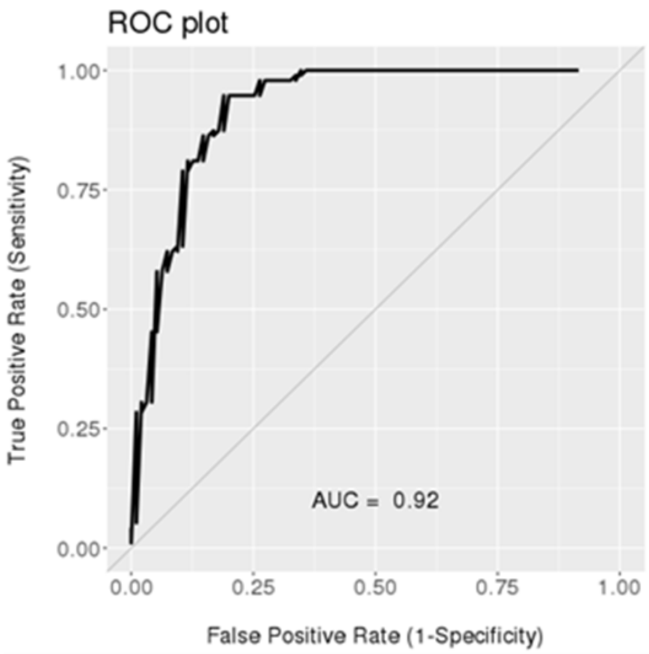

Figure 3. Robustness indicator of the model. ROC plot with AUC value of 0.92.

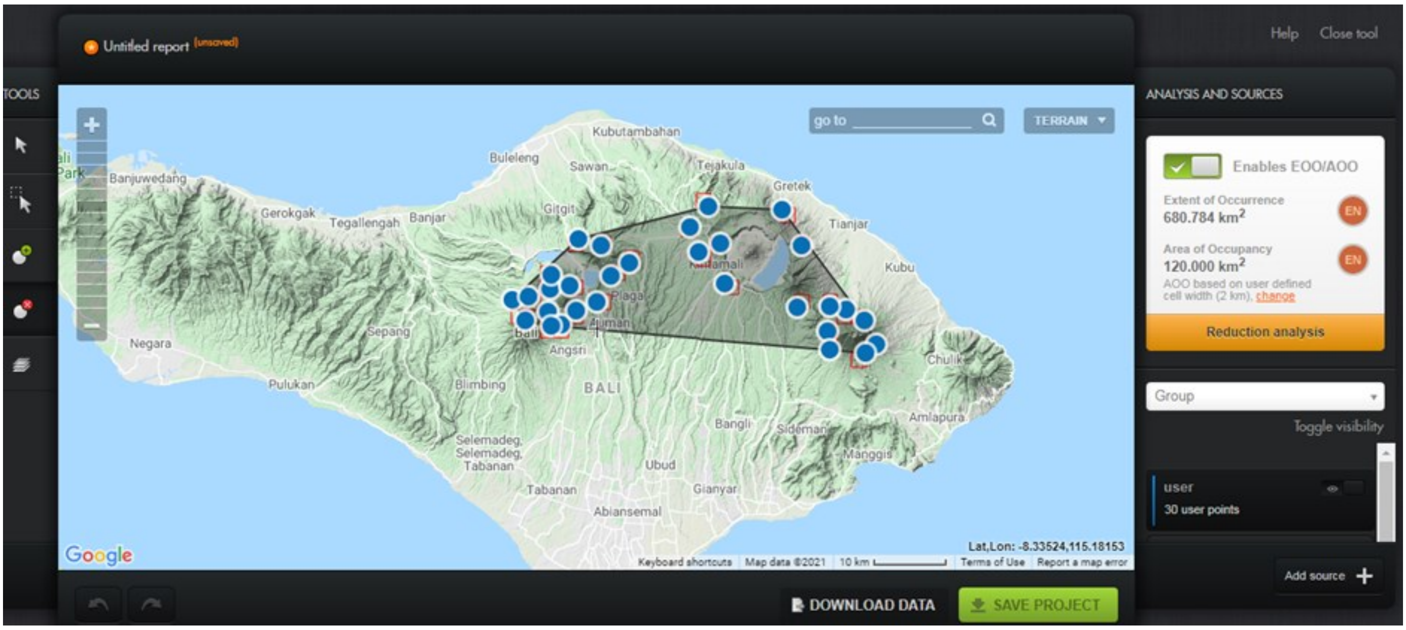

Figure 4. Results of assessment using the Geospatial Conservation Assessment Tool / GeoCAT http://geocat.kew.org/

men stored in the hortus botanicus Balinese and also has been successfully propagate the species. Several reintroduction efforts have also been initiated, especially on the Bukit Pohen in Bedugul, where the population of *D. imbricatus* is declining, mainly due to large forest fires that took place in 1994 (Sutomo 2009, 2011).

The distribution data of *D. imbricatus* and climate change modelling based on physical environmental variables can provide information regarding predictions of habitat preferences in the future taking into consideration anticipated climate change. Such predictions for the species in Bali for 2050 show a shifting of preferred habitat from Bedugul to the east towards Pupuan and Besakih, an area which has become more fragmented in recent decades. *Dacrycarpus imbricatus* has vulnerable (VU) status at global scale currently, but when the species' Area of Occupancy information approach is applied to the island landscape unit of Bali, its conservation status is endangered (EN) indicating potential extinction in the wild (EW).

AUTHORS CONTRIBUTION

S. is the main author who designed the research, analysed the data and supervised all the process, wrote parts of introduction, whole method and parts of results-discussion sections. M.B.A., re-formatted the draft based on the journal template, added part of the abstract section. I.D.P.D. helped in the discussion of the paper. R.I., wrote part of the abstract, introduction and conclusion sections. A.H., wrote part of the introduction section. I.M.S.W., wrote part of the introduction section. M.M.W., helped in the data collection and discussion of the paper. E.V.E. provide the English proofreading of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding research or funding in this paper.

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