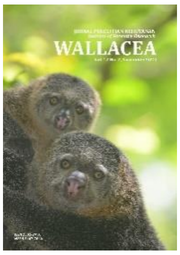

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Modeling suitable habitats of maleo (*Macrocephalon maleo* sal. müller 1846) in Gorontalo

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Abstract

Maleo (Macrocephalon maleo) is one of the endangered bird species in Indonesia. This avifauna species is an endemic bird to Sulawesi Island. It is distributed from the south to the north of Sulawesi, including Gorontalo. Currently, information on suitable habitat models for M. maleo is very limited, while this information is required to support the conservation of M. maleo. This study aimed to model the potential habitat for M. maleo using species distribution modeling (SDM) with vegetation cover variables as predictors. The model was built based on the M. maleo occurrence points. The suitable habitat was then evaluated using area under the curve analysis and the receiver operating characteristic curve (AUCROC). Based on the model, the AUC is valued at 0.729, which is considered reasonable and indicates that the model can be used to depict the potential habitats for the species. In this study, most of the west and east parts of Gorontalo were considered not suitable for Maleo. While the coastal areas of Gorontalo were considered very suitable. This was confirmed for both the north and south coastal areas of Gorontalo. Then it is strongly recommended to conserve and protect most of those coasts to ensure the Maleo conservation.

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INTRODUCTION

Sulawesi Island has a high species richness of birds, there are 381 endemic bird species belonging to 14 endemic genera of Sulawesi. One endemic species that is well known is the Maleo bird (*Macrocephalon maleo*). Its distribution is relatively wide across most of the island of Sulawesi which is part of the Wallacea region (Baker, 2002). One landscape that was known inhabited by Maleo is in Gorontalo, North of Sulawesi. Maleo in Gorontalo was observed residing in Hungayono Wildlife Sanctuary. A previous study has confirmed a population of Maleo in this location and this indicates Gorontalo landscape as a potential habitat for this species (Karim et al., 2021).

Maleo birds are classified as rare wild animals and are protected based on Law Number 5 of 1990 concerning Conservation of Natural Resources and their Ecosystems. The protection of Maleo birds is also regulated in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.20/MENLHK/SETJEN/KUM.1/6/ 2018 Concerning Types of Plants and Animals That Are Protected. Meanwhile, in 2016, the *IUCN* (International Union for Conservation of Nature) published its latest assessment and included the Maleo on the red list of endangered species (Endangered), as well as CITES (Convention On International Trade in Endangered species of wild Fauna and Flora) determining the Maleo bird in Appendix I of plant species and wild animals that are prohibited in all forms of international trade (CITES, 2017). In 2021, the IUCN RedList categorized Maleo bird as Critically Endangered. Despite recent study shows recovery of Maleo, the presences of this species were still threatened due to habitat losses, poaching, including egg poaching (Tasirin et al., 2021) and nest disturbances (Gorog et al., 2005). This research on Maleo is important because this species is endangered. A research is needed to focus on Sulawesi region as priority sites for conservation (Butchart et al., 2000).

Based on the previous reviews, Maleo species is residing Gorontalo landscape. While the information about suitable habitats for Maleo in Gorontalo landscape is still limited. Then, this study aims to assess and model the suitable habitats of *M. maleo* in Gorontalo landscape. The findings from this study can be used to support the conservation of Gorontalo landscape and *M. maleo*. In this study, the predictors used to model the suitable habitats for *M. maleo* are the vegetation and forest covers. Vegetation and forest covers were known as important variables for *M. maleo* by providing natural habitats.

MATERIALS AND METHODS

The method used in this study is a combination of field survey, database and literature survey, and the use of geographic information system (GIS) and modeling approach. Field survey, database and literature survey activities aimed to collect and record the presences of for *M. maleo*. While the use of GIS aiming to model the suitable habitats of *M. maleo*.

