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ORIGINAL ARTICLE

An assessment of the impact of climate change on the distribution of the grey-shanked douc *Pygathrix cinerea* using an ecological niche model

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Abstract
Climate change can have many negative impacts on wildlife species, and species with narrow distributions are more likely to be significantly affected. In this study, we used ecological niche modeling for species (MaxEnt software) as well as species occurrence data and climate variables to assess the impacts of climate change on the distribution of the grey-shanked douc—an endemic and rare primate species of Vietnam. We used climate data at the current time and two future times (2050 and 2070). Climate data were generated for two climate scenarios RCP4.5 and RCP8.5, together with three climate models ACCESS1-0, GFDL-CM3, and MPI-ESM-LR. We predicted that the distribution of the grey-shanked douc would be sharply reduced by the effects of climate change. The species' suitable distribution range in the future tended to shift toward the center of their current range and to higher mountainous areas. A larger suitable area, in particular highly suitable areas to the north and west of its current potential distribution range, would become less suitable or even unsuitable in 2050 and 2070. Kon Cha Rang Nature Reserve and Kon Ka Kinh National Park should be given priority in conservation of the grey-shanked douc because they now support important populations of the species and are in the highly suitable area remaining for the species in the future. The establishment of a new protected area for grey-shanked douc conservation should be considered in Kon Plong District, Kom Tum Province, which will be the center of the species distribution range.

Keywords Climate change · Douc · Ecological niche modeling · MaxEnt · *Pygathrix*

Introduction

Climate-driven changes in environmental conditions have a significant effect on biodiversity in general, and wildlife in particular. As environmental variables change, the populations of many species often decline, even leading to extinctions (Thomas et al. 2004; Pearson et al. 2014). Past records provide strong evidence that global climate change has produced shifts in the distribution of a wide range of species, including both vertebrate and invertebrate species (Parmesan et al. 1999; Thomas and Lennon 1999; Brommer et al. 2012; Hitch and Leberg 2007). Climate change will continue to act as one of the major drivers of species extinction in the twenty-first century because of changes in breeding times and shifts in the distributions of species. More than 20% of plant and animal species are predicted to be at higher risk of extinction due to global warming. Importantly, a significant proportion of endemic species may become extinct by 2050 (Kaeslin et al. 2012).

Recent studies have shown that many primate species have been strongly affected by climate change in the twenty-first century, with Southeast Asia one of the regions which should receive priority in conservation for primate species in the climate change context (Graham et al. 2016). In addition, climate change has led to fragmentation and loss of habitat, which are two of the greatest threats to primate populations (Sesink-Clee et al. 2015; Gouveia et al. 2016; Estrada et al. 2017).

Vietnam is a key country for conservation of primate species. Of the 25 primate species present, two are considered among the most endangered primate species in the world (Schwitzer et al. 2017). However, studies of

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the effects of climate change on endemic and endangered wildlife species in general, and primates in particular, in Vietnam and Indochina are lacking. In particular, there have been no in-depth studies on the effects of climate change on the distribution of any species in the *Pygathrix* genus, one of the most threatened taxa in Vietnam.

The grey-shanked douc (*Pygathrix cinerea*) is one of three species of the genus *Pygathrix* that lives in Vietnam. The species is listed as critically endangered in the Vietnam Red Book (2007) and the International Union for Conservation of Nature (IUCN) Red List (2019). The species' total population is now estimated at only 550–700 individuals. The grey-shanked douc is endemic to Vietnam, with a present distribution only from 14°N to 16°N (Ngoc et al. 2008). The species has been recorded in several sites, both inside and outside protected areas (Nadler 1997; Ha 2000, 2003, 2004, 2007; Nadler et al. 2003; Minh et al. 2005; Nguyen et al. 2010; Bailey 2014; Tran and Hoang 2015). However, the largest confirmed populations inhabit Kon Ka Kinh National Park and Kon Cha Rang Nature Reserve in Gia Lai Province (Ha 2007) and Kon Plong District, Kon Tum Province (pers. com).

