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MODELING SHIFTING GEOGRAPHICAL DISTRIBUTIONS OF LEAST CONCERN ASIAN BRACKISH FROG *FEJERVARYA CANCRIVORA* (GRAVENHORST, 1829) (ANURA: DICROGLOSSIDAE) IN WEST JAVA, INDONESIA RELATED TO CMIP 5 RCP 8.5 CLIMATE CHANGE SCENARIO

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ABSTRACT

Amphibians and their geographical distribution are threatened by climate change, including species in West Java, Indonesia. It is estimated that 300 amphibian species are threatened, including the family Dicroglossidae. At the same time, information on how climate change impacts amphibian species in Indonesia is very limited. This study aims to assess and model the suitable habitat for the least concern Asian brackish frog, *Fejervarya cancrivora* (Gravenhorst, 1829), under the CMIP 5 RCP 8.5 future climate change scenario by 2070, analyzed using Maximum Entropy (MaxEnt). The models developed with MaxEnt showed good predictivity, with an AUC value of 0.701. The models that inform the precipitation of the wettest month, isothermality, and mean diurnal range variables have significant contributions to make in shaping *F. cancrivora* geographical distributions. The models confirm that *F. cancrivora* had shifted its geographical distribution and had gained and lost habitats under a future climate change scenario by 2070. *F. cancrivora* will lose 4,428 km^2 of its current habitat and will gain 2,673 km^2 of new habitat. In total, climate change will cause *F. cancrivora* to lose its habitat by 1,755 km^2.

Key words: amphibian, climate change, MaxEnt, precipitation, RCP

INTRODUCTION

Fejervarya cancrivora (Gravenhorst, 1829), an amphibian belongs to Dicroglossidae and commonly known as Asian brackish frog, marsh frog, rice-field frog, or crab-eating frog,inhabiting wide habitats across South East Asia ecosystems including Indonesia and Java Island, specifically in West Java, in Karawang (Kurniati & Laksono, 2022) and Dramaga (Akhsani, et al., 2021). This species is very common in aquatic parts of terrestrial ecosystems including man-made ecosystems in rice fields. It can adapt to various elevations ranging from 0 to 1,500 m asl (Kurniati & Sulistyadi, 2017). Although listed as Least Concern (https://www.iucnredlist.org/search?query=Fejervarya%20cancrivora), attention has been paid to this species due to population decline, over-harvesting, habitat loss, and climate change impacts (Zhao et al., 2022).

Recently, climate change and greenhouse gas concentration determined large-scale patterns of species distribution including amphibians (Alves-Ferreira et al., 2022). Among vertebrates, amphibians represent one of the most vulnerable groups to global warming since amphibians are highly dependent on specific climatic conditions and have narrow ecological niches. Climate change may increase the vulnerability of amphibians in combination with other impacts like habitat loss, emerging diseases, and chemical contaminants. Climate change has According to the Global already placed 32% of amphibian species under some of the IUCN Red List threat categories (i.e., Vulnerable, Endangered, or Critically Endangered). Thus, anticipating the effects of climate change on the amphibians' distribution, modeling amphibians' species distribution has become a priority for conservation (Araújo & Peterson, 2012).

The Intergovernmental Panel on Climate Change (IPCC) has created several climate scenarios based on greenhouse gas concentrations known as Representative Concentration Pathways (RCP). RCP 8.5 is an emission scenario without policies to reduce emissions with a rapid increase in methane, high use of fossil fuels, and the slow development of technology to reduce the impact of climate change. Then, the RCP 8.5 climate scenario is considered suitable to simulate the impacts of climate change on the amphibians' distribution (Doulabian et al., 2021).

Recent research has indicated the role of model species distribution. As a result, several methods have been developed to model species distribution at spatial scale. One approach that has been used widely to model the potential spatial distributions of a species is known as Maximum Entropy (MaxEnt) modelling. This model has been used widely to estimate potential distributions of animal (Stephenson et al., 2022), ticks (Sanchez et al., 2023), vegetation (Dong et al., 2023), and crops. Besides MaxEnt, there are a growing variety of methods for estimating habitat appropriateness, including MaxEnt (Maximum Entropy), BIOCLIM, DOMAIN, generalized additive model (GAM), GLM, and BIOMAPPER. Each tool is unique, with its own set of pros and downsides. According to Marcer et al. (2013), among other things, MaxEnt is one of the best and is most often used habitat suitability modeling tools. Several advantages of MaxEnt include the need for only species presence data, the capacity to run with a limited quantity of data, the high accuracy of prediction results, the high reproducibility, and the ability to predict the most discriminating environmental factors (Fois et al., 2018).

On Java Island, West Java is a region that has been reported frequently for the presence of amphibian species including *F. cancrivora.* This species was recorded in rice fields in Karawang, West Java (Phadmacanty & Kurniati, 2019). It was also reported in Dramaga West Java (Akhsani et al., 2021). While at higher altitudes, this species was observed in Mount Sawal, Ciamis, West Java (Maulana et al., 2023). In Banten areas, *F. cancrivora* was reported present in Ujung Kulon (Kusrini, 2014). Despite growing research on *F. cancrivora* in West Java, information about how this amphibian species can cope with climate change scenarios is very limited. Here, this study aimed to model the geographical distributions of *F. cancrivora* under RCP 8.5 climate change scenario using MaxEnt analysis as the novelty.

