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Modeling the future distributions of *Centropus bengalensis* (Lesser coucal) in Muara Gembong Wetlands, West Java, Indonesia, related to CMIP5 climate change scenarios

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Abstract. *Wibowo AA, Meylani V, Pratiwi NA, Febriani DN, Suryawati NN. 2024. Modeling the future distributions of* Centropus bengalensis *(Lesser coucal) in Muara Gembong Wetlands, West Java, Indonesia, related to CMIP5 climate change scenarios. Intl J Bonorowo Wetlands 14: 49-56*. Wetlands and their water birds have been threatened recently due to climate change. In West Java, Muara Gembong is a threatened wetland along with Lesser coucal (*Centropus bengalensis*, Gmelin 1788). This study aimed to model and forecast the distribution of Lesser coucal in the remaining wetland habitats to support species conservation. The novelty of this study is that it uses future Species Distribution Modeling (SDM) based on climate change scenarios. Modeling was performed based on SDM using R platforms incorporating 19 bioclimatic variables. The climate change scenarios used trajectories based on the 5th Coupled Model Intercomparison Project (CMIP) using RCP 2.6 and RCP 8.5 trajectories for 2050 and 2070. A multicollinearity test was performed, and the coucal occurrences were recorded at five sampling points. The results show climate change scenarios will significantly alter the suitable habitats for coucal, and the Area Under the Curve (AUC) is 0.75. The distribution of the species is mostly affected by isothermality (Bio 3), temperature annual range (Bio 7), and precipitation seasonality (Bio 15). In the low emission scenario, or RCP 2.6, from 2050 to 2070, it is predicted that the suitable habitats for coucals will be increased and expanded to the east and the north in coastal areas. Habitats classified in 2050 as less suitable will become moderately suitable in 2070 under the RCP 2.6 scenario. This condition is contrary to the high emission scenario under RCP 8.5. In this scenario, the habitats with high suitability only increased slightly. At the same time, and opposite to the low emission scenario, the RCP 8.5 scenario will cause moderately suitable habitats to become less suitable or have low suitability. This study provides empirical evidence of how a climate change scenario with high emissions can impact the water birds living in the wetlands.

Keywords: Climate change, coucal, RCP, SDM, wetlands

Abbreviations: CMIP: 5th Coupled Model Intercomparison Project, RCP: Representative Concentration Pathways, SDM: Species Distribution Modeling

INTRODUCTION

Currently, two coucal species exist in the wetland ecosystems: greater coucal (*Centropus sinensis* Stephens, 1815) and Lesser coucal (*Centropus bengalensis*, Gmelin 1788). The diet of *Centropus* is mainly insects, which makes this species important in controlling insect populations so as not to become pests in ecosystems. The difference lies in size and some morphological characteristics; first, compared to the greater coucal, the Lesser coucal has a slightly smaller body size and a shorter bill than the greater coucal. Pale shaft streaks on the head and back feathers differentiate the lesser from the greater coucal. Compared to the greater coucal, which has a crimson red iris, the Lesser coucal has a darker brown iris than the greater coucal. Regarding behavior characteristics and environmental requirements, the Lesser coucal has similar characteristics. The Lesser coucals require the undergrowth in marshy or grassy areas adjoining forests to live in singles or pairs, and for the climate presents to prefer mainly the lowland climate ecosystems. Coucals build a dome-shaped nest made of grass blades on a low tree, where this species hatches from 2 to 4 eggs inside the nests.

The species has a wide distribution from the west, including the Indian subcontinent, and extends to the east across Southeast Asia. Species in Southeast Asia have smaller sizes. It is widely distributed in Indonesia, from inland to coastal habitats. Despite inland or coastal habitats, the preferred habitats were wetlands. On Sumatra Island, *C. bengalensis* is common in Sugihan wetlands, South Sumatra (Setiawan et al. 2020). Still in Sumatra, *C. bengalensis* is commonly found in inland forests and plantations; this includes Lampung in rubber plantations (Tohir et al. 2020). Lorenza (2023) reported the presence of *C. bengalensis* in the inland secondary forest in Jambi Province, Sumatra, far from wetlands and coastal areas. The presence of grass and shrubs has supported the presence of *C. bengalensis* in this secondary forest. In urban Tangerang City, *C. bengalensis* is observed in Situ Cihuni, a wetland in the form of a lake in the middle of the city (Ekowati 2019). In this habitat, *C. bengalensis* appeared in almost 80% of those Situ Cihuni areas.

