Pol. J. Environ. Stud. Vol. 32, No. 3 (2023), 2845-2853
DOI: 10.15244/pjoes/161669 ONLINE PUBLICATION DATE: 2023-04-07

Original Research

Potential Geographic Distribution of *Durio oxleyanus* (Malvaceae): a Threatened Wild Fruit Plant Species in Sumatra, Indonesia

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Received: 13 January 2023
Accepted: 25 February 2023

Abstract

Durio oxleyanus is a threatened species native to Southeast Asia, particularly Borneo and Sumatra. Future climate changes are expected to have a significant impact on *D. oxleyanus*. The aims of this study, therefore, were (1) assessing the potential distribution of *D. oxleyanus* in Sumatra, (2) determining the main variables influencing *D. oxleyanus* distribution and their suitable range, and (3) simulating the changing trend of *D. oxleyanus* suitable habitat under climate change scenarios. We modeled the current and future distributions of *D. oxleyanus* using three representative concentration pathways (SSP1-2.6, SSP2-4.5, and SSP5-8.5). The findings demonstrate that the AUC values of all simulations were greater than 0.916. The key environmental variables influencing the potential distribution of *D. oxleyanus* were mean temperature of the coldest quarter (20-25ºC), elevation (400-800 m), temperature seasonality (50-60%), and precipitation of coldest quarter (500-750 mm). The highly suitable habitat covered 1,303.85 ha, with the majority of it concentrated in two provinces, i.e. Aceh and Sumatera Barat. The total areas of the suitable habitat of *D. oxleyanus* showed decreasing trends under the three climate change scenarios, and the geometric center of the highly suitable habitat shifted west-south of Sumatra. Our findings can serve as a scientific foundation for the protection, cultivation, and long-term management of *D. oxleyanus*.

Keywords: *Durio oxleyanus*, distribution modelling, climate change, Sumatra

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Introduction

Global climate change has emerged as a major issue in recent decades, threatening the survival of all living organisms on Earth. Cloudbursts, dry spells, rising sea levels, thawing permafrost, salinization, increased wildfires, decreased crop harvests, water scarcity, health problems, and ablation are among the most common effects of climate change on humans and wildlife [1]. Environmental factors, particularly precipitation and temperature, are important aspects of climate variability that have an immediate and significant impact on biodiversity [2]. Climate change causes changes in abiotic factors, which affect biological systems and processes, altering the structure and function of the ecosystem [3,4]. As a result of climate change, many species have shifted their geographical ranges, distributions, and phenologies [1]. Several species, on the other hand, have failed to reestablish their habitats and phenological responses [1], placing them at risk of extinction. Understanding the relationships between climate and natural vegetation, as well as forecasting the effects of future climate change, is thus critical for both conservation and human well-being [5].

Climate is a major determinant of plant species distribution on a global scale [6, 7], including *Durio oxleyanus*. *Durio oxleyanus* Griff. 1845 (Malvaceae) is native to the tropics and is commonly grown in Southeast Asia, particularly Borneo and Sumatra, and has been recognized as a threatened species [8]. The species is characterized by curvy and thorn fruit as well as its medium to large, oblong, leathery leaf that is densely stellate-hairy with scales along the midrib, secondary veins and margin, and abaxially [9]. *D. oxleyanus* fruit is edible [10], and is commonly consumed by local communities [11, 12]. In addition, the wood from this plant was widely used as a building material [13, 14], causing the population in nature to decline. Despite the fact that the natural population of *D. oxleyanus* has been declining, but lack of information about its potential habitat suitability and spatio-temporal distribution, particularly in Sumatra, Indonesia. Assessing the potential suitability of plant species is critical for conservation, monitoring, habitat restoration, cultivation, and conservation management [15].

The species distribution models (SDMs) have been widely used to explain, understand, and predict the spatio-temporal distribution of biodiversity [16, 17]. SDMs use quantitative analyses to estimate the geographical distribution of a species based on occurrence datasets and environmental conditions [18]. The maximum entropy-based general-purpose machine learning method (MaxEnt) is one of the SDMs algorithms that has been widely used to simulate and predict the potential distribution of species [19]. The MaxEnt model is considered to be a useful tool for predicting potential habitat suitability, current distribution, environment factors influencing distribution, and projecting the changing trend of suitable habitat for *D. oxleyanus* under climate change scenarios. The aims of this study, therefore, were (1) assessing the potential distribution of *D. oxleyanus* in Sumatra, (2) determining the main variables influencing