The small distribution range of grey-shanked doucs indicates that the ecological niche of the species might be

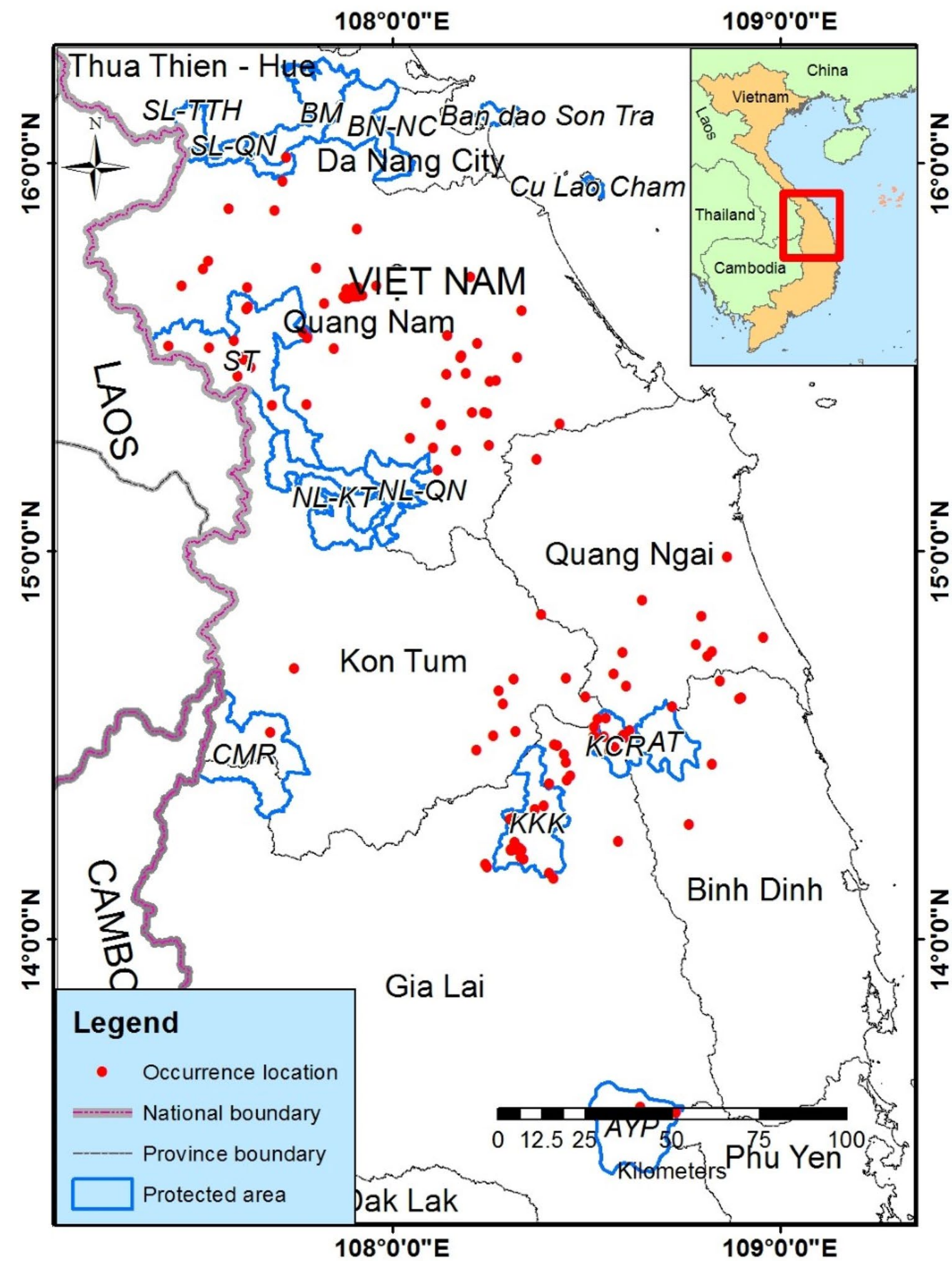


Fig. 1 Recorded locations of the grey-shanked douc used in this study (162 points; *SL-TTH* Thua Thien Hue Saola Nature Reserve, *SL-QN* Quang Nam Saola Nature Reserve, *BM* Bach Ma National Park, *BN-NC* Ba Na–Nui Chua Nature Reserve, *ST* Song Thanh Nature Reserve, *NL-KT* Ngoc Linh Nature Reserve (Kon Tum), *NL-QN* Ngoc Linh Nature Reserve (Quang Nam), *KKK* Kon Ka Kinh Nature Reserve, *KCR* Kon Cha Rang Nature Reserve, *AT* An Toan Nature Reserve, *CMR* Chu Mom Ray National Park)

narrow, because there are no significant physical barriers for the species to expand its home range. Additionally, using modeling, Bett et al. (2012) found that the precipitation of the driest quarter and isothermality might shape the distribution of three douc species. The dry season may prevent red- and grey-shanked doucs from expanding southward, and changes in isothermality may limit the black-shanked doucs from moving north (Bett et al. 2012). With a very narrow ecological niche, the grey-shanked douc will likely be very sensitive to climate change and subject to distribution shifts in the future.