The species distribution model is significant, as evidenced by current research. As a result, a wide range of methods have been developed to replicate the spatial distribution of species. Species Distribution Modeling (SDM) based on machine learning is one technique widely used to estimate potential species spatial distributions. This model has been used to estimate the probable distributions of animals (Stephenson et al. 2022), crops (Dong et al. 2023), ticks (Pérez et al. 2023), and vegetation. There are many techniques for assessing an SDM's habitat suitability. The Generalized Additive Model (GAM), Bioclim, Domain, MaxEnt (Maximum Entropy), GLM, and Biomapper are some techniques. Each machine-learning technique is unique and has advantages and disadvantages therein. Marcer et al. (2013) claim that SDM is one of the most effective and widely used strategies for modeling the habitat suitability of certain species. SDM is performed in R environments, and R has advantages for developing SDM algorithms.

Currently, SDM has been used in avifauna studies, mainly in modeling the suitable habitats of bird species. In Sanjiangyuan National Park, Zhang et al. (2019) have successfully modeled suitable habitats for three raptor species. In their study, using SDM, it was predicted that the suitable habitats of raptors ranged from 60 to 90%. For water birds, Tian et al. (2023) have found suitable habitats for the anatid Baer's Pochard (*Aythya baeri* Radde, 1863). In Indonesia, SDM has been used to model the suitable habitats of the Javan hawk-eagle (*Nisaetus bartelsi* Stresemann, 1924) (Aryanti et al. 2021), indicating that highly suitable habitats accounted for 30%. Despite growing research on SDM on avifauna species, studies of SDM on particular shorebirds are still limited. Besides that, studies on how those avifaunal species respond to climate change are still lacking.

Muara Gembong is a remaining wetland on the coasts of West Jawa, Indonesia that is threatened due to the land use conversion from mangrove forests and wetlands to fish ponds and settlements. This wetland contains diverse shorebirds, accounting for 43 species (Fathani 2020), including *C. bengalensis* (Lesser coucal). According to the IUCN Red List, lesser coral is classified as the least concern (LC), as can be accessed from https://www.iucnredlist.org/species/22684254/93021566. The rapid conversion of remaining wetlands (Maulani et al. 2021), threatening the wetlands of Muara Gembong, will also threaten the presence of Lesser coucals. Those threats will become more imminent when combined with climate change phenomenon. Then, this study aims to model and forecast the distribution of Lesser coucals in the remaining wetland habitats to support this species' conservation. The novelty of this study is that it uses future distribution modeling based on climate change scenarios.

MATERIALS AND METHODS

The research was conducted on Muara Gembong's wetlands in West Java Province, Indonesia. Based on Species Distribution Modeling (SDM), the study methodology followed methods developed by Semu et al. (2021), including species occurrence, environmental variables, and model evaluations.

Study area

The study areas included 5 sampling locations (Figure 1) in Muara Gembong's wetlands, West Java Province, with geocoordinates of 106.96°-107.44° east longitude and 5.96°-6.20° south latitude. This wetland covers Bekasi Districts in the west and Karawang Districts in the east. The sea bordered the northern parts of the wetlands, and paddy fields and settlements bordered the southern parts. The wetlands are combinations of water vegetated with mangroves and fish ponds.