MATERIALS AND METHODS

The method to estimate and model the potential geographical distributions of *F. cancrivora* comprises several steps (Fig. 1). It starts with the species occurrence recording and multicollinearity test to select relevant environmental variables.

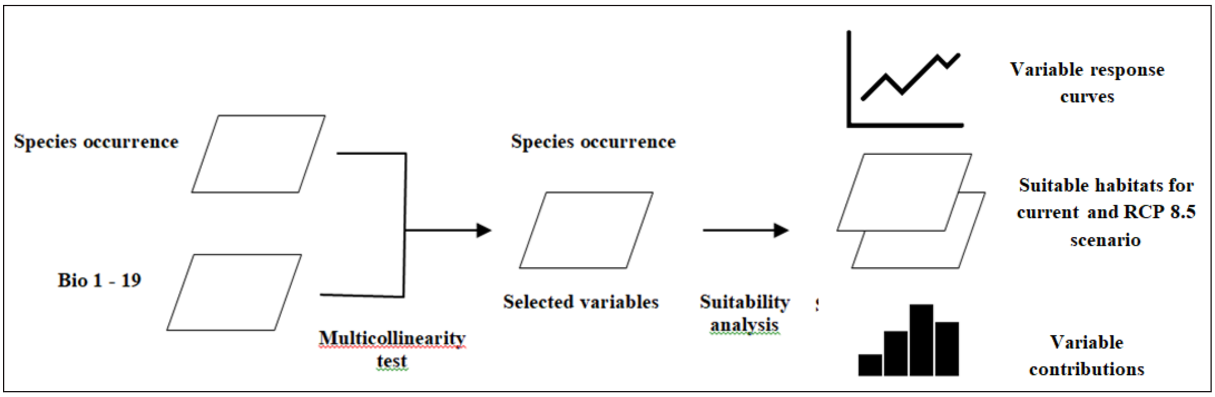


Figure 1. A flowchart of the suitability analysis and geographical distribution modeling.

Study area

The study areas in terrestrial ecosystems of West Java include Banten, Indonesia with geocoordinates of $6.0^0 – 8.0^0$ S and $105.0^0 – 110.0^0$ E (Fig. 2). West Java and Banten regions, as a part of the Pacific Ring of Fire, have more mountains and volcanoes than any of the other regions in Indonesia. The presences of volcanoes cause the lands to become more fertile and followed by high biodiversity. Forest in West Java covers 764,387.59 ha or 20.62% of the total size of West Java. Forest in West Java is dominated by productive forest 362,980.40 ha (9.79%), protected forest 228,727.11 ha (6.17%), and conservation forest 172,680 ha (4.63%) and made theses areas suitable habitats for amphibian species. Air temperature in West Java ranges from 20.0 ^{0}C to 27.6 ^{0}C. Annual precipitation in West Java ranges from 1,414 mm to 4,347 mm with an average of 3,000 mm/year.

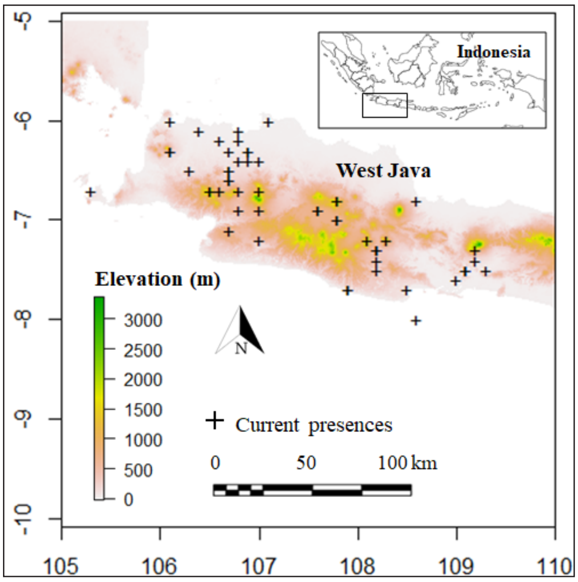


Figure 2. Study area and current occurrences of *Fejervarya cancrivora* across elevation gradients in West Java, Indonesia

F. cancrivora occurrence surveys and recordings

Explorations or field surveys combined with literature and database reviews were conducted to survey and record the presence of *F. cancrivora* in West Java (Fig. 2) from November 2022 to March 2023. The presence of *F. cancrivora* was recorded using Visual Encounter Survey (VES) and a database provided and gathered from literature reviews sourced from journal articles and reports provided by government agencies, including the agency of agriculture and forestry at the Indonesian Ministry of Environment and Forestry. All habitat types in every survey site were surveyed by VES twice both during the day and at night. The VES is used when the researcher actively looking for *F. cancrivora* on all microhabitats including beneath logs, debris, and rocks. Night visual observation was also undertaken assisted by a headlamp and slowly walking across an area of broadly consistent habitat type with time duration. The visual observation was consistently applied for three hours of day censuses and three hours of night censuses following Riyanto (2011). The VES started from 09:00 to 12:00 for day censuses and from 20:00 to 23:00 for night censuses. Following Zakaria et al. (2022), a sweep net was used to help capture *F. cancrivora*, as they are very slippery, thus making them easily escape, and they are very delicate and can be easily injured if handled recklessly with bare hands. The geographical coordinates of *F. cancrivora* presences in the field were recorded using the Garmin Etrex 30 type Global Positioning System (GPS). The data were converted to Microsoft Excel and saved in CSV format for use in MaxEnt habitat suitability modeling. Following Riyanto and Rahmadi (2021), the species identification to determine *F. cancrivora* was based on amphibian identification keys (Kusrini, 2013; Frost et al., 2021; Uetz et al., 2021).