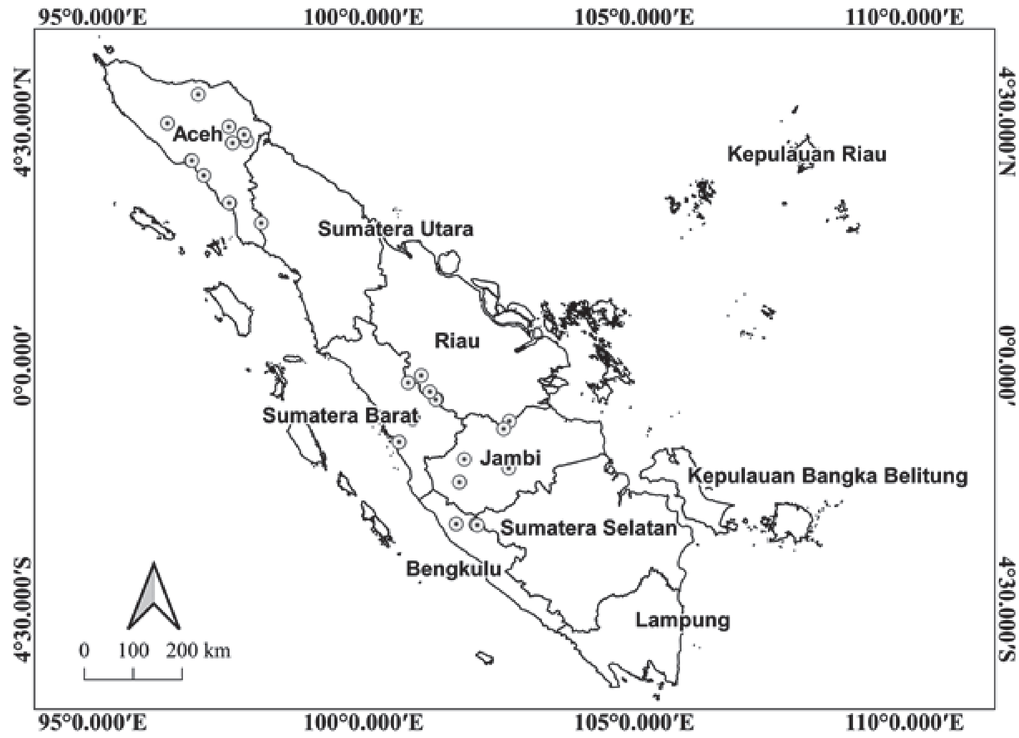

Fig. 1. Distribution point data for *D. oxleyanus* in Sumatra, Indonesia.

D. oxleyanus distribution and their suitable range, and (3) simulating the changing trend of *D. oxleyanus* suitable habitat under climate change scenarios.

Materials and Methods

Geographical Location Data Collection

The geographical distribution data (longitude and latitude) of *D. oxleyanus* was obtained from field investigation in six provinces of Sumatra, Indonesia, i.e Aceh, Sumatera Utara, Sumatera Barat, Jambi, Riau, and Bengkulu on Apr to Sep 2022. A total of 22 distribution points of *D. oxleyanus* were collected (Fig. 1). All data were entered into Microsoft Excel version 2018 programs and saved in "CSV" format for future analysis.

Eighteen (82%) of the 22 individuals collected were discovered growing wild in the forest, while four (18%) were discovered in community farmlands (Fig. 2).

Environmental Factors Variables Screening

The climate variables and elevation were obtained from the Global Climate Database (https://www.worldclim.org/, accessed on 12 November 2022) [20] in this study. The spatial resolution was 2.5 arc minutes for 19 environmental variables. For models based on future climate projections (year 2040, 2060, and 2080), the Global Climate Database was used and was modeled using the Beijing Climate Center Climate System Model (BCC-CSM2-MR) that was developed at the National Climate Center and includes three emissions scenarios (shared socioeconomic pathway (SSP1-2.6, SSP2-4.5, and SSP5-8.5). All environmental variables were imported into the MaxEnt model operation, the variables with contribution rates of 0 were deleted and SDM tools in ArcGIS software is used to remove variables with high correlation (Pearson's |r| 0.80) [21]. As a results, ten environmental factors were selected (Table 1).

Table 1. Environmental variables in the MaxEnt model.

Code	Description	Unit
Bio3	Isothermality	%
Bio4	Temperature seasonality	%
Bio11	Mean temperature of coldest quarter	ºC
Bio12	Annual precipitation	mm
Bio13	Precipitation of wettest month	mm
Bio14	Precipitation of driest month	mm
Bio15	Precipitation seasonality	%
Bio18	Precipitation of warmest quarter	mm
Bio19	Precipitation of coldest quarter	mm
Elev	Elevation	m

Model Construction and Verification

The potential distribution for *D. oxleyanus* was modeled by using MaxEnt version 3.4.3 [22] and was downloaded from (https://biodiversityinformatics.amnh.org/, accessed on 12 November 2022) in this study. The distribution data and environmental variables were imported into MaxEnt software, and the parameters were set as follows: 25% of the distribution points were set as test data, 75% of the distribution points were set as training data, 10 repetitions were set with a maximum of 500 iterations, the convergence threshold was set to 1×10^{-6} for each training repetition, and the output was in Logistic format. In order to describe the

Fig. 2. *D. oxleyanus* photographed from wild habitat.

distribution changes of *D. oxleyanus*, the simulated results were reclassified by the natural breakpoint method in ArcGIS 10.8 (Esri, Redlands, CA, USA) [23]. The natural discontinuous point method was used to divide the suitable area into 4 grades, i.e. highly suitable (0.5≤P≤1.0), moderately suitable (0.3≤P≤0.5), poorly suitable (0.1≤P≤0.3), and unsuitable (0.0≤P≤0.1) [24]. Finally, maps of suitable habitats under current and future climate scenarios were drawn in ArcGIS 10.8. The grid number of each grade was counted, and the proportion of suitable area for each grade in different periods was calculated.