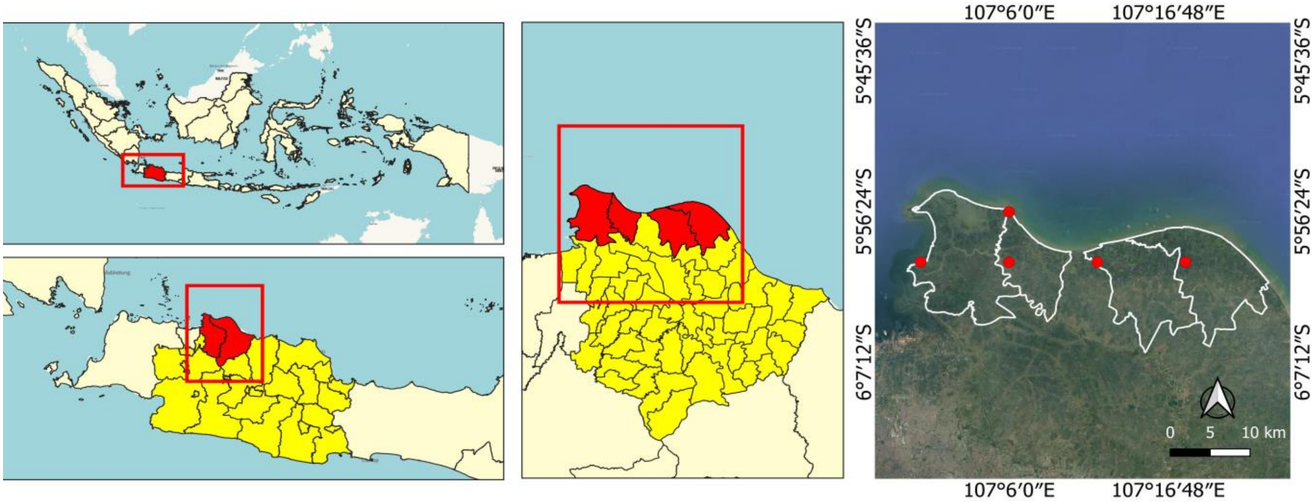

Figure 1. A map of the study area shows five sampling points of occurrences located in Muara Gembong's wetlands, West Java Province, Indonesia

Procedures

Coucal occurrence surveys

The coucal survey in the wetlands of Muara Gembong was conducted for two months, from January to February 2024, with 3 replications for each sampling point. The survey techniques used included visual encounter surveys and multiple surveys through random visits. The survey was conducted during various periods of the day using direct observations supported by binoculars and unaided eyes. Based on the coucal activities, the survey was conducted at 05.30-7.00 am and continued at 04.00-06.15 pm. Coucal was identified using a bird identification book and field guide (MacKinnon and Phillipps 1993). The presence of coucal is then tabulated into a Geographical Information System (GIS) to be mapped into Muara Gembong basemap layers.

Coucal bioclimatic variables

This study includes a range of bioclimatic variables (Table 1), in line with Dong et al. (2023) and Arshad et al. (2022). Bioclimatic variables (Bio 1-19) from the global climate database WordClim (www.worldclim.org, the new version 2.0) (Khanum et al. 2013; Rana et al. 2017) were accessed in January and February 2024 (Hijmans et al. 2005). In recent years, including in Southeast Asia, bioclimatic variables have been extensively utilized in habitat suitability modeling.

Those bioclimatic variables were chosen based on the selection and evaluation of bioclimatic variables that had a significant impact, aiming to create an accurate and comprehensive habitat suitability model. Jackknife analysis was used to evaluate the contribution of each bioclimatic variable to the final model. The model did not evaluate a few bioclimatic variables from the Jackknife analysis since their percentage contribution equaled 0 and had no effect. The bioclimatic variables are thought to have a low average contribution if the values are less than 6% or a low permutation if the values are less than 6%, according to Wei et al. (2018). The contribution percentage and permutation are two important indicators representing the comprehensive quantification of the bioclimatic variable's contribution and significance to the SDM model.

Multicollinearity test

A multicollinearity test was conducted using Pearson's correlation tests (Préau et al. 2018) on 19 bioclimatic variables, ranging from Bio 1 to Bio 19 (Table 1), to prevent collinearity between the variables and develop a model that performs better with fewer variables. Variables that were highly cross-correlated and had r^2 values larger than 0.8 were removed, while variables with r^2 values less than 0.8 were kept for further analysis concerning particular distribution modeling. A variable's predictive ability is deemed unstable and erroneous when multicollinearity occurs because of its strong association with other variables in the model (As'ary et al. 2023). The chosen bioclimatic variables to be employed were Bio 3, 4, 7, 13, and 15 based on the results of the multicollinearity test.

Coucal habitat suitability analysis

The R application version 3.6.3 (Mao et al. 2022) machine learning SDM methods were used in this study to create predicted suitability maps of *C. bengalensis* over Muara Gembong Wetlands. Many R applications, including sp, dismo (Khan et al. 2022), maptools, rgdal (Bivand 2022), and raster packages (Lemenkova 2020), are needed to create the suitability maps. The SDM uses received inputs from 19 bioclimatic variables (Bio 1-19). The receiver operating curve (AUC) area was utilized to assess the performance model, and a Jackknife Test was employed to ascertain the impact and contribution of each bioclimatic variable on the *C. bengalensis* habitat suitability model (Promnikorn et al. 2019). AUC values vary from 0 (least appropriateness) to 1, where a value of more than 0.5 indicates that the final model is extremely good and informative, and a value of less than 0.5 suggests that the final model represents uninformative data.