Environmental variables

This study included various environmental variables (Table 1). For the recent time, bio-climatic variables (Bio 1 – Bio 19) from the global climate database WorldClim (www.worldclim.

org, the new version 2.0) (Hijmans et al., 2005) have been employed extensively in habitat suitability modeling (Khanum et al., 2013) and are widely used in the Asian region (Rana et al., 2017). Furthermore, geophysical data in the form of topography and altitude were collected from satellite imagery and remote sensing interpretation and analyses following The Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 30 m.

Those environmental variables were chosen based on the selection and utilization of environmental elements having a significant influence on obtaining an accurate and informative habitat suitability model. Jackknife analysis was used to evaluate the contribution of each environmental variable to the resulting model. Some environmental variables were not used due to the lack of contribution to the model-making (percent contribution = 0). Those environmental variables were variables with a small average contribution (<6%) or permutation importance (<6%) (Wei et al., 2018). The contribution percentage and permutation are two important factors for understanding and measuring the environmental variable's contribution as well as importance to the MaxEnt model.

Table 1. Environmental variables used in this study (Ulak & Paudel, 2021)

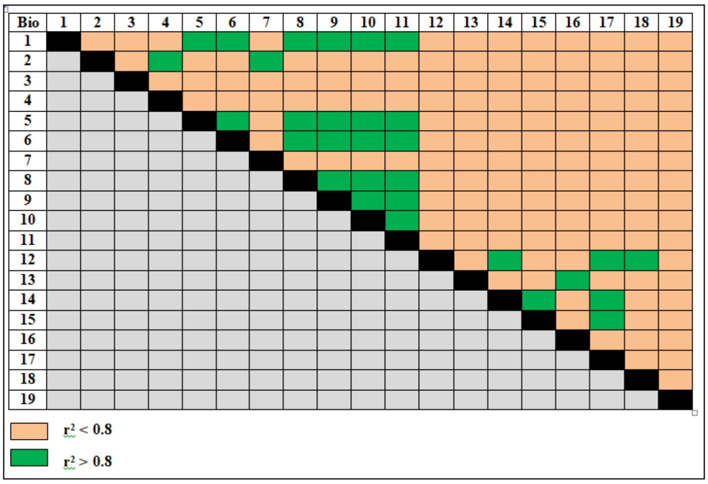
Variables	Sources	Format	Unit
Annual mean temperature (Bio 1) *	www.worldclim.org	Image data in Raster	^{0}C
Mean diurnal range (Bio 2) * (mean of monthly (max temp - min temp))	www.worldclim.org	Image data in Raster	^{0}C
Isothermality (Bio 3) *	www.worldclim.org	Image data in Raster	%
Temperature seasonality (Bio 4)	www.worldclim.org	Image data in Raster	^{0}C
Max temperature of warmest month (Bio 5)	www.worldclim.org	Image data in Raster	^{0}C
Min temperature of coldest month (Bio 6)	www.worldclim.org	Image data in Raster	^{0}C
Temperature annual range (Bio 7)	www.worldclim.org	Image data in Raster	^{0}C
Mean temperature of wettest quarter (Bio 8)	www.worldclim.org	Image data in Raster	^{0}C
Mean temperature of driest quarter (Bio 9)	www.worldclim.org	Image data in Raster	^{0}C
Mean temperature of warmest quarter (Bio 10)	www.worldclim.org	Image data in Raster	^{0}C
Mean temperature of coldest quarter (Bio 11)	www.worldclim.org	Image data in Raster	^{0}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
Topography and altitude	30 m SRTM	Image data in Raster	dimensionless
Current climate	www.worldclim.org	Image data in Raster	^{0}C
CMIP 5 RCP 8.5 2070	www.worldclim.org	Image data in Raster	^{0}C

*: selected variables based on multicollinearity test

Multicollinearity test

To establish a model that has better performance with fewer variables and to avoid collinearity between the variable, a multicollinearity test was performed using Pearson's correlation tests

(Preau et al., 2018) on 19 environmental variables (Bio 1 – Bio 19). The variables that have highly cross-correlated variables ($r^2 > 0.8$) were excluded and variables having $r^2 < 0.8$ were kept for further analysis for geographical distribution modeling (Fig. 3). If multicollinearity occurs, then a variable is strongly correlated with other variables in the model, and its predictive power is unreliable and unstable (As’ary et al., 2023). Based on the multicollinearity test, the selected environmental variables to be used were Bio 1, 2, 3, 12, 13, and 19 (Table 1).