The application of subject work characteristics (ROC), the area under the curve (AUC), and true skill statistics (TSS) were used to evaluate the prediction accuracy of the model. An AUC value closer to 1 indicates that the model prediction effect is better. The evaluation criteria for model prediction accuracy were divided into four grades: poor (AUC≤0.80), general (0.80<AUC≤0.90), good (0.90 AUC≤0.95), and best (0.95) [7,19]. TSS recognizes a model's overall accuracy based on its random accuracy, assigning a score between -1 and 1, with values close to 1 indicating optimal performance [25]. TSS values greater than 0.5 are considered adequate for informing model performance [26].

Results and Discussion

Model Accuracy

The MaxEnt model was used to simulate and predict the potential habitat suitability and distribution of *D. oxleyanus* in Sumatra based on 22 individuals, with AUC values of training and test data were 0.916 and 0.906, indicating that the results were good category (Fig. 3), while TSS value is 0.641, indicating that the results are adequate for informing model performance.

Table 2. Percent contribution and permutation importance of each variable to the potential distribution of *D. oxleyanus* defined by MaxEnt.

Code	Percent contribution (%)	Permutation importance (%)
Bio11	36.4	31.7
Elev	16.1	13.0
Bio4	13.1	8.5
Bio19	10.9	7.6
Bio14	5.2	11.5
Bio13	4.9	4.1
Bio3	3.7	2.3
Bio18	3.6	10.5
Bio12	3.2	5.8
Bio15	2.9	5.1

Importance Variable and Environmental Factor Preference

The percentage contribution showed that nine environmental variables for model construction were mean temperature of coldest quarter (Bio 11)>elevation (Elev)>temperature seasonality (Bio4)>precipitation of coldest quarter (Bio19)>precipitation of driest month (Bio14)>precipitation of wettest month (Bio13)> isothermality (Bio3)>precipitation of warmest quarter (Bio18)>annual precipitation (Bio12)>precipitation seasonality (Bio15). The four percent contributions were

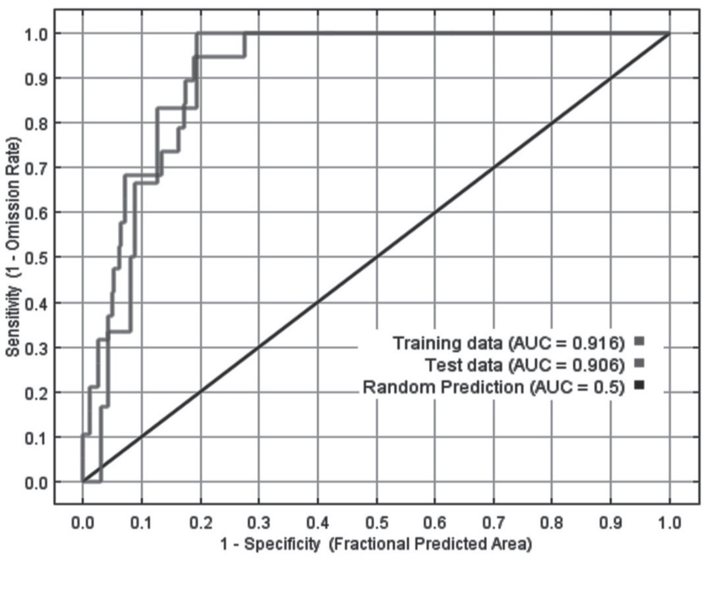

Fig. 3. ROC curve of the Maxent model of *D. oxleyanus*.

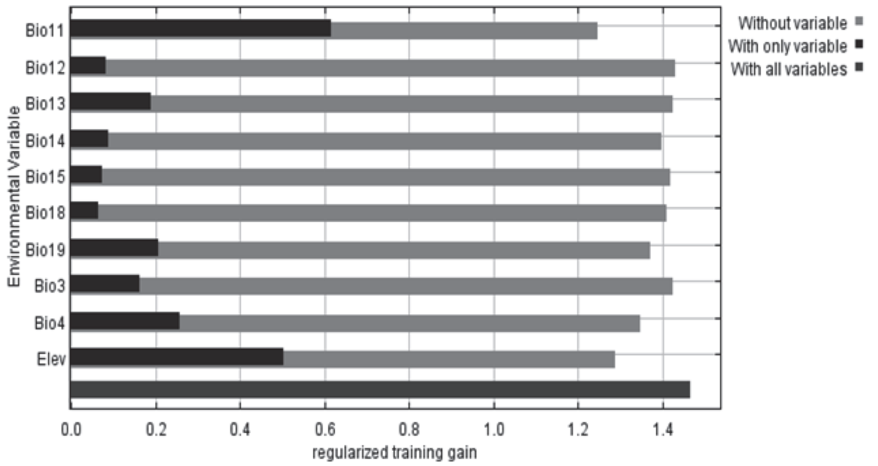

Fig. 4. Importance of environmental variable to *D. oxleyanus* by jackknife test.

highest for mean temperature of coldest quarter (Bio11, 36.4%), elevation (Elev, 16.1%), temperature seasonality (Bio4, 13.1%), and precipitation of coldest quarter (Bio19, 10.9%), with the four variables contributing 76.5% in total. Moreover, the permutation importance for four important variables is mean temperature of coldest quarter (Bio11, 31.7%), elevation (Elev, 13%), temperature seasonality (Bio4, 8.5%), and precipitation of coldest quarter (Bio19, 7.6%), with a cumulative rate of 60.8% (Table 2).