Tran et al. (2018) modeled the potentially suitable distribution of grey-shanked doucs at the current time. However, spatial autocorrelations were not taken into account that might reduce the accuracy of the predicted distribution. Of the 16 variables used, 11 variables were climatic and the other five variables were related to vegetation cover and terrain, namely forest type, tree cover, normalized difference vegetation index (NDVI), elevation, and slope. However, vegetation and terrain variables had a much smaller contribution to the model (16.7%) than climatic variables (83.3%). In another study, six climatic variables used by Bett et al. (2012) showed a strong ability to predict the observed distribution of grey-shanked douc, with all area under the curve (AUC) values > 0.98. Therefore, climatic variables alone can be useful in predicting grey-shanked douc potential distribution, especially for future scenarios, because future vegetation data are not available.

There are a variety of computer programs to predict the future distribution of species. Among them, MaxEnt is a software program that uses predictive methods and simulates the potential distribution of species from existing information (Phillips et al. 2006). The MaxEnt model uses the location appearance of species as input data (called occurrence data), as well as the use of climate condition variables (such as temperature and precipitation). Among several software programs for predicting species distributions, MaxEnt is widely used by conservationists (Elith et al. 2006; Peterson et al. 2007; Kumar and Stohlgren 2009; Merow et al. 2013). Additionally, this tool requires only "presence" data with a small number of occurrence points, and thus is suitable for poorly studied species in sparsely surveyed areas such as Indochina. Consequently, the MaxEnt model has been widely used by ecologists to assess the impacts of climate change on wildlife species (e.g., Adams-Hosking et al. 2012; Sesink-Clee et al. 2015).

In this study, we used MaxEnt to predict shifts in the distribution of the grey-shanked douc in the context of climate change. We aimed to provide more information on the species distribution shifts in the future and where to prioritize protected areas for long-term conservation of the species. The study also provides information for future assessments of the vulnerability of species as well as aiding conservation designs in the region.