The prediction map generated by the SDM models was put into GIS for presentation and additional study, according to Hijmans et al. (2005). On the SDM model map, habitat suitability levels are divided into five categories, according to Wei et al. (2018): 0 for unsuitable, 1 for having low suitability, 2 for moderate suitability, 3 for high suitability, and 4 for very high suitability.

CMIP5 future scenario

Two scenarios were used in this investigation. The first scenario is the situation as it is in 2024 or the current distribution, and the second is a future scenario based on the RCP 2.6 and RCP 8.5 estimates from the 5th Coupled Model Intercomparison Project (CMIP) for the year 2070. The future scenario is based on the Fifth Assessment Report (AR5) (IPCC 2008) of the Intergovernmental Panel on Climate Change (IPCC) using downscaled global climate model data from CMIP5. The IPCC's 2014 AR5 applied multiple Representative Concentration Pathways (RCPs) for the CMIP5, representing trajectories of greenhouse gas concentrations rather than emissions. This has replaced the forecasts from the Special Report on Emissions Scenarios (SRES) issued in 2000 (Vuuren et al. 2009). These routes in climate modeling and study describe four potential future climates, all of which are thought to be feasible depending on the quantity of greenhouse gases released shortly. The four RCPs—RPP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5—are called after potential ranges of Radiative Forcing values in the year 2100 in comparison to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively), according to Weyant et al. (2009). Therefore, to simulate the habitat suitability distributions of *C. bengalensis* by the years 2050 and 2070, this study chose the RCP 2.6 models representing low emission scenarios followed by RCP 8.5 models representing high emission scenarios.

Table 1. Bioclimatic variables were used in this study (Ulak and Paudel 2021)

Variables	Sources	Format	Unit
Annual mean temperature (Bio 1)	www.worldclim.org	Image data in Raster	°C
Mean diurnal range (Bio 2) (mean of monthly (max temp - min temp))	www.worldclim.org	Image data in Raster	°C
Isothermality (Bio 3)*	www.worldclim.org	Image data in Raster	%
Temperature seasonality (Bio 4)*	www.worldclim.org	Image data in Raster	°C
Max temperature of the warmest month (Bio 5)	www.worldclim.org	Image data in Raster	°C
Min temperature of the coldest month (Bio 6)	www.worldclim.org	Image data in Raster	°C
Temperature annual range (Bio 7)*	www.worldclim.org	Image data in Raster	°C
Mean temperature of the wettest quarter (Bio 8)	www.worldclim.org	Image data in Raster	°C
Mean temperature of the driest quarter (Bio 9)	www.worldclim.org	Image data in Raster	°C
Mean temperature of warmest quarter (Bio 10)	www.worldclim.org	Image data in Raster	°C
Mean temperature of coldest quarter (Bio 11)	www.worldclim.org	Image data in Raster	°C
Annual precipitation (Bio 12)	www.worldclim.org	Image data in Raster	mm
Precipitation of wettest month (Bio 13)*	www.worldclim.org	Image data in Raster	mm
Precipitation of driest month (Bio 14)	www.worldclim.org	Image data in Raster	mm
Precipitation seasonality (Bio 15)*	www.worldclim.org	Image data in Raster	dimensionless
Precipitation of wettest quarter (Bio 16)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest quarter (Bio 17)	www.worldclim.org	Image data in Raster	mm
Precipitation of driest quarter (Bio 18)	www.worldclim.org	Image data in Raster	mm
Precipitation of coldest quarter (Bio 19)	www.worldclim.org	Image data in Raster	mm

Note: *: selected variables based on multicollinearity test

RESULTS AND DISCUSSION

Coucal occurrences

According to the collected occurrence data and survey, coucals are mainly found (Figure 1) in the middle and towards the coasts of Muara Gembong. They are expanded from the western in the Bekasi and to the eastern in Karawang. Near the coastal areas, coucals were observed in the wetlands mixed with mangroves and fishponds. In the middle parts, coucals were observed in the wetlands mixed with fishponds and settlements.