Study Locations

The study area was located at Gorontalo Province, Sulawesi Island (Figure 1) located precisely at 0° 19′ 00”–1° 57′ 00” N (North Latitude) and 121° 23′ 00”–125° 14′ 00” E (East Longitude). The total area of Gorontalo Province is 12,435 km^2. The province is bordered by Sulawesi Sea in the North and Tomini/Gorontalo Gulf in the South. The landscape of Gorontalo Province is mostly hills combined with many mountains with different heights. Mount Tabongo, located in Boalemo Regency, is the highest mountain, while Mount Litu-Litu, located in Gorontalo Regency, is the lowest.

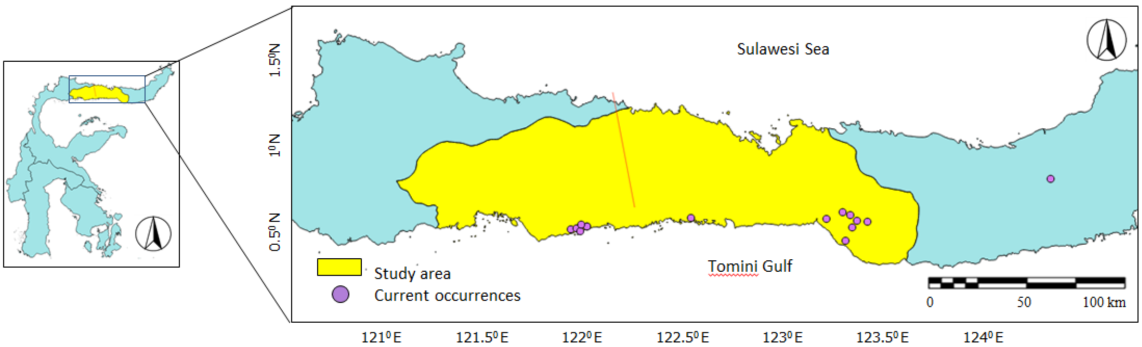

Figure 1. Study locations and Maleo current occurrences in Gorontalo

Maleo Occurrence Assessment

The *M. maleo* occurrence in the Gorontalo was recorded and assessed through surveys, database, and literature reviews following Karim et al. (2020). The survey techniques used included visual encounter surveys and multiple surveys through random visits. The survey was conducted during various time periods of the day using direct observations supported by binoculars and unaided eyes. Based on the *M. maleo* activities, the survey was carried out at 05.30–7.00 am and continued at 04.00–06.15 pm. The bird sampling followed methods by Buckland et al. (2001), Broekema and Overdyck (2012), Ma (2012), Thunhikorn et al. (2016), and Chiok et al. (2020) using a point count distance sampling methods by locating sampling point with three (3) replications in each land cover location and within the detection radius of 50 m considering the Maleo bird is elusive species and often hiding inside vegetation. The identification of *M. maleo* was done using a bird identification book and field guide (MacKinnon & Phillipps 1993). Then, presence and occurrence points of *M. maleo* were tabulated into a Geographical Information System (GIS) to be mapped. The ecological characteristics of the species were defined based on vegetation types including vegetation, forest, and non-vegetated areas as bird ecological traits following Morelli et al. (2024).

Data Analysis

Data analysis includes the modeling of Maleo suitable habitats known as Species Distribution Modelling (SDM) (Figure 2). The modeling was based on vegetation and forest cover predictors. The model then validated using Area under the curve analysis and receiver operating characteristic curve (AUCROC).