Methodology

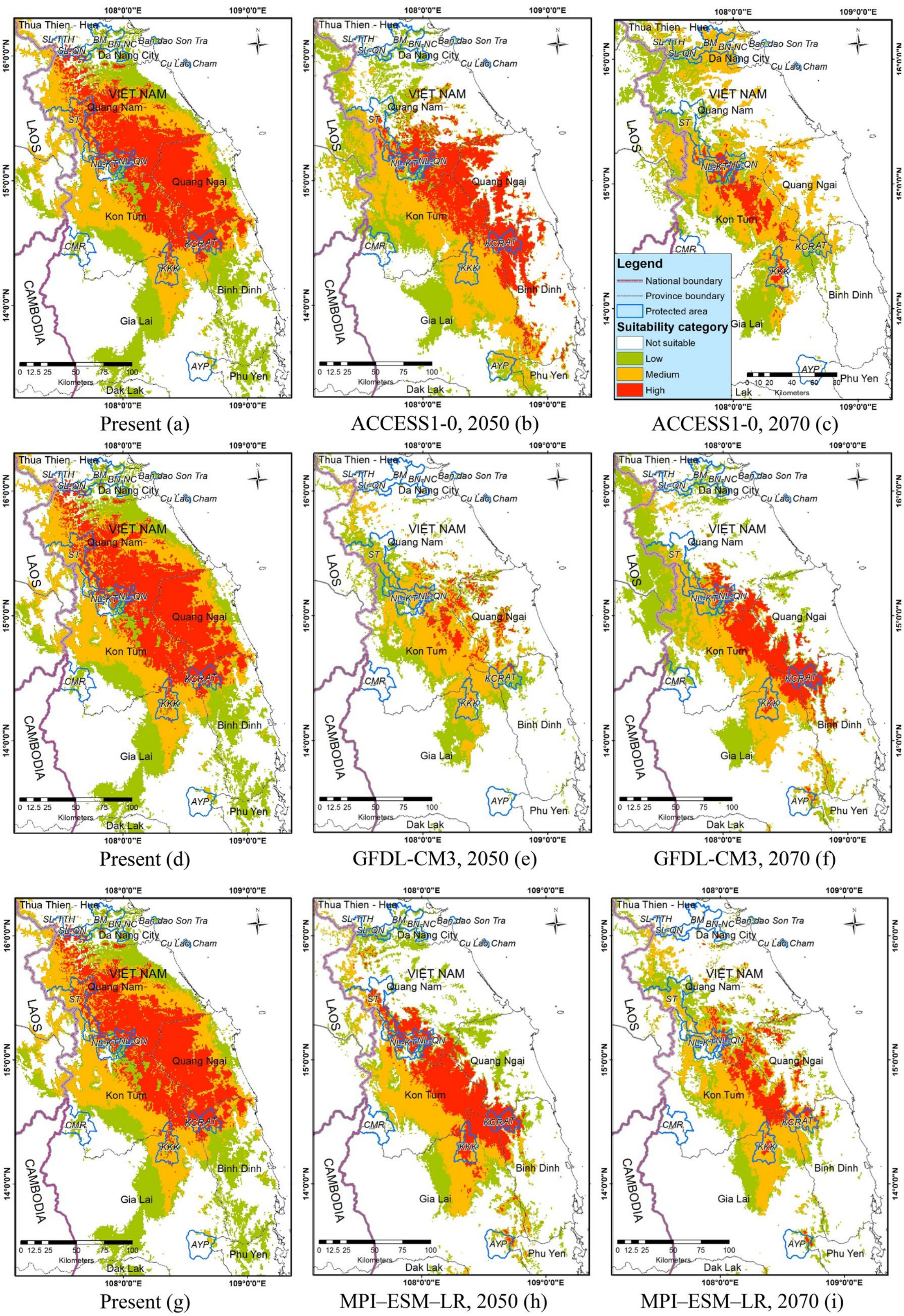
Species occurrence data

We used 162 points where grey-shanked doucs were recorded from previous studies, including those by Nadler (1997), Ha (2000, 2003, 2004, 2007), Nadler et al. (2003), Minh et al. (2005), Nguyen et al. (2010), Bett et al. (2012), Tran and Hoang (2015), and ourselves (Fig. 1). All of these researchers used line transects to record the locations of the grey-shanked douc based on visual detection.

We standardized the field data to the same coordinate projection. We then exported the point coordinate as a CSV file to suit the MaxEnt software (Phillips et al. 2017). MaxEnt, by default, randomly keeps only one point for modeling if more than two points are recorded in the same pixel to account for spatial autocorrelation. Finally, 131 points were used to model the potential distribution of grey-shanked douc. We then selected 90% of the data for training and the remaining 10% for testing.

Table 1 Climate variables used in modeling the distribution of the grey-shanked douc

Variables used	Variables omitted
BIO2 = mean diurnal range (mean of monthly = max temp − min temp)	BIO1 = annual mean temperature
BIO3 = isothermality (BIO2/BIO7) (× 100)	BIO4 = temperature seasonality (standard deviation × 100)
BIO8 = mean temperature of wettest quarter	BIO5 = max temperature of warmest month
BIO11 = mean temperature of coldest quarter	BIO6 = min temperature of coldest month
BIO12 = annual precipitation	BIO7 = temperature annual range (BIO5–BIO6)
BIO13 = precipitation of wettest month	BIO9 = mean temperature of driest quarter
BIO15 = precipitation seasonality (coefficient of variation)	BIO10 = mean temperature of warmest quarter
BIO17 = precipitation of driest quarter	BIO14 = precipitation of driest month
	BIO16 = precipitation of wettest quarter
	BIO18 = precipitation of warmest quarter
	BIO19 = precipitation of coldest quarter


Legend
National boundary
Province boundary
Protected area
Suitability category
Not suitable
Low
Medium
High
Thua Thien - Hue
Da Nang City
Ban dao Son Tra
Cu Lao Cham
VIET NAM
Quang Nam
Quang Ngai
Kon Tum
Binh Dinh
Gia Lai
Phu Yen
Dak Lak
LAOS
CAMBODIA
SL-TTH
SL-QN
BM
BN-NC
ST
NL-KT
NL-QN
CMR
KCRAT
KKK
AYP
108°0'0"E
109°0'0"E
16°0'0"N
15°0'0"N
14°0'0"N
Kilometers
Present (a)
ACCESS1-0, 2050 (b)
ACCESS1-0, 2070 (c)
Present (d)
GFDL-CM3, 2050 (e)
GFDL-CM3, 2070 (f)
Present (g)
MPI–ESM–LR, 2050 (h)
MPI–ESM–LR, 2070 (i)