When a single environmental variable was used in the jackknife test (Fig. 4), the mean temperature of the coldest quarter (Bio11) was significantly higher than other variables, which indicated that this variable contained unique information affecting the distribution of *D. oxleyanus*.

Threshold Analysis of Important Environmental Variables

The probability response curves demonstrate how the logistic prediction for *D. oxleyanus* datum changes, while the remaining predicting factors are maintained at their average values (Fig. 5). The threshold values

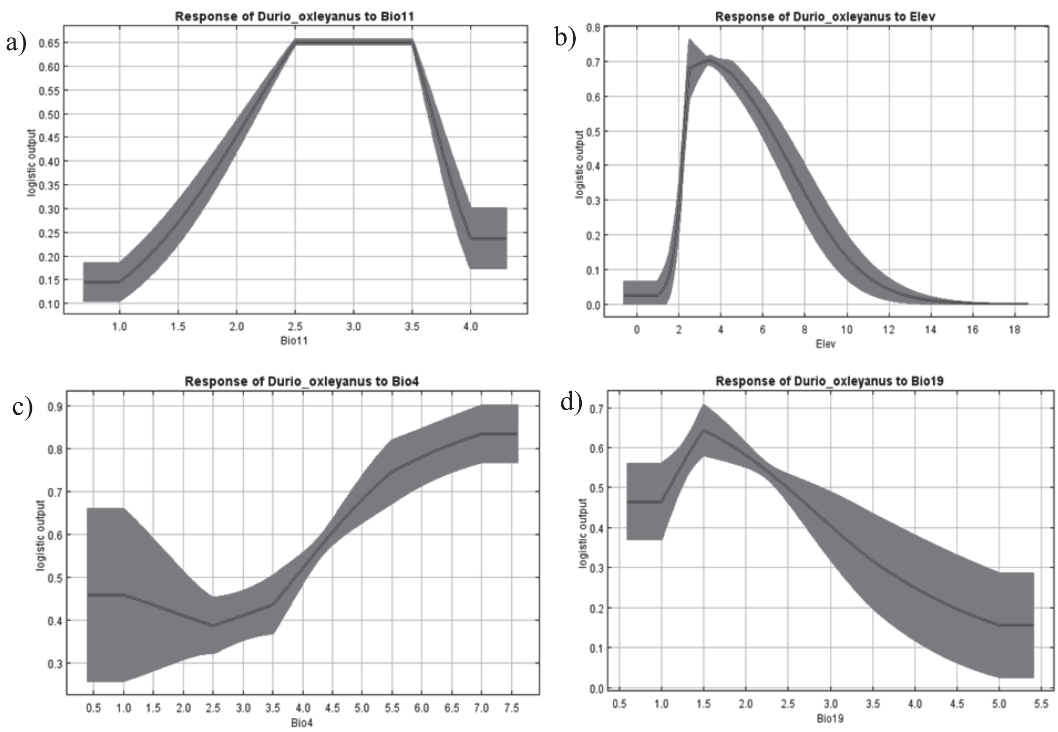

Fig. 5. Probability response curves for the main predictor variables of the modeled distribution of *D. oxleyanus* based on the MaxEnt algorithm. a) Mean temperature of coldest quarter (Bio11), b) elevation (Elev), c) temperature seasonality (Bio4), and d) precipitation of coldest quarter (Bio9). The red curves represent the mean response of the 10 replicate Maxent runs, and the blue shades represent the mean +/ one standard deviation.