Vegetation and Forest Cover Analysis

The vegetation and forest cover in the Gorontalo landscape was classified using the Geographical Information System (GIS) (Thoha & Triani, 2021). The method starts with retrieving the Gorontalo boundary and Sentinel 2 Level 2A images of this province with a spatial resolution of 30 m per pixel. For preprocessing process, the image data sets were geometrically corrected using the World Geodetic System

(WGS) 1984 datum and the European Petroleum Survey Group (EPSG) Geodetic Parameter Dataset 4326. The images were georeferenced using ground control points that were collected from a Gorontalo Province base map. Meanwhile, the study area was determined by performing a subset operation with the Gorontalo Province vector boundary as a guide. The Sentinel 2 Level 2A images imagery of the Gorontalo Province village was then classified into several land-cover classes: vegetation and non-vegetated (Utami et al., 2017). The classification adopted supervised classification. Prior to the classification process, ground-truthing of vegetation and forest cover was carried out to create a training data set and a signature file—a set of data that defines a training sample or cluster. By applying the training data, a supervised classification approach was performed to produce a vegetation cover map. The result is a thematic layer in the form of shapefiles (shps) of the Gorontalo Province and vegetation cover. This layer then was overlaid with the Maleo occurrence points for further analysis.

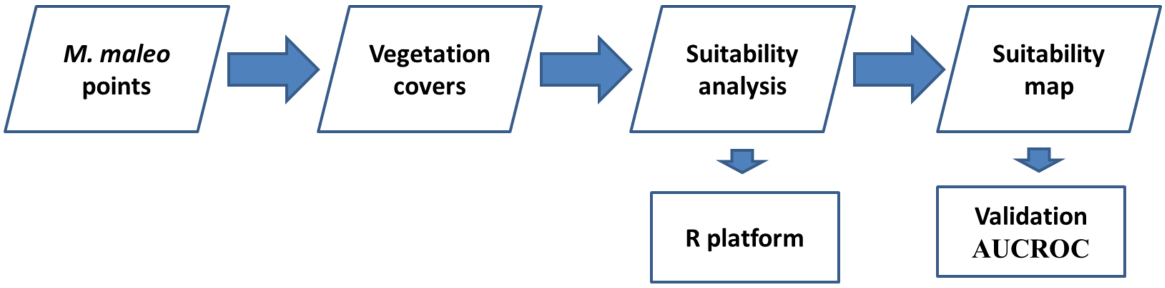

Figure 2. Flowchart of SDM

Suitability Analysis

This suitability analysis employed Species Distribution Modelling (SDM) analysis using R platform version 3.6.3 (Mao et al., 2022) (Figure 2) to generate predicted suitability maps of Maleo across the Gorontalo landscape. Several R packages required to develop the suitability maps include library("sp"), library("dismo") (Khan et al., 2022), library("maptools"), library("rgdal") (Bivand 2022), and library("raster") (Lemenkova, 2020). The inputs for SDM were included forest cover variables. This variable was selected since there was a correlation between the presences of Maleo with vegetation and forest cover (Karim et al. 2022). The results of SDM were suitable habitats that were classified into five classes including very low, low, moderate, high, and very high suitable.

Model Evaluation

This SDM model evaluation follows Reddy et al. (2015) and Song et al. (2023). Area under the curve analysis (AUC) was used to examine the SDM model. The size of the receiver operating characteristic curve (ROC) and the area under the curve (AUC) were used to assess SDM model prediction accuracy. The higher the AUC value, the greater the accuracy of the model's prediction outcomes, and the parameters of the SDM model were selected by Zhao et al. (2018). AUC is an effective and efficient independent threshold index with the capacity to assess the model's capacity to distinguish the presence and absence. AUC values are categorized into five different classes based on performance. The performance classes are failing (0.5 to 0.6), bad (0.6 to 0.7), reasonable (0.7 to 0.8), good (0.8 to 0.9) and great (0.9 to 1). Models with values less than 0.5 indicate that the occurrence in the real-life scenario is rare or can be considered as a guesstimate (Shcheglovitova & Anderson, 2013). Jackknife was run to systematically exclude each variable or evaluate the leading NDVI and NDMI variables. Jackknife evaluates the leading variables in determining the potential distribution of species.