Coucal bioclimatic variables

There were selected bioclimatic variables according to the multicollinearity test. Those selected bioclimatic variables include Bio 3 (isothermality), Bio 4 (temperature seasonality), Bio 7 (temperature annual range), Bio 13 (precipitation of the wettest month), and Bio 15 (precipitation seasonality). According to percentage contributions 3 (Figure 2), Bio 3 has the highest contributions, accounting for 47.24%, followed by Bio 7 and Bio 15, with values of 21.78% and 16.53%, respectively, indicating the contributions of temperature and precipitation bioclimatic variables in determining the suitable habitats for coucal in Muara Gembong. For Bio 3 (Figure 3), the most suitable habitats for coucal were characterized by isothermality (Bio 3) (47.24%) with values of 80-85. For the temperature annual range (Bio 7) (21.78%), the suitable habitats had differences in annual temperature with ranges of 11.0-11.3°C and 70-75 for precipitation seasonality (Bio 15) (16.53%). The highest suitability occurred when air temperature seasonality (Bio 4) (13.91%) ranged from 420 to 450 and precipitation of the wettest month (Bio 13) (0.52%) ranged from 38.5 to 40.0 mm.

Coucal current potential distributions

Figure 4 shows the current potential distributions of coucal in the Muara Gembong's wetlands with an Area Under the Curve (AUC) value of 0.75 (Figure 5), indicating the model performance of SDM is good. Based on the SDM analysis, the potential habitats are available in the western in the Bekasi District and Karawang in the eastern. The potential habitats were concentrated on the coast and rarely observed in the middle regions. This habitat follows the availability of the wetlands that remain in the coastal area of Muara Gembong. The current potential habitat sizes for coucal based on the suitability levels are high > low > very high suitability levels, with values of 425 km^2 for both high and low suitability levels and 100 km^2 for very high suitability levels (Figure 6). The suitable habitats with very high suitability levels were available in the Karawang Districts, and most of the suitable habitats with high suitability levels were located in the Bekasi District, which expanded to southwestern Jakarta in the west of Bekasi. Those areas are considered suitable for coucals since they have a suitable climate.

Coucal future potential distributions

Climate change will impact the potential habitats for coucal, which is apparent in the suitable habitats' size and locations (Figure 7). Under RCP 2.6, areas considered suitable will decrease compared to current habitats. This includes reducing the suitable habitats classified as highly suitable under the current scenario that will be reduced under RCP 2.6 in 2050. However, in 2070, the highly suitable habitats will be estimated to increase to the extent stated, similar to the current conditions. Under RCP 2.6 in 2070, habitat classified as very suitable, especially in Bekasi District, will be expanded to the southern, increasing from 50 km^2 in 2050 to 350 km^2 in 2070. At the same time, in Karawang District, habitats classified as very suitable will be expanded to the northern to include coastal habitats. Besides that, under RCP 2.6 in 2070, a habitat classified as less suitable or having low suitability in 2050, particularly Karawang District, will be changed to moderately suitable (Figure 7).

Under RCP 8.5 (25 km^2) in the year 2050, the areas classified as very highly suitable are reduced in comparison to similar suitable habitats under RCP 2.6 (50 km^2) in 2050 (Figure 7). In 2070, the suitable habitats classified as very-high suitable will be slightly increased; those very high suitable habitats will be increased to the eastern in Karawang. Compared to the year 2050, under RCP 8.5, very highly suitable habitats will only be available in Karawang in 2070. Under RCP 8.5, habitats previously classified as moderate in 2050 will disappear in 2070 and be replaced by low-suitability habitats (Figure 5).

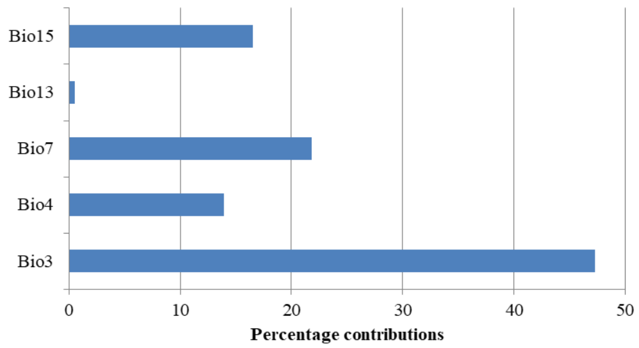

Figure 2. Percentage contribution averages of selected bioclimatic variables (Bio 3, Bio 4, Bio 7, Bio 13, Bio 15) representing different climatic scenarios