Bio	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	■	🟧	🟧	🟧	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
2		■	🟧	🟩	🟧	🟧	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
3			■	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
4				■	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
5					■	🟩	🟧	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
6						■	🟧	🟩	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
7							■	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
8								■	🟩	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
9									■	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
10										■	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
11											■	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
12												■	🟧	🟩	🟧	🟧	🟩	🟩	🟧
13													■	🟧	🟧	🟩	🟧	🟧	🟧
14														■	🟩	🟧	🟩	🟧	🟧
15															■	🟧	🟩	🟧	🟧
16																■	🟧	🟧	🟧
17																	■	🟧	🟧
18																		■	🟧
19																			■

🟧 $r^2 < 0.8$

🟩 $r^2 > 0.8$

Figure 3. Pearson’s correlation analysis matrix of the 19 environmental variables (Bio 1 – Bio 19), and the green squares represent the significant correlation ($r^2 > 0.8$) among variables.

Suitability analysis

This study employed MaxEnt analysis using MaxEnt packages within R platform version 3.6.3 (Mao et al., 2022) and Bioclim within DIVA-GIS platform (Xie et al., 2020) to generate predicted suitability maps of *F. cancrivora* across West Java. Several R packages were 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 MaxEnt included Bio 1, 2, 3, 12, 13, and 19 selected variables.

Within the model, the contribution and impact of each environmental variable on the *S. bicolor* habitat suitability model were determined using a jackknife test (Promnikorn et al., 2019), and the receiving operating curve (AUC) area was used to evaluate the performance model. According to Zhu et al. (2017), AUC values range from 0 (least appropriateness) to 1, with a value less than 0.5 indicating that the resultant model is not better than random and uninformative data, and a value greater than 1.0 indicating that the resulting model is highly good and informative.

Following that, the analysis findings from MaxEnt models predicting *F. cancrivora* suitability ranges were imported into GIS for presentation and additional study (Hijmans et al., 2012). According to Wei et al. (2018), habitat suitability levels on the MaxEnt model map can be classified into five suitability level included 0: no suitability, 1: low suitability, 2: medium suitability, 3: high suitability, 4: very high suitability.

CMIP 5 RCP 8.5 2070 future scenario

This study used two scenarios. The first scenario is the current scenario by year of 2023 and second was a future scenario based on the 5th Coupled Model Intercomparison Project (CMIP) 5 RCP 8.5. The future scenario based on downscaled global climate model data from CMIP5 based on Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (IPOC, 2008). The CMIP 5 was divided into several Representative Concentration Pathways (RCPs) representing greenhouse gas concentration (not emissions) trajectories adopted by the IPCC in its AR5 in 2014. This supersedes the Special Report on Emissions Scenarios (SRES) projections published in 2000 (Vuuren et al., 2009). These pathways are used in climate modeling and research to describe four possible future climates, all of which are considered possible depending on how many greenhouse gases are emitted in the near future. According to Weyant et al. (2009), The four RCPs include RCP2.6, RCP4.5, RCP6, and RCP8.5—are named after a possible range of Radiative Forcing values in the year 2100 relative to pre-industrial values (+ 2.6, + 4.5, + 6.0, and + 8.5 W/m^2, respectively). Here, this study selected the RCP8.5 models to simulate habitat suitability distributions of *F. cancrivora* by the year 2070.

Model evaluation and validation

This study's model evaluation follows Reddy et al. (2015) and Song et al. (2023). Area under the curve analysis (AUC) was used to examine the model. The MaxEnt model calculated the percentage contribution of each factor to the species distribution. The percentage contribution represents the value of each factor's contribution to the spread of the species. The size of the receiver operating characteristic curve (ROC) and the area under the curve (AUC) were used to assess model prediction accuracy. The higher the AUC value, the greater the accuracy of the model's prediction outcomes. The parameters of the MaxEnt model were selected as in 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 a 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 bioclimatic or topographic variables. Jackknife evaluates the leading variables in determining the potential distribution of species. The relationship between the environmental and topographic factors and the potential habitat for the species is determined from the created response curve from the model (Vilà et al., 2012). The relative contributions in percentage of each environmental variable to the MaxEnt model were calculated.

RESULTS

This study assessed the habitat suitability of *F. cancrivora* in West Java in the present time and in the future time by the year 2070 under the RCP 8.5 climate scenario. The detailed results are explained as follows.

F. cancrivora current occurrence

Current occurrences of *F. cancrivora* across West Java including Banten areas are shown in Fig 2. This species was observed common in the northern parts of West Java mainly from Bogor area northwards to Jakarta Bay and Cilegon Coast in Banten. It is also distributed southwards toward Sukabumi areas. Related to the elevation features of West Java, *F. cancrivora* has inhabited lowland areas with elevation ranges of 0 – 1,000 m as can be seen in Bogor area northwards to Jakarta Area. Some individuals were recorded occupying elevation ranges of 1,500 - 2,000 m covering Halimun-Salak and Pangrango mountainous areas and elevation ranges of 1,000 - 1,500 as can be seen in Lembang and Tasikmalaya hilly areas.