Besides using AUC values, the SDM model was validated using TSS (True Skill Statistics) (De et al., 2020). According to Allouche et al. (2006), the TSS is expressed as Sensitivity + Specificity − 1 and ranges from −1 to +1, where +1 indicates a perfectly performing model with no error, 0 indicates the model with totally random error and -1 indicates the model with total error (Marcot 2012, Ruete & Leynaud, 2015).

RESULTS

This study is the first attempt to model Maleo on Sulawesi Island, in particular Gorontalo. This study used vegetation covers as predictors to project the suitable habitat for Maleo. The result section will be divided into several sections, including the current occurrences of Maleo and vegetation covers, suitable habitats, and model validation.

Maleo Occurrences

Based on the surveys, database, and literature reviews, Maleos were residing in some parts of Gorontalo (Figure 1, Table 1) with totals of 12 sampling points. At least Maleo was recorded on the south side of Gorontalo. It means Maleo was absent in the northern parts of Gorontalo. In the south, Maleo was recorded in the east and west parts of Gorontalo. In those areas,

Table 1. Sampling point coordinates and vegetation types

Sampling points	Coordinates	Regions	Vegetation types
1	0°27'17"N, 121°56'56"E	West	Forest
2	0°27'43"N, 121°57'55"E	West	Forest
3	0°27'19"N, 121°58'49"E	West	Forest*
4	0°27'51"N, 121°58'45"E	West	Forest*
5	0°27'38"N, 121°59'29"E	West	Forest
6	0°30'32"N, 123°04'57"E	East	Forest
7	0°24'32"N, 123°10'58"E	East	Forest
8	0°32'33"N, 123°10'27"E	East	Forest
9	0°31'14"N, 123°11'14"E	East	Forest
10	0°29'45"N, 123°12'15"E	East	Forest
11	0°27'49"N, 123°11'22"E	East	Forest
12	0°28'39"N, 123°12'58"E	East	Forest

*Mixed with non-vegetated areas

Maleo was clustered near the coasts. It means that Maleo was absent in the central parts of Gorontalo.

Vegetation Covers

Vegetation covers for Gorontalo are available in Figure 3. The map divided Gorontalo into non-vegetated and vegetation areas. The vegetation covers include forest covers. Gorontalo, mostly in its central parts, was fragmented by non-vegetated land covers. These non-vegetated covers were distributed and encroached on the coastal areas. Vegetation covers dominated the west and east parts of Gorontalo. The coastal areas on the south side bordered with the Tomini Gulf were still covered by vegetation, especially the east parts.

Maleo was preferred and recorded in areas with vegetation cover. In the eastern parts, most observations were recorded in areas covered by vegetation. In the west, in the areas between Marisa and Bumbulan, the Maleo records coincided with the non-vegetated areas. This is different from the Maleo records in the eastern parts.