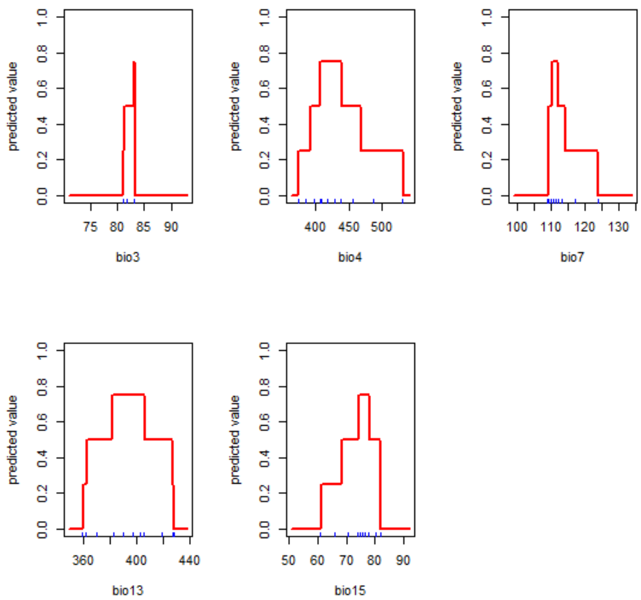

Figure 3. Response curves of selected bioclimatic variables (Bio 3, Bio 4, Bio 7, Bio 13, Bio 15)

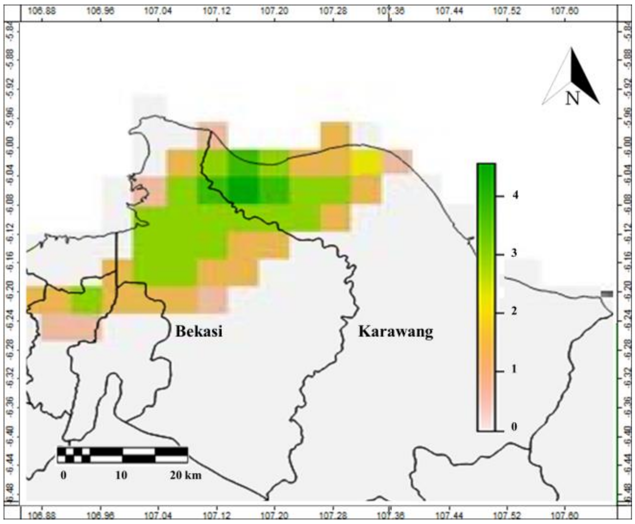

Figure 4. A map of the study area shows the current potential distribution of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia (Suitability level 0: unsuitable, 1: low suitability, 2: moderate suitability, 3: high suitability, 4: very high suitability)

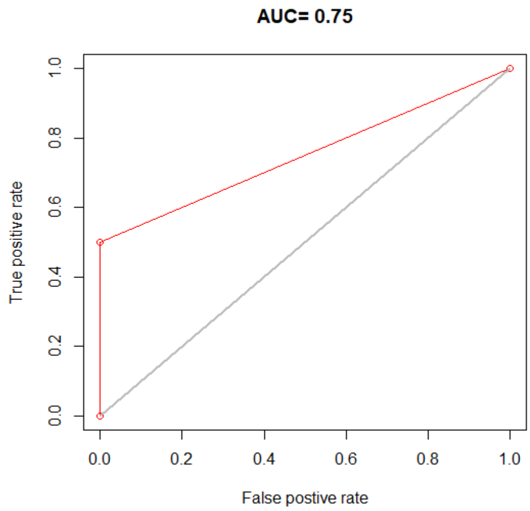

Figure 5. Area Under the Curve (AUC) of the model

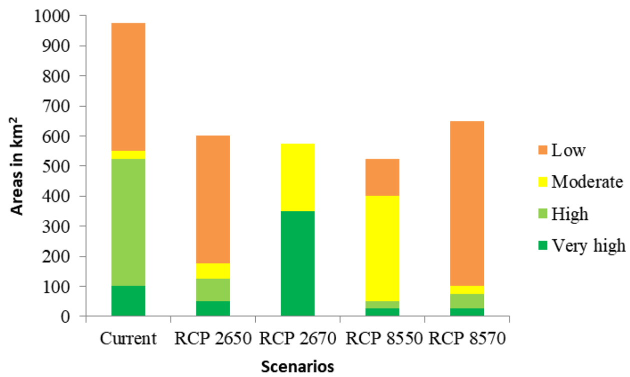

Figure 6. Compositions of areas in km^2 based on current and future potential distributions of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia, based on RCP 2.6 and RCP 8.5 scenarios for 2050 and 2070