◂**Fig. 2** Predicted distribution of the grey-shanked douc (*Pygathrix cinerea*) generated by MaxEnt under the RCP4.5 scenario (*SL-TTH* Thua Thien Hue Saola Nature Reserve, *SL-QN* Quang Nam Saola Nature Reserve, *BM* Bach Ma National Park, *BN-NC* Ba Na–Nui Chua Nature Reserve, *ST* Song Thanh Nature Reserve, *NL-KT* Ngoc Linh Nature Reserve (Kon Tum), *NL-QN* Ngoc Linh Nature Reserve (Quang Nam), *KKK* Kon Ka Kinh Nature Reserve, *KCR* Kon Cha Rang Nature Reserve, *AT* An Toan Nature Reserve, *CMR* Chu Mom Ray National Park)

Climate data

We used climate data downloaded from the WorldClim website http://www.worldclim.org/ (Hijmans et al. 2005). The size of the pixels in the variables is 0.83 × 0.83 km. The climate data used to run the model cover areas of Indochina, southern China, and part of Thailand. To eliminate highly correlated variables, we used the Band Collection Statistics tool in ArcGIS to calculate the correlation among variables, with variables having a correlation coefficient greater than 0.85 being eliminated (Elith et al. 2000). Of a pair of highly correlated variables, we followed Bett et al. (2012) to select the variables that influenced grey-shanked douc distribution; other variables were omitted. As a result, eight climatic variables were selected, including four variables related to temperature and four variables related to precipitation (Table 1).

Climate change scenario

To model distribution of the grey-shanked douc at the current time, 2050 and 2070, we used three climate models, including ACCESS1-0 (CSIRO-BOM, Australia), GFDL-CM3 (NOAA, GFDL, USA) and MPI-ESM-LR (MPI-N, Germany), to calculate future scenarios in the study area as suggested by McSweeney et al. (2014) for the Southeast Asia region. For each model, we then generated climatic data for 2050 and 2070 under two different Representative Concentration Pathway (RCP) scenarios: medium-low greenhouse gas concentration (RCP4.5) and high greenhouse gas concentration (RCP8.5).

The area under the response curve (AUC), with values ranging from 0 to 1, was used under application of the receiver operating characteristic (ROC) model to determine the goodness of fit of the model (Phillips et al. 2006; Nazeri et al. 2012). The model with a higher AUC value has better goodness of fit. We used models with AUC > 0.75 to model the distribution of species (Elith 2000).

MaxEnt software generated a map layer with pixels representing environmental suitability levels, with values ranging from 0 (not suitable) to 1 (highly suitable) in an ASCII file (*.asc). We used ArcMap 10.1 software to transform the map layer into a raster (*.tif). In this study, we used the "equal training sensitivity and specificity" threshold to determine the suitability level of the pixels (Liu et al. 2005). Pixels were divided into two levels: suitable level (≥ 0.116) and unsuitable level (< 0.116). The suitability level was then divided into four categories, as suggested by Yang et al. (2013), including: high suitability (> 0.6), medium suitability (0.4–0.6), low suitability (0.116–0.4), and not suitable.