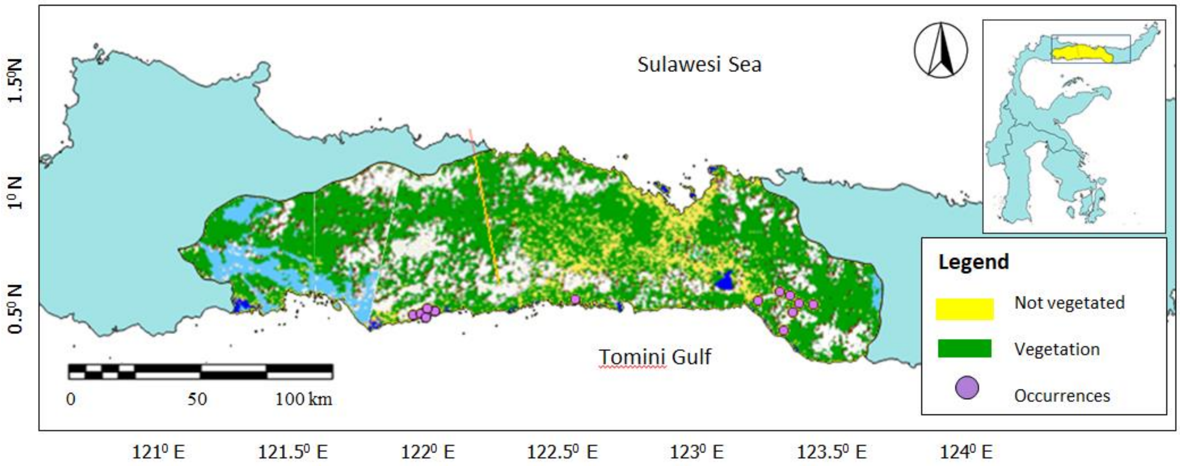

Figure 3. Vegetation covers and Maleo current occurrences in Gorontalo

Suitable Habitats

In this study, suitable habitats of Maleo were modeled by using predictors and the Maleo occurrence points. The results, model of suitable habitats was available in Figure 4. According to the model, most of the west and east parts of Gorontalo were considered not suitable for Maleo. While the coastal areas of Gorontalo were considered very suitable. This confirmed for both the north and south coastal areas of Gorontalo.

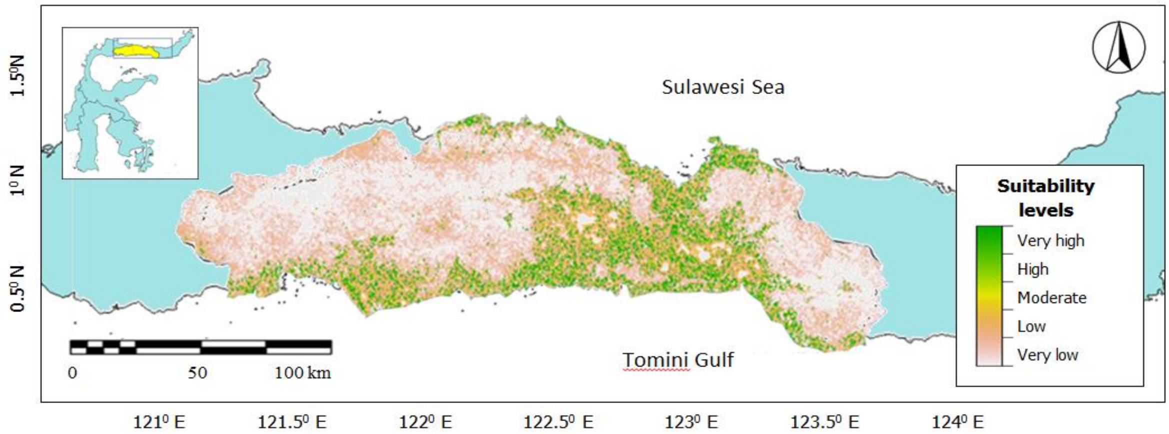

Figure 4. Suitable habitat model of Maleo in in Gorontalo

Model Evaluation

Figure 5 shows the results of SDM model evaluations based on the AUCROC values. SDM models were based on the vegetation cover variables. The AUCROC value was at 0.729 and 0.111 for TSS. Then according to AUCROC value, the model was considered reasonable.