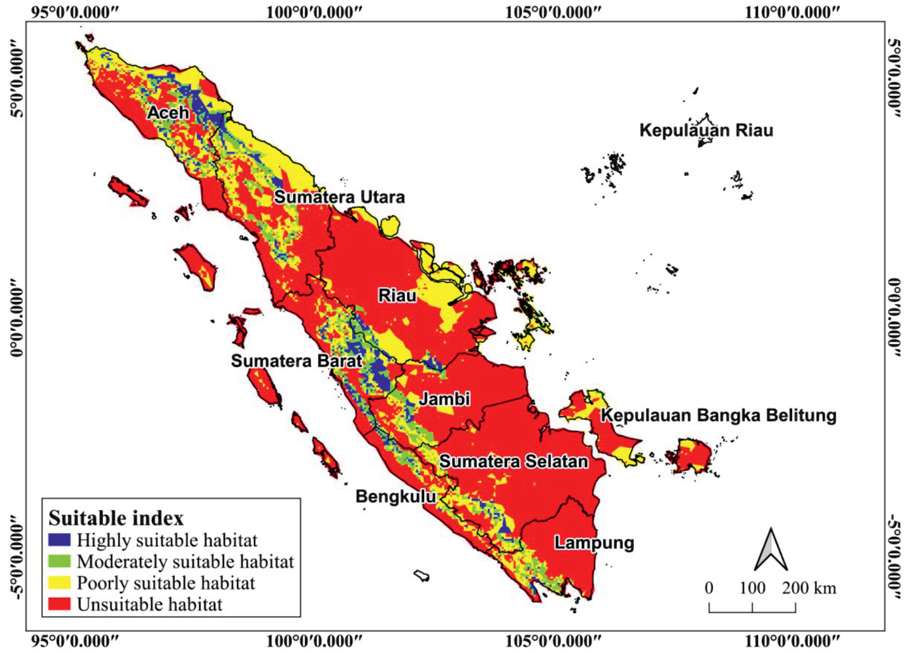

Fig. 6. Potential suitable habitat for *D. oxleyanus* under current climate condition.

of mean temperature of coldest quarter (Bio11) for the probability of *D. oxleyanus* presence were found to be approximately 20 to 25ºC, the threshold values of elevation (Elev) were 400 to 800 m, the threshold values of temperature seasonality (Bio4) were 50 to 60%, and the threshold values of precipitation of coldest quarter (Bio19) were 500-750 mm.

Potential Distribution Areas of *D. oxleyanus* in Sumatra

The model prediction of the habitat suitability and the potential distribution of *D. oxleyanus* was produced by MaxEnt and the greatest concentration of highly suitable areas was mainly predicted in two provinces, i.e. Aceh and Sumatera Barat (Fig. 6).

In this study, we used MaxEnt to explore the effects of environmental variables on the distribution pattern of *D. oxleyanus*. Our result revealed, under current environmental factors indicated that the *D. oxleyanus* distribution range was more influenced by temperature (temperature of coldest quarter and temperature seasonality), elevation, and precipitation (precipitation of coldest quarter). The results showed that the temperature of coldest quarter had the highest percent contribution (36%) and permutation importance (31.7%) to the simulation, which was the key variable affecting its distribution. It indicates that the presence to probability of *D. oxleyanus* was higher when the temperature of the coldest quarter was 20-25ºC and confirmed the importance of the temperature factor to the distribution of *D. oxleyanus* on a large scale. Temperature regulates plant metabolic rates, which are critical for plant survival, growth, and reproduction. The variation range of temperature was closely related to the large-scale landscape geographical distribution of plant species [27, 28]. The elevation is also a second important factor in the distribution of *D. oxleyanus*, with a percent contribution and permutation importance of 16.1% and 13%, respectively, and the habitat suitability

Table 3. Potentially suitable habitat area for *D. oxleyanus* (Ha).

Period	Scenario	Highly suitable	Moderately suitable	Poorly suitable	Total suitable
Current		154.82	267.51	881.52	1,303.85
Future 2050s	SSP1-2.6	175.41	273.09	1,070.33	1,070.33
	SSP2-4.5	201.68	295.57	1,042.18	1,042.18
	SSP5-8.5	175.42	314.02	1,181.25	1,181.26
Future 2070s	SSP1-2.6	221.83	325.31	1,208.05	1,208.05
	SSP2-4.5	275.32	305.26	1,204.95	1,204.95
	SSP5-8.5	171.71	315.75	1,142.32	1,142.32

at elevation was 400-800 m asl. The findings confirmed Lim [10] report that *D. oxleyanus* is typically found in lowland mixed dipterocarp primary forests at elevations ranging from 400 to 690 m asl. Elevation has a strong relationship with temperature, with elevation increasing linearly as temperature decreases. Lower temperatures at higher elevations would affect plant performance as well as slow soil microbial activity and other soil processes, resulting in lower nutrient availability. As a result, temperatures between 20 and 25ºC and elevations between 400 and 800 m asl are considered to provide adequate nutrient availability and promote survival, growth, and reproduction of *D. oxleyanus*.

Potential Habitat for D. oxleyanus under Climate Change Scenarios

Under SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios, the area of the total suitable habitat of *D. oxleyanus* decreased in the 2050s and 2070s compared to the current condition (Table 2).