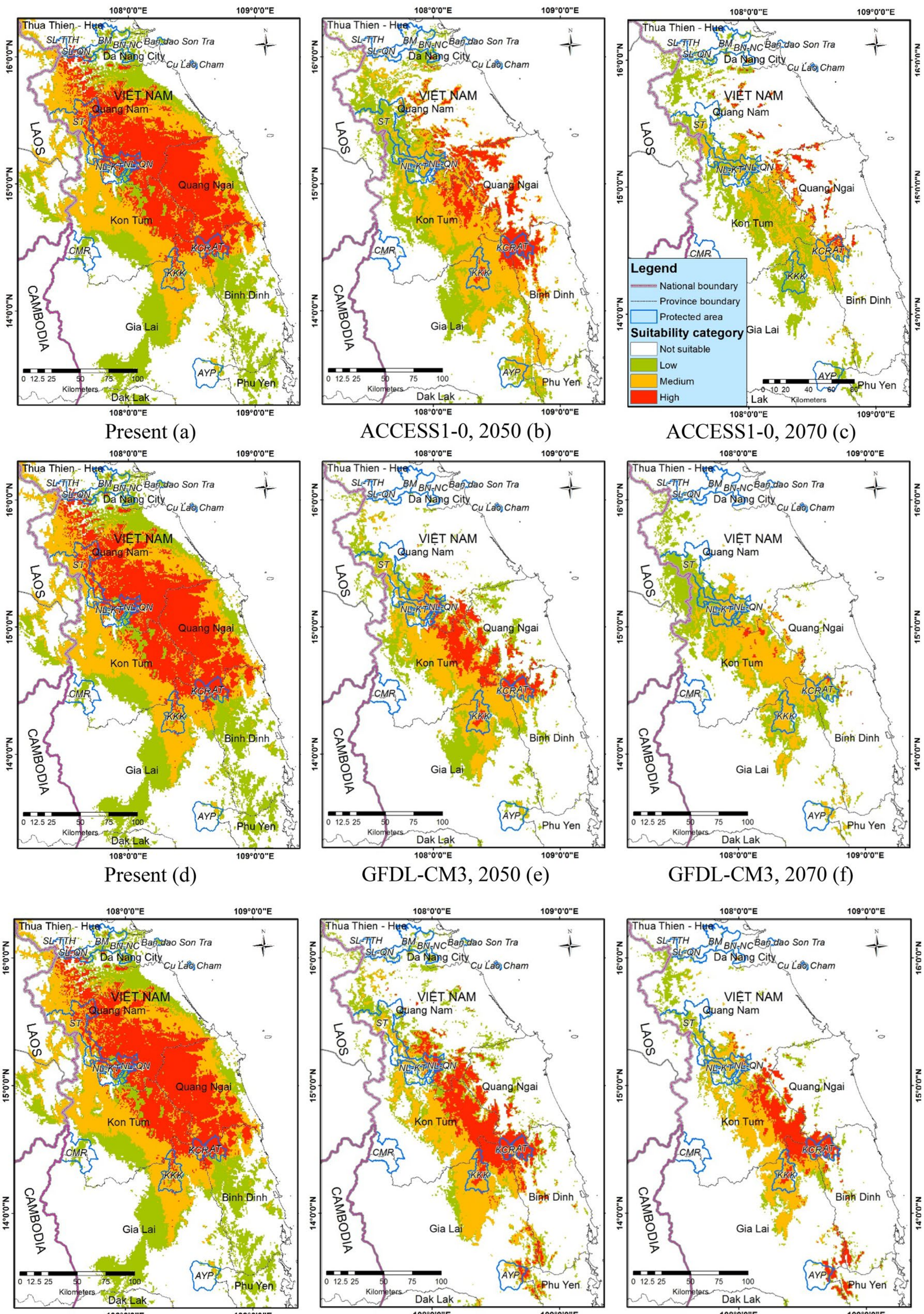
Results

The study results showed that the predictive model was much better than random prediction, with all models running different climate scenarios having an AUC greater than 0.992. Therefore, the models simulated the distribution of grey-shanked douc well (Elith 2000; Phillips et al. 2006).

The predicted distribution of grey-shanked douc at the current time aligned with the recorded distribution (Fig. 2). The total area of the suitable distribution of the grey-shanked douc at the current time was 29,934.08 km^2, in which the areas of low suitability, medium suitability, and high suitability were 12,743.27 km^2, 9121.04 km^2, and 8069.77 km^2, respectively. Three variables with highest contribution in the models were isothermality, mean temperature of coldest

Table 2 Changes in the suitable distribution of grey-shanked douc (*Pygathrix cinerea*) under climate change scenarios modeled by MaxEnt software (unit: km^2)