F. cancrivora response curves

Response curves of suitability predicted values of *F. cancrivora* habitats are shown in Fig. 4 with Bio 1: annual mean temperature, Bio 2: mean diurnal range (mean of monthly (max temp - min temp)), Bio3: isothermality, Bio 12: annual precipitation, Bio 13: precipitation of wettest month, and Bio 19: precipitation of coldest quarter. Among those environmental variables, significant responses were observed for precipitation of wettest month variables. *F. cancrivora* responds immediately toward slight increases in precipitation of the wettest month. This condition differs as can be seen for annual mean temperature, mean diurnal range, and annual precipitation variables. *F. cancrivora* responds gradually toward those variables.

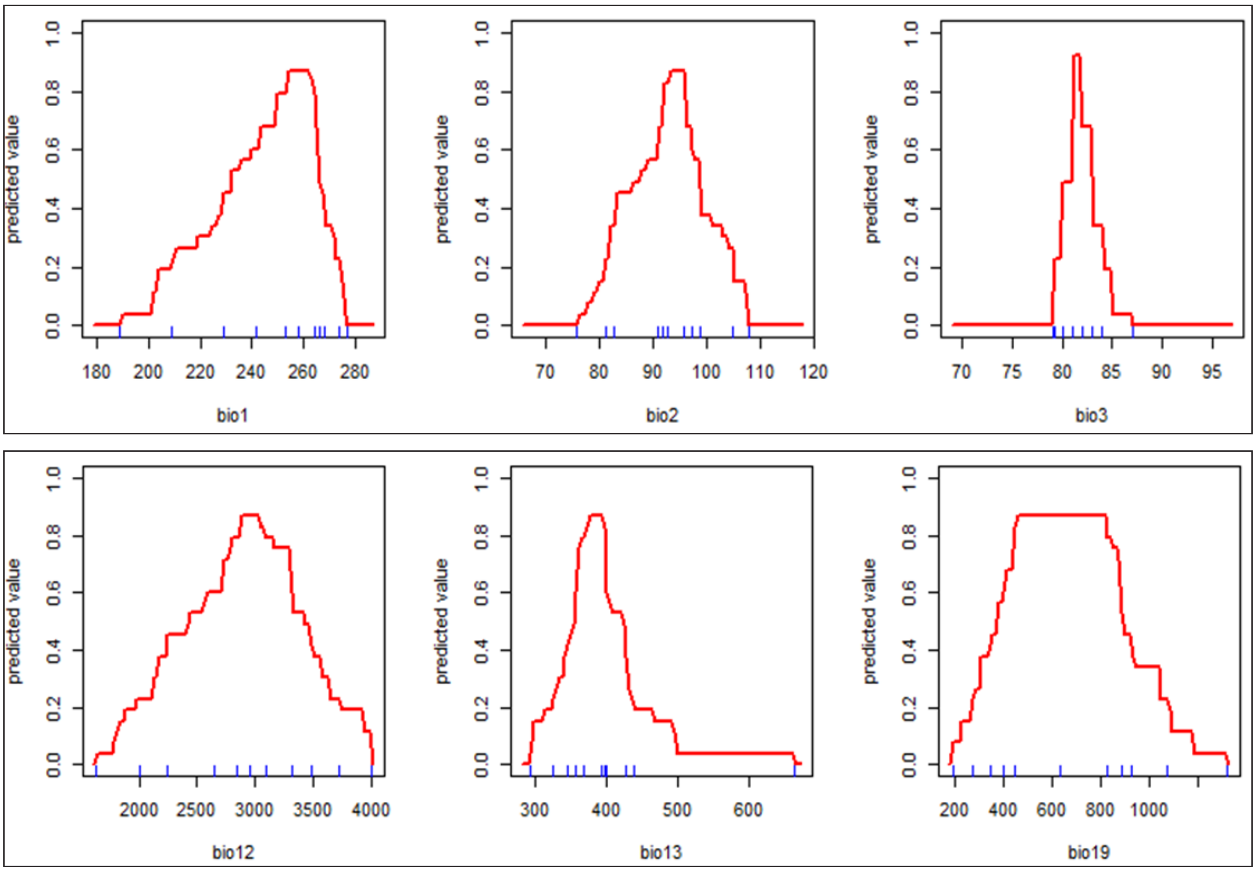


Figure 4. Response curves of suitability predicted values of *Fejervarya cancrivora* with bio 1: annual mean temperature, bio 2: mean diurnal range (mean of monthly (max temp - min temp)), bio3: isothermality, bio 12: annual precipitation, bio 13: precipitation of wettest month, and bio 19: precipitation of coldest quarter.

F. cancrivora environmental variable contributions

The selected environmental variables used in creating the habitat suitability model included the annual mean temperature, mean diurnal range (mean of monthly (max temp - min temp)), isothermality, annual precipitation, precipitation of wettest month, and precipitation of coldest quarter. The contribution of each environmental variable was assessed by looking at the percent contribution and permutation contribution and by looking at the results of the jackknife analysis.

The percent contribution is a value that indicates the importance of the role of environmental variables in the results of the model. The higher the percent contribution, the greater the contribution of this variable to the habitat suitability for *F. cancrivora*. Based on the percent contribution (Fig. 5), 3 variables were found to contribute the most including precipitation of the wettest month at 37.18%, isothermality at 25.02%, and mean diurnal range at 24.15%. The total contribution of these 3 variables was 86.36%.