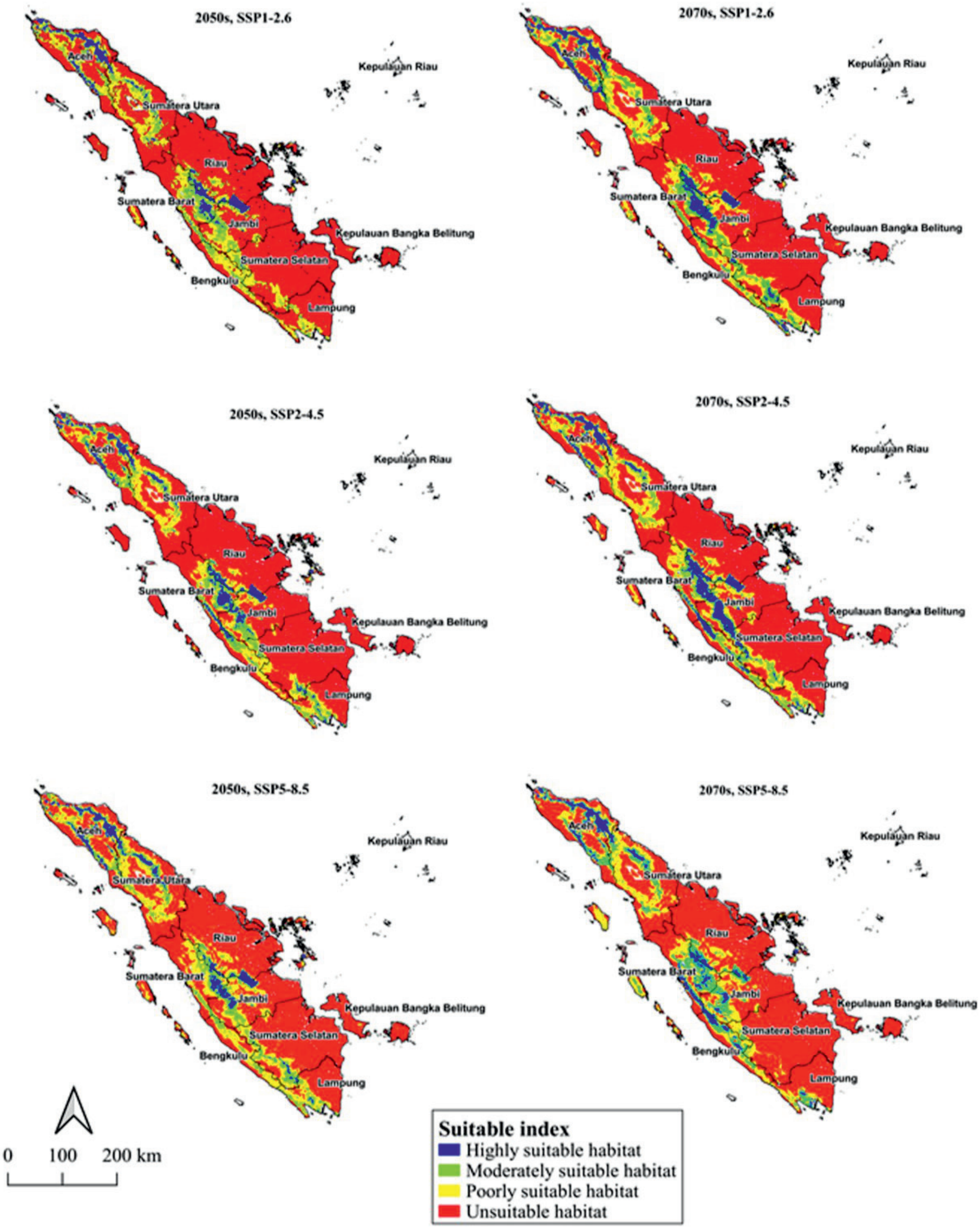

Fig. 7. Potential suitable habitat for *D. oxleyanus* under climate change scenarios.

Compared to the current condition, by 2050s, the total suitable habitat area under the three SSPs will decrease by 17.91%, 20.07%, and 9.4%, respectively, but the area of the highly suitable habitat will increase by 13.3%, 30.27%, and 13.31%, respectively. Moreover, compared to the current condition, by 2070s, the total suitable habitat area under the three SSPs will decrease by 7.35%, 7.59%, and 12.39%, respectively, but the area of the highly suitable habitat will increase by 43.28%, 77.83%, and 10.91%, respectively. In the present study, we found that the geometric center of the highly suitable area of *D. oxleyanus* would shift to the west-south (Fig. 7). The increasing trend of highly suitable habitats in Bengkulu and Lampung, confirms that climate change will improve the living environment of *D. oxleyanus*. Climate change is expected to increase annual rainfall and decrease the temperature at both sites, making them suitable for the growth of *D. oxleyanus*. However, the findings of this study differ from previous studies in that, in the future, under the influence of climate change, the suitable areas for many plants will shift northward [7, 29]. The majority of changes in the geographical distribution of plant species caused by climate change are related to temperature changes during the growing season [30]. The effect of climate change on the distribution patterns of various species varies [31]. Moreover, the Intergovernmental Panel on Climate Change (IPCC) global climate model predicts that the warming trend will continue, but the extent and speed of the warming are uncertain [32]. Several studies, on the other hand, have found that deforestation is the primary cause of endangered species in Indonesia [33-36], and reducing human activities is one of the key measures to protect of *D. oxleyanus* in the future. Climate change, in general, will reduce suitable habitat for *D. oxleyanus* in the future, affecting their presence in Sumatra. *D. oxleyanus* is an edible fruit with a high nutritional value [37, 38]. As a result, efforts to domesticate and transfer cultivation technology are critical. This effort is significant because, in addition to conservation, it can provide an alternative source of income for local communities.

This study is the first report on the suitable habitat and distribution of *D. oxleyanus* under climate change scenarios in Sumatra. Information on a species' distribution and habitat suitability is critical for management and conservation decisions and actions [39]. SDMs are useful machine learning methods that can produce such data, and MaxEnt is one of the best SDM algorithms currently available, which is widely used to address environmental factors that influence target species distribution. The findings of this study can be applied to conservation efforts for *D. oxleyanus* in Sumatra. High-suitability areas must be protected from deforestation and habitat destruction in order to ensure the sustainability of *D. oxleyanus* in the future.