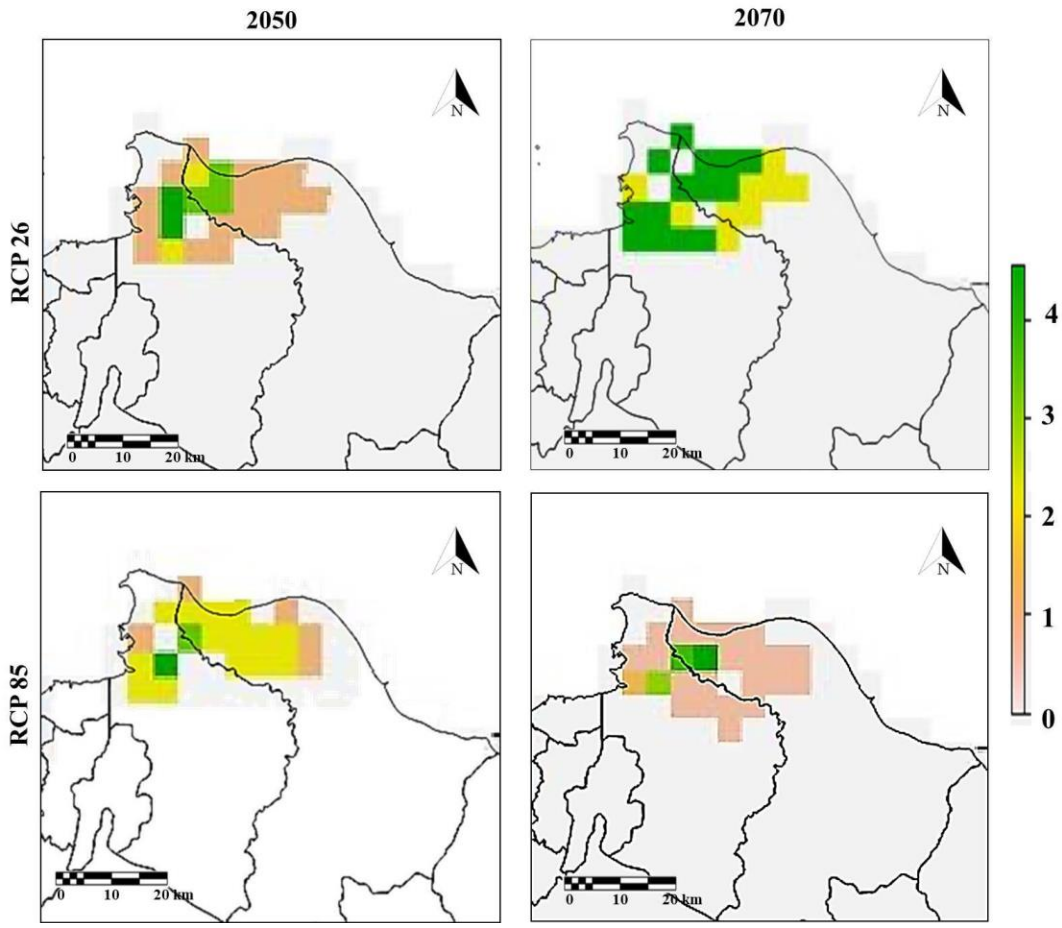

Figure 7. A map of the study area shows the future potential distribution of *Centropus bengalensis* in Muara Gembong's wetlands, West Java Province, Indonesia, based on RCP 2.6 and RCP 8.5 scenarios for 2050 and 2070 (Suitability level 0: unsuitable, 1: low suitability, 2: moderate suitability, 3: high suitability, 4: very high suitability)

Discussion

This is the first study that successfully modeled and forecasted future distributions of particular avifauna species, in this case, Lesser coucal species, in particular wetland habitats in Southeast Asia, specifically West Java. Therefore, using SDM methods, this study completed similar previous studies (Moreno et al. 2011, Montenegro et al. 2017). This study confirms that climate change will reduce the suitable habitats for coucals; the high emission scenario of climate change will cause a loss of almost half of its suitable habitats. The loss of significant habitats experienced by avifauna species due to climate change, as found in this study, agrees with current studies. Şekercioğlu et al. (2012) estimated that an avifauna species would lose 25% to 56% of its suitable habitats under low-emission scenarios. At the same time, under the high emissions scenarios, an avifauna species will lose even from 27% to 74% of its suitable habitats, confirming habitat reduction increases due to climate change. This situation is also observed in the Muara Gembong, where under RCP 8.5, a previously classified moderate habitat can become less suitable or have low suitability levels.