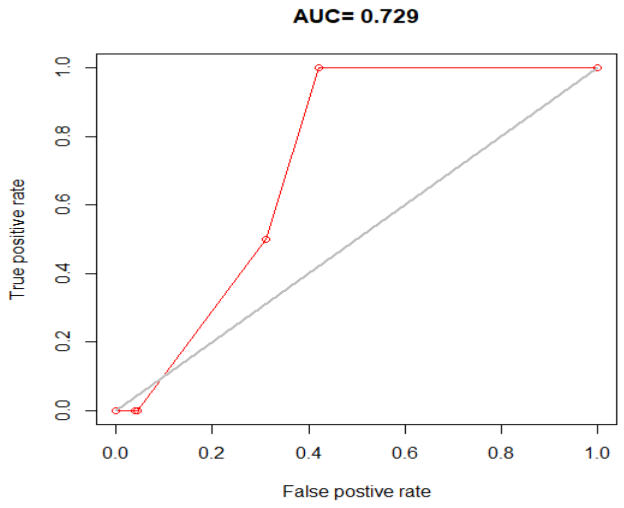

Figure 5. AUCROC of the model

DISCUSSION

SDM is one approach that has been widely used recently as a versatile tool to model the suitable habitats of certain species, including birds. Recently, many studies have modeled the avifaunal species. While sustainable habitat model studies for megapods, including Maleo, are still very limited. Then, to the best of our knowledge, this study is the first to have modeled the megapode-suitable habitats.

In this study, the model predicts an inland area far from the coasts as suitable habitat for Maleo. This may contradict the current research and observations that record that most of the Maleo preferred habitats were on the coasts. Actually, observation by Karim et al. (2020) has confirmed Maleo residing in inland habitats. In Towuti, in South Sulawesi, Maleo was recorded in Towuti Lake, which is 29.24 km from the nearby coast. Besides that, several results have also reported off the coast of Maleo habitats. Apriadi (2009) reported occurrences in Lore Lindu National Park (44.17 km from the coast) and (Jamili et al., 2015) observed Maleo in Savanna of Rawa Aopa Watumohai National Park at South Sulawesi at a distance of 9.73 from the coast. It confirms that inland areas far from the coast can also be suitable habitats for Maleo. While the inland areas indicated by the model may not be applied in Gorontalo, this is considering that, based on the vegetation cover predictors, those inland-suitable areas were already converted from vegetation cover to non-vegetated areas. There is an exception for this. In inland areas, the areas nearby Lake Limboto are still covered by vegetation. Then Lake Limboto, at a distance of 6.42 km, is considered to be an inland habitat for Maleo.

In Gorontalo, the most suitable habitats for Maleo were identified in the coastal areas. Maleo is known as a bird species that utilizes two habitats, both the coastal and inland areas, with vegetation and forest covers. Maleo requires a sandy substrate to bury its eggs (Maulany et al., 2021). It also requires open areas without shading because it requires solar radiation to heat up the eggs since Maleo does not incubate its eggs. This explains why the modeled suitable habitats were selected mostly from coastal areas.

After incubating its eggs, Maleo individuals will travel to the forest interior (Tasirin et al., 2021). Maleo uses forests for avoiding predators and nesting. This also explains why the SDM modeled and combined the inland areas with vegetation covers as suitable habitats for Maleo. Movements of Maleo from open areas to closed forest interiors were supported by the presence of green corridors that connect those distinct habitats. Those corridors can be forest covers or even tree covers within plantations, paddy fields, and even settlements (Beaugeard et al., 2021).

CONCLUSIONS

Gorontalo has suitable habitats for supporting Maleo. According to the vegetation covers, Maleo occurrence points, and model, most of the west and east parts of Gorontalo were considered not suitable for Maleo. While the coastal areas of Gorontalo were considered very suitable. This confirmed for both the north and south coastal areas of Gorontalo. The suitability model was considered reasonable since the AUCROC was valued at 0.729.

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AUTHOR CONTRIBUTIONS

A: field data collection, research implementer, data analysis, map making; FM: interpretation.

CONFLICTS OF INTEREST

The authors declare there is no conflict of interest related to financial funding and authorship order for this article.

REFERENCES

Allouche. O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). Journal of Applied Ecology, 43(6), 1223–1232.http://dx.doi.org/10.1111/j.1365-2664.2006.01214.x.

Apriadi, S.T. (2009). Analisis preferensi habitat Burung Maleo (*Macrocephalon maleo*) di Taman Nasional Lore Lindu Sulawesi Tengah. Tesis tidak diterbitkan, Sekolah Pascasarjana IPB, Bogor.

Baker, G. C. (2002). Conservation status of Maleo *Macroplalon maleo* nesting grounds: an update. Megapode Newsletter, 16,4-6.