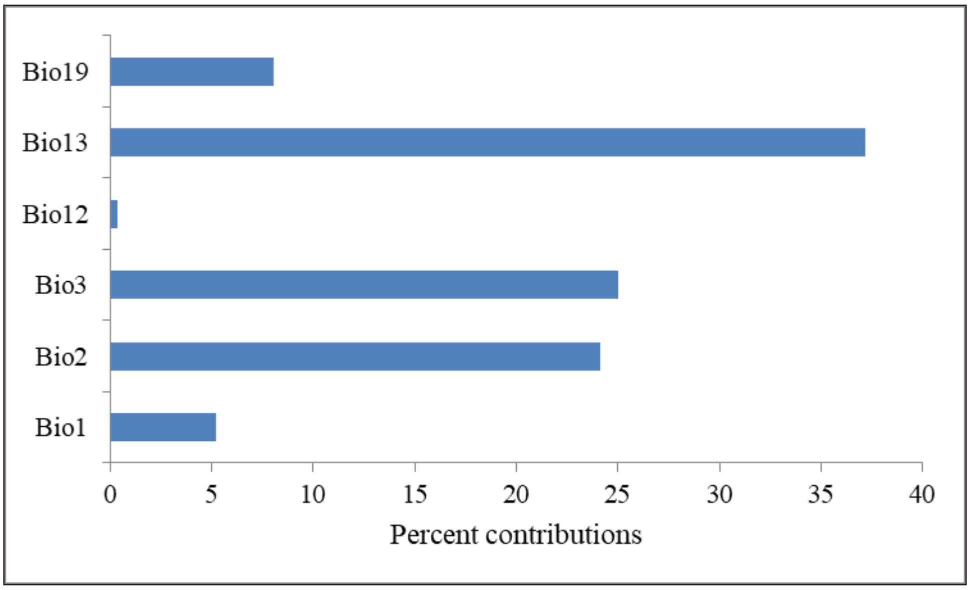


Figure 5. Contribution of each selected environmental variable.

Model evaluation and validation

The assessment of model accuracy can be measured by looking at the Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) curve. The AUC is the area under the Receiver Operating Curve (ROC) and is a standard method for identifying the prediction accuracy of distribution models. The ROC curve is given in Fig. 6. The *F. cancrivora* habitat suitability model on West Java had an AUC value of 0.701. The suitability model performance is failing if AUC is within ranges of 0.5 - 0.6, bad for 0.6 - 0.7, reasonable for 0.7 - 0.8, good for 0.8 - 0.9, and great for 0.9 - 1. The *F. cancrivora* habitat suitability model for Java Island achieved a reasonable performance with the value of 0.701.

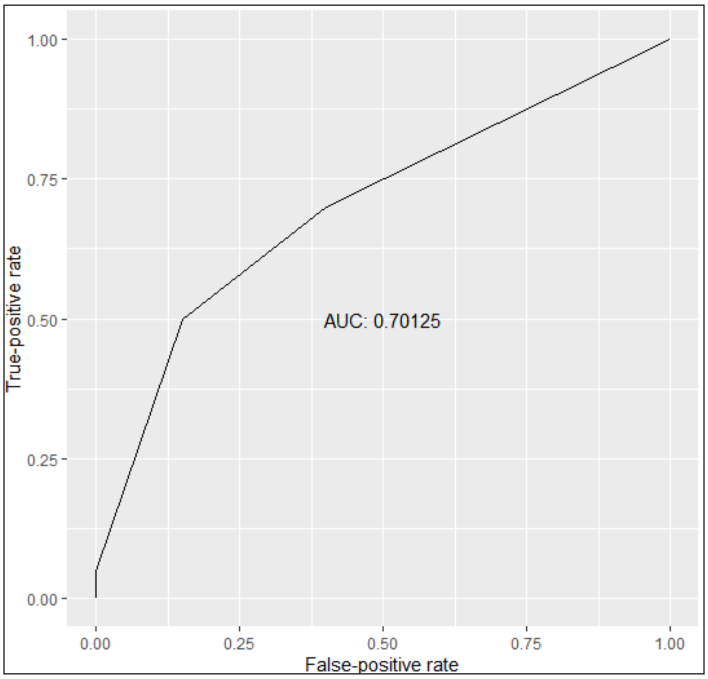


Figure 6. Receiver Operating Characteristic (ROC) curve.

Current and future suitable habitats

Both the current and future suitable habitats by 2070 under the RCP 8.5 climate change scenario are depicted in Fig.7. The current suitable habitats indicate at least very potential habitats in the southern parts of West Java. This area covers Sukabumi areas and spans over 80 km at elevations of 500–1,000 m. The future suitable habitats by 2070 under the RCP 8.5 climate change scenario confirm a potential loss of suitable habitat (Fig. 8). At least three areas will not be suitable for *F. cancrivora* by 2070. Those areas include the southern parts of Sukabumi, which were previously very suitable. The second and third areas were located in the northern parts, including the Cilegon Coast in Banten province and the Indramayu Coast in West Java province. Despite the loss of suitable habitats, by 2070, some areas will be considered suitable for *F. cancrivora*. Those areas include Ujung Kulon in Banten province, Ujung Genteng in Sukabumi, West Java, and an area covering Karawang and Purwakarta in West Java. Based on calculations (Fig. 9), by 2070, under the RCP 8.5 climate change scenario, *F. cancrivora* suitable habitat will gain an additional 2,673 km^2 of new habitat and at the same time lose 4,428 km^2. In total, climate change will cause *F. cancrivora* to lose its habitat of 1,755 km^2.