Conclusions

Using the MaxEnt model identified a total of 4 environmental variables that have a significant important effect on the survival and distribution of *D. oxleyanus* including mean temperature of coldest quarter (Bio 11), elevation (Elev), temperature seasonality (Bio4), and precipitation of coldest quarter (Bio19). The total areas of the suitable habitat of *D. oxleyanus* will decrease in the future under the three climate change scenarios. Compared to the current period, MaxEnt predicts that total suitable distribution areas of *D. oxleyanus* will decrease by 7.35% (2050s) and 7.35% (2070s) for SSP1-2.6; 7.35% (2050s) and 7.59% (2070s) for SSP2-4.5; and 12.39% (2050s) and 12.39% (2070s) for SSP5-8.5 climatic scenario. Based on the predictions of this study, the future environment will have a certain impact on the survival of *D. oxleyanus*, and its suitable distribution will tend to shift west-south of Sumatra. It is expected that this study will provide a scientific foundation for the protection, cultivation, and long-term management purposes of *D. oxleyanus*.

Acknowledgments

We are grateful to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for funding this study through the Dissertation Research Grant/PDD 2022 (Grant No. 083/E5/PG.02.00/PT/2022) and the National Research and Innovation Agency for funding through the Expedition and Exploration Research Grant/PEE 2022 (Grant No. 01/PEE/PPK-DFRI/2022). We would also like to thank all the people who assisted in this study.

Conflict of Interest

The authors declare no conflict of interest

References

1. SATTAR Q., MAQBOOL M.E., EHSAN R., AKHTAR S. Review on climate change and its effect on wildlife and ecosystem. Open J Environ Biol., **6** (1), 8, **2021**.
2. SONI D.K., ANSARI F. Climate change and biodiversity; impacts, vulnerability and mitigation in Indian perspective: A review. J. Appl. & Nat. Sci., **9** (1), 632, **2017**.
3. BELLARD C., BERTELSMEIER C., LEADLEY P., THUILLER W., COURCHAMP F. Impacts of climate change on the future of biodiversity. Ecol. Lett., **15** (4), 365, **2012**.
4. REMOLINA-FIGUEROA D., PRIETO-TORRES D.A., WESLEY DÁTTILO W.,DÍAZ E.S., ROSAS L.E.N., RODRÍGUEZ-FLORES C., NAVARRO-SIGÜENZA A.G., ARIZMENDI M.C. Together forever? Hummingbird-plant relationships in the face of climate warming. Climatic Change, **175**, 2, **2022**.