Model	RCP	Present	2050			2070		
			Remaining area	Area lost	%	Remaining area	Area lost	%
ACCESS1-0	4.5	29,934.08	24,437.35	5496.73	18.36	18,479.05	11,455.03	38.27
GFDL-CM3	4.5	29,934.08	12,167.35	17,766.73	59.35	18,088.45	11,845.63	39.57
MPI-ESM-LR	4.5	29,934.08	17,637.91	12,296.17	41.08	13,988.11	15,945.97	53.27
Average			18,080.87	11,853.21	39.60	16,851.87	13,082.21	43.70
ACCESS1-0	8.5	29,934.08	16,582.51	13,351.57	44.60	9090.04	20,844.04	69.63
GFDL-CM3	8.5	29,934.08	11,935.19	17,998.89	60.13	9456.53	20,477.55	68.41
MPI-ESM-LR	8.5	29,934.08	14,015.67	15,918.41	53.18	10,088.25	19,845.83	66.30
Average			14,177.79	15,756.29	52.64	9544.94	20,389.14	68.11


108°0'0"E
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Thua Thien - Hue
SL-TTH
SL-QN
BM
BN-NC
Ban dao Son Tra
Da Nang City
Cu Lao Cham
VIỆT NAM
Quang Nam
LAOS
ST
NL-KT
NL-QN
Quang Ngai
Kon Tum
CMR
KCRAT
KKK
Binh Dinh
CAMBODIA
Gia Lai
AYP
Phu Yen
Dak Lak
0 12.5 25 50 75 100
Kilometers
Legend
National boundary
Province boundary
Protected area
Suitability category
Not suitable
Low
Medium
High
0 10 20 40 60 80
Present (a)
ACCESS1-0, 2050 (b)
ACCESS1-0, 2070 (c)
Present (d)
GFDL-CM3, 2050 (e)
GFDL-CM3, 2070 (f)
Present (g)
MPI–ESM–LR, 2050 (h)
MPI–ESM–LR, 2070 (i)

◂**Fig. 3** Predicted distribution of the grey-shanked douc (*Pygathrix cinerea*) generated by MaxEnt under the RCP8.5 scenario (*SL-TTH* Thua Thien Hue Saola Nature Reserve, *SL-QN* Quang Nam Saola Nature Reserve, *BM* Bach Ma National Park, *BN-NC* Ba Na–Nui Chua Nature Reserve, *ST* Song Thanh Nature Reserve, *NL-KT* Ngoc Linh Nature Reserve (Kon Tum), *NL-QN* Ngoc Linh Nature Reserve (Quang Nam), *KKK* Kon Ka Kinh Nature Reserve, *KCR* Kon Cha Rang Nature Reserve, *AT* An Toan Nature Reserve, *CMR* Chu Mom Ray National Park). For RCP8.5, the suitable distribution area was reduced significantly, with an average reduction of 52.64% and 68.11% by 2050 and 2070, respectively. The variation in the area lost was less than in RCP4.5. All models predicted that more than 40% and more than 65% of the suitable distribution area would disappear by 2050 and 2070, respectively. Similar to the RCP4.5 scenario, eastern Kon Tum Province, northeast Gia Lai Province, and only small areas in southwestern Quang Nam Province, western Quang Ngai Province, and northeastern Binh Dinh Province would be highly suitable for the grey-shanked douc in 2070

quarter, and precipitation seasonality. Mean isothermality of low suitability, medium suitability, and high suitability were 55.17, 55.43, and 55.83, respectively. Mean precipitation seasonality of low suitability, medium suitability, and high suitability were 82.56, 80.89, and 72.78, respectively. Mean temperatures of the coldest quarter of low suitability, medium suitability, and high suitability were 20.961, 20.233, and 19.902, respectively.

The simulation model for the greenhouse gas emissions scenarios RCP4.5 in 2050 showed that the distribution of the grey-shanked douc may narrow toward the center of its range and shift to higher elevation. By 2070, the potential distribution could shrink a great deal (Table 2, Fig. 2). A large area that is currently suitable for the species was predicted to be lost, such as the majority of Quang Nam, Quang Ngai, and Binh Dinh Provinces. The suitable distribution of the grey-shanked douc was less affected by climate change in Kon Tum Province, which extends down the Pleiku plateau into Gia Lai Province. A notable finding was also that much of the "high suitability" areas changed to less suitable categories.

The influence of climate change on the potential distribution of the grey-shanked douc under the RCP8.5 scenario was stronger than that under the RCP4.5 scenario (Fig. 3). Large suitable areas, such as in central Quang Nam and Kon Tum Province, disappeared completely. The locations of the remaining suitable areas were quite similar to those predicted under the RCP4.5 scenario, but were smaller and more fragmented.