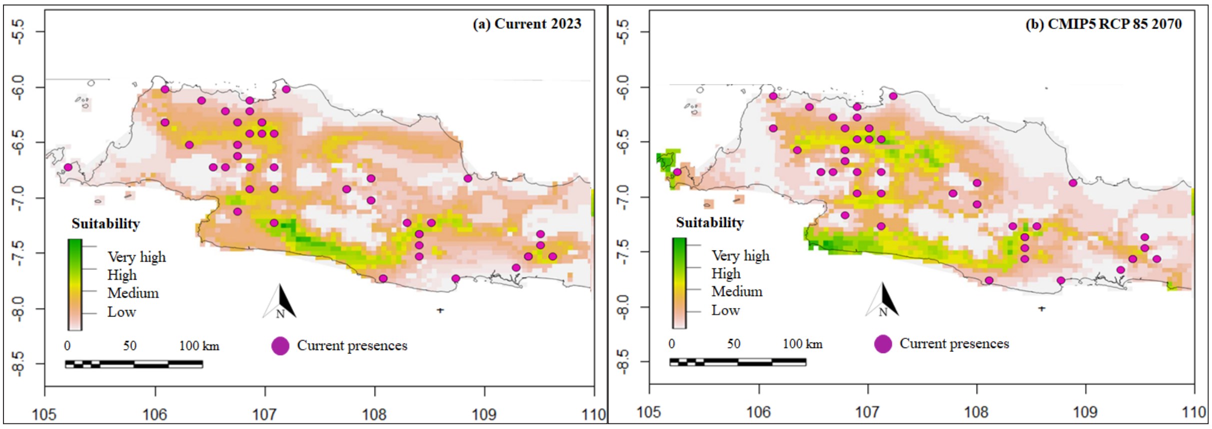


Figure 7. The predicted current (a) and future (b) potential geographical distributions of *Fejervarya cancrivora* by 2070 according to the climate scenarios CMIP 5 RCP 8.5 in West Java with various suitability level.