Beaugeard, E., Brischoux, F., & Angelier, F. (2021). Green infrastructures and ecological corridors shape avian biodiversity in a small French city. Urban Ecosystems, 24(3).http://dx.doi.org/10.1007/s11252-020-01062-7.

Broekema, I. & Overdyck, O. (2012). Distance sampling to estimate densities of four native forest bird species during multi species surveys. New Zealand Journal of Ecology, 36(3).

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. & Thomas, L. (2001). Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press.

Butchart, S. H. M., & Baker, G. C. (2000). Priority sites for conservation of maleos (*Macrocephalon maleo*) in central Sulawesi. Biological Conservation, 94(1), 79–91. https://doi.org/10.1016/S0006-3207(99)00161-5.

CITES. (2017). Convention On International Trade In Endangered Species Of Wild Fauna and Flora. Appendices I, II, and III. Valid from 4 October 2017.

Chiok, W., Ng, E., Tang, Q., Lee, J. & Rheindt, F. (2020). A distance sampling survey of the Critically Endangered Straw-headed Bulbul *Pycnonotus zeylanicus* in Singapore. Bird Conservation International, 1-13.

De, K., Ali, S.Z., Dasgpta, N., Uniyal, V.P., Johnson, J.A., & Hussain SA. (2020). Evaluating performance of four species distribution models using Blue-tailed Green Darner Anax guttatus (Insecta: Odonata) as model organism from the Gangetic riparian zone. Journal of Threatened Taxa, 12(14), 16962–16970. http://dx.doi.org/10.11609/jott.6106.12.14.16962-16970

Gorog, A. J., Pamungkas, B., & Lee, R. J. (2005). Nesting ground abandonment by the maleo (*Macrocephalon maleo*) in North Sulawesi: Identifying conservation priorities for Indonesia's endemic megapode. Biological Conservation, 126(4), 548–555. https://doi.org/10.1016/j.biocon.2005.07.006

IUCN. (2021). The IUCN Red List of Threatened Species. Version 2021-3.

Jamili, Analuddin, & Rudia, L. O. A. P. (2015). Studi karakteristik mikro-habitat burung maleo (*Macrocephalon maleo*) pada kawasan Taman Nasional Rawa Aopa Watumohai

(TNRAW) Sulawesi Tenggara. Biowallacea, 2(1), 182–195.

Karim, H.A., Najib, N.N., Darman, D., & Alam, A. (2020). Estimation of population and nesting behavior of Maleo bird (*Macrochepalon maleo*) in TWA Towutilake, East Luwu District. Gorontalo Journal Of Forestry Research, 3(2), 100–113.

Karim, F.R., Mas'yud, B., & Hernowo, J.B. (2022). Nesting site characteristics and egg hatching success of Maleo (*Macrocephalon maleo*) in Hungayono Sanctuary, Gorontalo. JPSL, 12(4), 570–578. http://dx.doi.org/10.29244/jpsl.12.4.570–578

Karim, H.A., Najib, N.N., & Sofyan, N. (2022). Vegetation characteristics of the Maleo Bird (*Macrochepalon maleo*) habitat at Natural Tourism Park of Towuti Lake, South Sulawesi. Jurnal Wasian, 9(1), 570–578

Khan, A. M., Li, Q., Saqib, Z., Khan, N., Habib, T., Khalid, N., Majeed, M., & Tariq A. (2022). MaxEnt modelling and impact of climate change on habitat suitability variations of economically important Chilgoza Pine (*Pinus gerardiana* Wall.) in South Asia. Forests, 13, 715. http://dx.doi.org/10.3390/f13050715

Lemenkova, P. (2020). Using R packages 'Tmap', 'Raster' And 'Ggmap' for cartographic visualization: an example of dem-based terrain modelling of Italy, Apennine Peninsula. Zbornik radova - Geografski fakultet Univerziteta u Beogradu 68, 99-116. http://dx.doi.org/10.5937/zrgfub2068099L.