This study revealed the suitable habitats for coucals will shift. In 2070, the suitable habitats will shift eastward under RCP 2.6, and under RCP 8.5, the suitable habitats will shift slightly eastward in 2070. The shifting of suitable habitats is an impact of climate change. In their study, Wang et al. (2024) observed that the avifauna suitable habitats shifted southeast in 2050 in the Central Urban Area of Chongqing Municipality. The shifting of suitable habitats varied depending on the characteristics of study areas that were unique and varied among geographical locations.

This study shows most bioclimatic variables influencing climate suitability are dominated by temperature and precipitation-related bioclimatic variables. Those variables include Bio 7, Bio 13, and Bio 15. This finding agrees with previous studies observing that particular Bio 7, Bio 13, and Bio 15 are determinant bioclimatic variables. Temperature-related bioclimatic variables were considered the most important variables that could potentially impact species metabolisms; the other variable is temperature, which affects animal reproductive systems and growth. Under the high emission scenario 2070 indicating temperature rises, some areas previously suitable for climate change became less suitable. Therefore, under the climate change scenario, those areas are becoming warmer, indicating a temperature increase that may not suit climate change. Warming temperatures are associated with slower growth and smaller bird hatchlings (Weeks et al. 2022). The warmer temperatures can inhibit the increases in some avifauna body parts required for movements and flights, including lengths of tarsus, feathers, and head and body sizes (Sauve et al. 2021).

Temperature can also affect breeding regarding the breeding timing of avifauna species, causing habitat to become unsuitable. Climate change, characterized by increased temperature, will lead an avifauna to lay its eggs earlier (Li et al. 2022), and this becomes an unsuitable condition if the food is unavailable for hatchlings. As a result, the bird hatchling does not have the necessary food supply and will starve to death.

Climate change, followed by temperature rise, will affect the presence of avifauna species, including insects that are the coucal's main diet. Coucals are known as insectivores and feed on insects and caterpillars, and a habitat will become suitable if an insect is available in that habitat. According to previous studies, temperature rise due to climate change will cause a delay in the feeding activities of caterpillars (Chenon and Susanto 2006) and lead to a decline in their abundance. This explains why some areas in Muara Gembong become less suitable under the high emission scenario. This probably affects the coucal prey, particularly caterpillar availability and abundance in these areas, which may be reduced following climate change and temperature rises.

Moreover, the indirect causes, besides bioclimatic variables, were also responsible for explaining the suitable coastal habitat reductions in the wetlands of Muara Gembong under high-emission scenarios. Climate changes will be followed by sea level rises, and this is predicted to happen in the coastal areas of West Java, including in Muara Gembong. It is estimated that the sea level rises on Java coasts (Kismawardhani et al. 2018) accounted for 10.6 mm/year, and this, combined with the land subsidence, accounted for 5.37 cm/year, as reported by Andari et al. (2023) will treat coucal habitats in the wetlands. Climate change, followed by sea level rise and land subsidence, will cause flooding and inundation of dryland parts of wetlands that are inhabited by coucals. As a result, inundation caused by sea level rise and climate change (Rosencranz et al. 2018) will cause a coastal loss of areas of the wetlands, including habitats for coucals foraging and nesting.

This study has successfully modeled the future distribution of Lesser coucals under climate change scenarios in the Muara Gembong Wetlands. The low-emission scenario will provide an opportunity for coucals to strive. This condition is different under high-emission scenarios. Therefore, under RCP 8.5 and in the future, habitats classified as moderate will disappear in 2070 and be replaced by low-suitability habitats. This study contributes to the landscape ecology of *C. bengalensis* by informing us that the coastal habitats of this species may change and shift in the future, and conservation initiatives should be aware of these alterations.

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