Discussion

Our present model for the potential distribution of the grey-shanked douc was in accordance with the recorded species distribution range (Ha 2000, 2004; Nadler et al. 2003; Nguyen et al. 2010; Bett et al. 2012; Nadler and Brockman 2014), the species IUCN distribution map (Ngoc et al. 2008), and the potential distribution predicted by Bett et al. (2012) and Tran et al. (2018). The northern part of the suitable distribution area was blocked by the Hai Van Pass, the high mountains that divide the north and south of Vietnam into two climate regions. The northern region has a subtropical climate, with four distinct seasons. The southern region has a humid subtropical climate, with two distinct seasons, a dry season and a rainy season. The difference in climate regimes between two the regions explained why the potential distribution of the grey-shanked douc did not extend to northern Vietnam.

Areas of high suitability in the current potential distribution range were concentrated in the higher elevations of the Annamite mountain range, which has many peaks higher than 1000 m, such as Ngoc Linh peak (2598 m), indicating that this species might be very sensitive to temperature variables, as evidenced by the fact that the mean temperature of the coldest quarter was the second highest contribution to the model. These results also aligned with field records, as grey-shanked doucs were usually recorded at elevations ranging from 900 to 1300 m (Ha 2004, 2007). The areas of high suitability were limited to the eastern part of the Annamite mountain range, and this aligned with the difference in climate regimes between the two sides of the mountains. The climate on the eastern side is more humid, with high precipitation, while the climate on the western side is much drier, with lower precipitation.

In most cases, under the effects of climate change, the distribution regions of species affected by climate change move to the north (polar) (Root and Schneider 2002) or shift to higher elevations (Wilson et al. 2005; Parmesan 2006). In our case, future potential distribution ranges shrunk toward the center of the species distribution range where most high mountains are concentrated. The areas in the north of its distribution range become less suitable or even completely unsuitable for the species in the future under all climate change scenarios, because the climate regime in northern Vietnam is different from that of southern Vietnam, where the grey-shanked douc is distributed.

Most of Song Thanh Nature Reserve, the largest protected area in the region, would be unsuitable for grey-shanked doucs in 2050 and 2070. The rest of Song Thanh Nature Reserve would show low or medium suitability, even though most of the area in the nature reserve is currently of a high suitability level. The majority of Chu Mom Ray National Park, which is located on the western slope of the Annamite mountain range, would also become unsuitable for the grey-shanked douc in the future.

Four protected areas, including Ngoc Linh Nature Reserve (Quang Nam Province), An Toan Nature Reserve, Kon Cha Rang Nature Reserve, and Kon Ka Kinh National Park, were still within the future distribution range of the grey-shanked douc langur. Of those, An Toan Nature Reserve has been confirmed to support an extremely small population of grey-shanked douc (Bailey 2014), while Kon Cha Rang Nature Reserve and Kon Ka Kinh National Park were identified as containing populations of grey-shanked doucs that are important for conservation of this species (Ha 2007). In the context of climate change, the protected areas in the center and south of the grey-shanked douc distribution range, especially in Gia Lai Province, should receive higher priority for conservation of the species. One of the measures for adapting to climate change is the establishment of protected biodiversity corridors that link severely affected areas to areas less affected by climate change and facilitate gene exchange among populations. The biodiversity corridor will facilitate the movement of animals within the distribution areas where they are fragmented, to ensure their viability. The biodiversity corridor between Kon Ka Kinh National Park and Kon Cha Rang Nature Reserve was designed with a total area of 108,607 km^2 (Breese 2009). Several other corridors have been proposed to minimize the impact of climate change on biodiversity in this area, including Kon Cha Rang–Ngoc Linh, Ngoc Linh–Song Thanh, and Song Thanh–Sao La corridors (Vu 2014); however, these corridors have not been established. Maintaining the natural forest along the top of the Annamite mountain range would be a good strategy to keep the protected areas connected. Establishing a new protected area in Kon Plong District, Kon Tum Province, along the Kon Cha Rang–Ngoc Linh corridors would also be very important for long-term species conservation.

The distribution range of the grey-shanked douc shrank considerably in 2050 and 2070 under all climate models, so there was much less uncertainty in assessing the effects of climate change on the distribution of this critically endangered species. The protected areas in the central and southernmost parts of its current distribution range should receive priority for efforts toward the conservation of the grey-shanked douc langur.

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