Ma, X. (2012). Distance sampling to estimate the abundance of birds with sector and radial radar detection methods. Procedia Environmental Sciences, 13, 22804 2303.

MacKinnon, J.R., & Phillipps, K. (1993). A field guide to the birds of Borneo, Sumatra, Java, and Bali, the Greater Sunda Islands. Oxford University Press.

Mao, M., Chen, S., Ke, Z., Qian, Z., & Xu, Y. (2022). Using MaxEnt to predict the potential distribution of the little fire ant (Wasmannia auropunctata) in China. Insects, 13, 1008. http://dx.doi.org/10.3390/insects13111008 .

Marcot, B.G. (2012). Metrics for evaluating performance and uncertainty of Bayesian network models. Ecological Modelling, 230, 50–62. http://dx.doi.org/10.1016/j.ecolmodel.2012 .01.013

Maulany, R.I., Aliem, M.I., Nasri, & Ismail. (2021). A preliminary study of Maleo (*Macrocephalon maleo*) nesting in Kambunong Cape, West Sulawesi. IOP Conf. Ser.: Earth Environ. Sci. 681 012124

Morelli, F., Benedetti, Y., Stanford, J., Jerzak, L., Tryjanowski, P., Perna, P., & Santolini, R. (2024). Which bird traits most affect the goodness-of-fit of species distribution models? Ecological Indicators, 158, 111317. https://doi.org/10.1016/j.ecolind.2023.111 317.

Reddy, M.T., Begum, H., Sunil, N., Pandravada, S. R., & Sivaraj, N. (2015). Assessing climate suitability for sustainable vegetable roselle (*Hibiscus sabdariffa* var. sabdariffa l.) cultivation in India using Maxent. Agricultural and Biological Sciences Journal, 1(2), 62-70.

Ruete, A., Leynaud, G. C. (2015). Goal-oriented evaluation of species distribution models' accuracy and precision: True Skill Statistic profile and uncertainty maps. PeerJ PrePrints 3: e1208v1. http://dx.doi.org/10.7287/peerj.preprints.1 208v1

Shcheglovitova, M., & Anderson, R.P. (2013). Estimating optimal complexity for ecological niche models: a Jackknife approach for species with small sample sizes. Ecol. Model. 269, 9–17.

Song, D., Li, Z., Wang, T., Qi, Y., Han, H., & Chen Z. (2023). Prediction of changes to the suitable distribution area of Fritillaria przewalskii Maxim. in the Qinghai-Tibet plateau under Shared Socioeconomic Pathways (SSPS). Sustainability 15, 2833. http://dx.doi.org/10.3390/SU15032833.

Tasirin, J.S., Iskandar, D.T., Laya, A., Kresno, P., Suling, N. (2021). Maleo *Macrocephalon maleo* population recovery at two Sulawesi nesting grounds after community engagement to prevent egg poaching. Global Ecology and Conservation, 28, e01699.

Thoha, A.S., Triani, H. (2021). A spatial model of forest and land fire vulnerability level in the Dairi District, North Sumatra, Indonesia. Biodiversitas, 22, 3319-3326. http://dx.doi.org/10.13057/biodiv/d22082 7.

Thunhikorn, S., Grainger, M. J., Mcgowan, P. J. K. & Savini, T. (2016). Methods used to survey avian species and their potential for surveying ground-dwelling birds in Asia. Forktail, 32, 5–13.

Utami, N., Sapei A., & Apip. (2017). Landuse change assessment and its demand projection in Batanghari River Basin, Sumatera, Indonesia. Limnotek, 24 (2), 52-60

Zhao, W.L., Chen, H.G., Lin, L., Cui, Z.J., & Jin, L. (2018). Distribution of habitat suitability for different sources of Fritillariae cirrhosae bulbus. Chin. J. Ecol. 37, 1037–1042.