5. TOVAR C., CARRIL A.F., GUTIÉRREZ A.G., AHRENDS A., FITA L., ZANINELLI P., FLOMBAUM P., ABARZÚA A.M., ALARCÓN D., ASCHERO V., BÁEZ S., BARROS A., CARILLA J., FERRERO M.E., FLANTUA S.G.A., GONZÁLES P., MENÉNDEZ C.G., PÉREZ- ESCOBAR O.A., PAUCHARD A., RUSCICA R.C., SÄRKINEN T., SÖRENSSON A.A., SRUR A., VILLALBA R., HOLLINGSWORTH P.M. Understanding climate change impacts on biome and plant distributions in the Andes: Challenges and opportunities. Journal of Biogeography, **2022**, 1, **2022**.
6. WOLDEAREGAY M. Climate change impacts on the distribution and phenology of plants: A review. Tropical Plant Research, **7** (1), 196, **2020**.
7. LIU L., WANG R.L., ZHANG Y.Y., MOU Q.Y., GOU Y.S., LIU K., HUANG N., QUYANG C.L., HU J.Y., DU B.G. Simulation of potential suitable distribution of Alnus cremastogyne Burk. In China under climate change scenarios. Ecological Indicators. **133** (10), 108396, **2021**.
8. IUCN. Durio oxleyanus. Available online: http://www.iucnredlist.org. (Access 28 December 2022).
9. WONG X.J., LAW D., WANG Z.F., RAMAIYA S.H., LEE S.Y. The complete chloroplast genome sequence of *Durio oxleyanus* (Malvaceae) and its phylogenetic position. Mitochondrial DNA Part B, **7** (9), 1709, **2022**.
10. LIM T.K. *Durio oxleyanus*. Edible medicinal and non-medicinal plants, Springer: Dordrecht. 563, **2012**.
11. NAVIA Z.I., SUWARDI A.B., NURAINI. The importance of tropical edible fruit plants for tribal communities in East Aceh Region, Indonesia. Earth Environ Sci., **637**, 012003, **2021**.
12. SUWARDI A.B., NAVIA Z.I., HARMAWAN T., SYAMSUARDI, MUKHTAR E. Wild edible fruits generate substantial income for local people of the Gunung Leuser National Park, Aceh Tamiang Region. Ethnobot Res Appl., **20**, 1, **2020**.
13. SYAMSUARDI, MUKHTAR E., NURAINAS, SUWARDI A.B. Diversity and use of wild edible fruits in the Bukit Rimbang – Bukit Baling Wildlife Reserve, Kampar, Riau, Indonesia. Biodiversitas, **23** (10), 5035, **2022**.
14. SUWARDI A.B., NAVIA Z.I. Sustainable use and management of wild edible fruit plants: A case study in the Ulu Masen protected forest, West Aceh, Indonesia. Journal of Sustainable Forestry, 1, **2020**.
15. XU X., ZHANG H., YUE J., XIE T., XU Y., TIAN Y. Predicting shifts in the suitable climatic distribution of walnut (*Juglans regia* L.) in China: maximum entropy model paves the way to forest management. Forest, **9**, 103, **2018**.
16. PETERSON A.T., PAPES M., EATON M. Transferability and model evaluation in ecological niche modeling: A comparison of GARP and Maxent. Ecography, **30**, 550, **2007**.
17. LIAO C.C., CHEN Y.H. Improving performance of species distribution model in mountainous areas with complex topography. Ecological Research, **2021**, 1, **2021**.
18. BECK J., BÖLLER M., ERHARDT A., SCHWANGHART A. Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. Ecol Inform., **19**, 10, **2014**.
19. PHILLIPS S.J., ANDERSON R.P., SCHAPIRE R.E. Maximum entropy modeling of species geographic distributions. Ecol. Modell. **190** (3-4), 231, **2006**.
20. FICK S.E., HIJMANS R.J. WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. Int. J. Climatol., **37**, 4302, **2017**.
21. LIU L., GUAN L., ZHAO H., HUANG Y., MOU Q., LIU K., CHEN T., WANG X., ZHANG Y., WEI B., HU J. Modeling habitat suitability of *Houttuynia cordata* Thunb (Ceercao) using MaxEnt under climate change in China. Ecological Informatics. **63**, 101324, **2021**.
22. PHILLIPS S.J., ANDERSON R.P., DUDÍK M., SCHAPIRE R.E., BLAIR M.E. Opening the black box: an open-source release of Maxent. Ecography, **40**, 887, **2017**.
23. LIU M.L., SUN HY., JIANG X., ZHOU T., ZHANG Q.J., SU Z.D., ZHANG Y.N., LIU J.N., LI Z.H. Simulation and prediction of the potential geographical distribution of *Acer cordatum* Pax in different climate scenarios. Forests, **13**, 1380, **2022**.
24. SONGER M., DELION M., BIGGS A., HUANG Q.Y. Modeling impacts of climate change on giant panda habitat. Int. J. Ecol. **2012**, 1, **2012.**
25. ALLOUCHE O, TSOAR A, KADMIN R. Assessingthe accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology. **43**, 1223, **2006**.
26. SILVA J.L., CRUZ-NETO O., TABARELLI M., de ALBUQUERQUE U.P., LOPES A.V. Climate change will likely threaten areas of suitable habitats for the most relevant medicinal plants native to the Caatinga dry forest. Ethnobiology and Conservation. **11**, 15, 2022.
27. HUANG Y.I., ZENG Y., JIANG P., CHEN H., YANG J. Prediction of potential geographic distribution of endangered relict tree species *Dipteronia sinensis* in China based on MaxEnt and GIS. Pol. J. Environ. Stud., **31** (4), 3597, **2022**.
28. YANG J.T., JIANG X., CHEN H., JIANG P., LIU M., HUANG Y. Predicting the potential distribution of the endangered plant *Magnolia wilsonii* using MaxEnt under climate change in China. Pol. J. Environ. Stud., **31** (5), 4435, **2022**.
29. FLOWER A., MURDOCK T.Q., TAYLOR S., ZWIERS F.W. Using an ensemble of downscaled climate model projections to assess impacts of climate change on the potential distribution of spr uce and Douglas-fir forests in British Columbia. Environ. Sci. Policy, **26**, 63, **2013**.
30. KHALID A., CAIPING H., MANFRED H. Potential impact of global warming on virus propagation in infected plants and agricultural productivity. Front. Plant Sci. **12**, 649768, **2021**.
31. KELLY A.E., GOULDEN M.L. Rapid shifts in plant distribution with recent climate change. PNAS, **105** (33), 11823, **2008**.
32. MCSWEENEY C., JONES R., LEE R.W., ROWELL D. Selecting CMIP5 GCMs for downscaling over multiple regions. Clim. Dyn. **44**, 3237, **2015**.
33. NAVIA Z.I., SUWARDI A.B., HARMAWAN T., SYAMSUARDI, MUKHTAR E. The diversity and contribution of indigenous edible fruit plants to the rural community in the Gayo Highlands, Indonesia. J Agr Rural Dev Trop Subtrop., **121** (1), 89, **2020**.
34. ZAMZANI F., ONDA N., YOSHINO K., MASUDA M. Deforestation and agricultural expansion processes in Gunung Palung National Park, West Kalimantan, Indonesia. Jurnal Manajemen Hutan Tropika, **15** (1), 24, **2009**.
35. AUSTIN K.G., SCHWANTES A., GU Y., KASIBHATLA P.S. What causes deforestation in Indonesia? Environ. Res. Lett., **14**, 024007, **2019**.