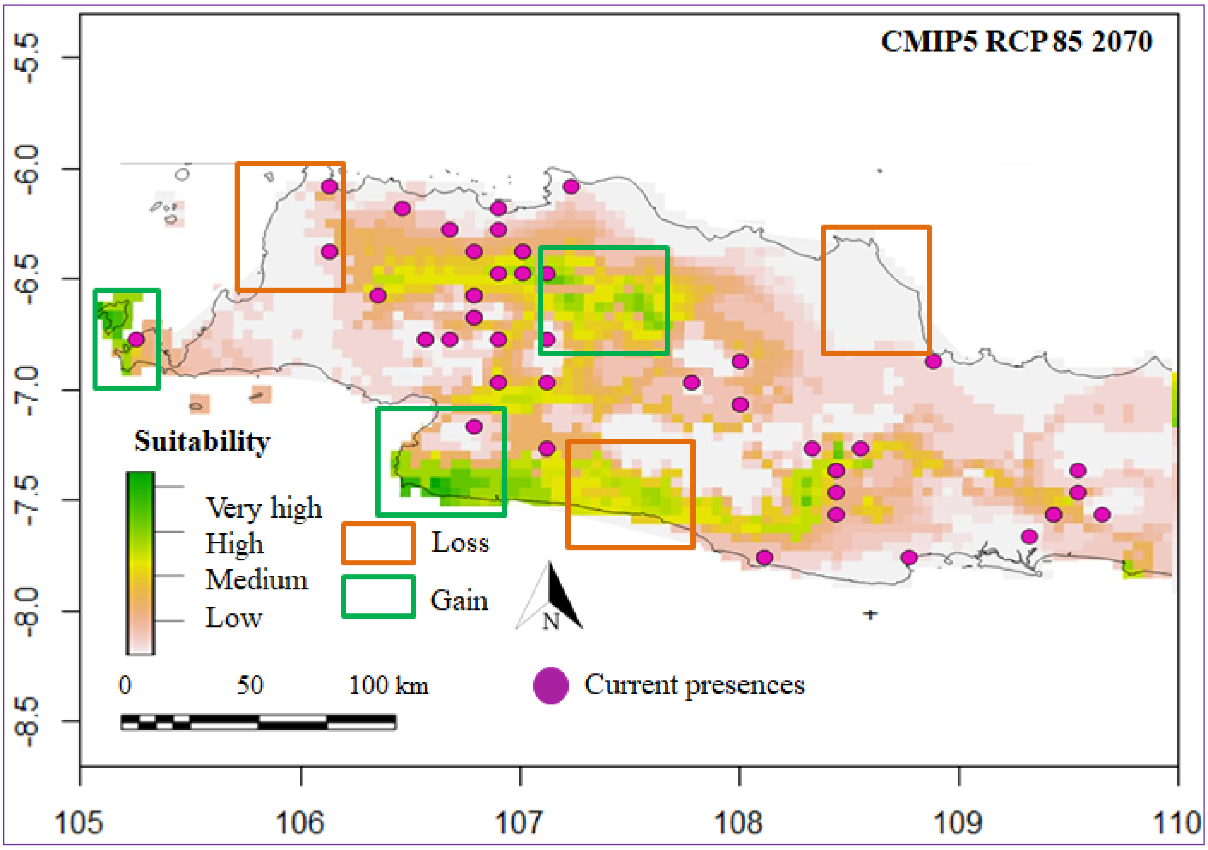


Figure 8. Loss and gain potential geographical distributions of *Fejervarya cancrivora* by 2070 according to the climate scenarios CMIP 5 RCP 8.5 in West Java.

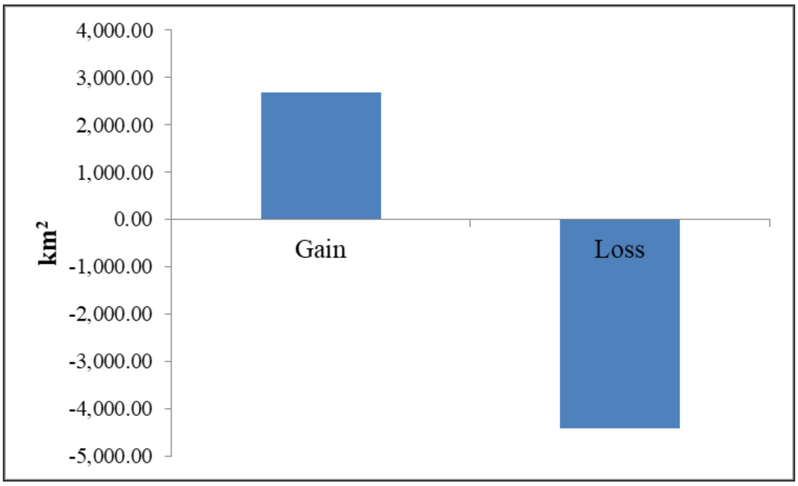


Figure 9. Loss and gain of potential habitat (km^2) of *Fejervarya cancrivora* by 2070 according to the climate scenarios CMIP 5 RCP 8.5 in West Java.

DISCUSSION

In this study, several variables selected as having important effects on shaping *F. cancrivora* geographical distributions are comparable and in agreement with other studies. In their study, Kim et al. (2021) reported that annual mean temperature (Bio1), mean diurnal temperature range (Bio2), isothermality (Bio3), annual precipitation (Bio12), and precipitation of the wettest month (Bio13) were also selected for MaxEnt modeling for amphibians. This study confirms that precipitation (Bio13) provides significant contributions among other variables. Amphibians are known as species that are highly dependent on precipitation (Dervo et al., 2016). Aside from that, the migration of amphibians was dependent on higher precipitation levels. As the skin is highly permeable, amphibians are sensitive to moisture conditions and regulated by precipitation. Amphibians also need stagnant water as their breeding area. The presence of stagnant water is highly dependent on high precipitation rates. This explains the high percent contributions observed in the precipitation of the wettest month.

Another significant variable that provides contributions is isothermality. For amphibians (Alves-Ferreira et al., 2022), as isothermality increases, the amount of suitable area gained in response to climate change also increases. Therefore, species from less isothermal regions or regions with lower "temperature uniformity" and more variation over a year (below 30%), mostly from the northern and southern temperate hemispheres, tend to lose climatically suitable areas, while species that occur in more isothermal regions (above 30%) in the tropical hemisphere tend to gain suitable areas with advancing climate change. This explains the highly significant contributions of isothermality in shaping *F. cancrivora's* geographical distributions, considering it is a tropical species.

Based on the future climate scenario, *F. cancrivora* will shift its geographical distributions, as can be seen by the new suitable habitats detected in the Ujung Kulon and Ujung Genteng coastal areas. This shifting geographical range to coastal areas and saline ecosystems is supported by the physiological adaptation of *F. cancrivora*. This species is euryhaline, has the highest salt tolerance among reported anuran species, and may exhibit a different pattern of compensatory growth after stress release (Hsu et al., 2017). Genus *Fejerfarya* can tolerate salinity levels up to 12 ppt and even has reproduction activity in brackish water (Chang et al., 2016). Another important adaptation of amphibians to climate change is related to their reproductive ability and breeding adaptations. A recent study (Ellepola et al., 2022) has confirmed a climate change-induced breeding adaptation in the form of spending the larval stage in gel nesting and foam nesting instead of in water, which may be threatened by climate change.

CONCLUSION

Geographical distributions of *F. cancrivora* were influenced mostly by the precipitation of the wettest month and isothermal variables. Climate change under the RCP 8.5 scenario would have caused *F. cancrivora* to lose its habitat and shift to a new habitat. Shifting to new habitats is related to the salinity tolerances of *F. cancrivora*. In total, climate change will cause *F. cancrivora* to lose its habitat of 1,755 km^2 in 2070.

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