Modelling the change in the distribution of the black-shanked douc, *Pygathrix nigripes* (Milne-Edwards) in the context of climate change: Implications for conservation

Dung V. Tran¹, Thinh T. Vu¹⁺*¹, Bao Q. Tran¹, Manh D. Nguyen², Phuong T. Vu¹², Trang H. Tran³, Hoa T. Nguyen⁴, Thong V. Pham⁵ & Thanh C. Nguyen⁶

Abstract. Climate change has affected many animals, causing shifts in distributions across a wide range of vertebrate and invertebrate species. Many primate species have small distributions with narrow ecological niches and are therefore sensitive to changes in the environment. However, there exists a lack of predictions with regards to how the distribution ranges of primate species might shift given future climate changes. In this study, we assessed the potential effects of climate change on the distribution of the black-shanked douc, *Pygathrix nigripes* (Milne-Edwards, 1871). We generated climatic conditions projected for 2050 and 2070 under the two scenarios, RCP4.5 and RCP8.5, with three climate models, ACCESS1-0, GFDL-CM3, and MPI-ESM-LR. We predicted that the distribution of the black-shanked douc would be sharply reduced with 66.19% of the current distribution lost by 2070 under the RCP8.5 scenario. The species’ suitable distributions were not projected to shift to higher latitudes but were instead expected to shift towards the centre of their current range. Under the context of climate change, higher priority in conservation efforts for the species should be given to the protected areas in the centre of the species’ current distribution, especially in the north of Lam Dong, south of Dak Lak, and middle of Dak Nong provinces. Specifically, Bidoup-Nui Ba and Chu Yang Sin National Parks should receive the highest priority in terms of conservation attention for this species. Our study also indicated that more surveys should be conducted in several forested areas, both inside and outside the current protected area network, in order to gain a better understanding of the black-shanked douc langur populations and their distributions.

Key words. climate change, douc, langur, MaxEnt, *Pygathrix*

INTRODUCTION

Climate change alters environmental conditions, and may thus strongly affect the populations of many species. Shifts in distributions have been observed in a wide range of vertebrate and invertebrate species (Parmesan et al., 1999; Thomas & Lennon, 1999; Root & Schneider, 2002; Brommer, 2004; Hitch & Leberg, 2007). If a species fails to adapt to its new environmental conditions or cannot shift its distribution to more suitable sites, it may face population decline and possibly even extinction (Thomas et al., 2004; Pearson et al., 2014). More than 20 percent of species globally, especially narrow endemics, are predicted to be at a higher risk of extinction from climate change impacts (Kaeslin et al., 2012). Foden et al. (2013) estimated that 608–851 bird species (6–9%), 670–933 amphibian species (11–15%), and 47–73 coral species (6–9%) are highly vulnerable to climate change and many are already threatened with extinction according to the IUCN Red List.

Many primate species have small distributions and narrow ecological niches, making them sensitive to changes in the environment (Levinsky et al., 2007; Sesink-Clee et al., 2015; Estrada et al., 2017). Primates have long life cycles, which inhibits these species from rapidly evolving to adapt to new environmental conditions. The populations of many primate species are already declining due to hunting and habitat loss, making them more vulnerable to climate change. Graham et al. (2016) showed that many primate species, especially those in Southeast Asia, will be strongly affected by climate change by the end of the 21st century. The conservation efforts for these primate species in this region should receive high priority within the context of climate change.

The black-shanked douc, *Pygathrix nigripes* (Milne-Edwards, 1871), is native to Indochina with a small distributional range which includes only Vietnam and Cambodia. In Vietnam, the species is recorded only in the latitudinal range from...
In this study, we used MaxEnt clustering of occurrence data, we used the ‘spatially rarefy model to predict spatially independent data due to spatial line-transect surveys. To avoid reducing the ability of the species in the context of climate change.

The animals were detected visually at these points during (2010), Rawson (2010), O’Brien (2014), as well as ourselves.

Species occurrence data. We used a total of 472 points (350 points in Vietnam and 122 points in Cambodia; Fig. 1) where black-shanked douces were recorded from previous studies, including those by Nadler et al. (2003), Phan et al. (2005), Hoang (2007), Hoang et al. (2010), Nguyen et al. (2010), Rawson (2010), O’Brien (2014), as well as ourselves. The animals were detected visually at these points during line-transect surveys. To avoid reducing the ability of the model to predict spatially independent data due to spatial clustering of occurrence data, we used the ‘spatially rarely occurrence data’ tool in ‘SDM toolbox’ (Brown et al., 2017) to randomly filter presence localities of P. nigripes. We selected only locations which were at least 1.0 km from other localities, resulting in 169 points for the final model. According to Hoang (2007), the home range size of P. nigripes is approximately 0.3–0.5 km², meaning that a group may live in an area with a radius of 0.3–0.4 km. Therefore, occurrence points recorded at locations that are more than 1 km apart are likely from two separate groups.

We standardised the data points to the same coordinate projection system before exporting the point coordinates as a .CSV file for use by the MaxEnt software.

Climate data. The climate data used to run the model was downloaded from the website, http://www.worldclim.org/ (Hijmans et al., 2005). The spatial resolution of climate variables was 30 arc seconds.

The prediction probability and performance of ecological niche modelling can potentially be affected by the background size (VanDerWal et al., 2009; Barve et al., 2011). Therefore, we defined our background as a bounding box of presence localities and plus additional distance of nearly 200 km, following recommendations for optimal distance of appropriate pseudo-absence points (VanDerWal et al., 2009). We also randomly used 10,000 background points from the buffered area for modelling as per the suggestions of Phillips (2008) and VanDerWal et al. (2009).

We used ENMTools version 1.4.4 (Warren et al., 2008) to calculate the correlation among variables. We then selected only one variable from every pair of variables that had a high correlation coefficient (r > 0.85) (Elith, 2000; Bett et al., 2012). The variables were chosen based on previous studies (Bett et al., 2012; Vu et al., 2020) and our understanding of the ecology of douces. From this process, eight climatic variables were eventually selected to model the distribution of the black-shanked douc (Table 1).

Climate change scenarios. In this study, we used two scenarios: the medium-low greenhouse gas concentration (RCP4.5) scenario and the high greenhouse gas concentration (RCP8.5) scenario (RCP standing for ‘Representative Concentration Pathways’) (Moss et al., 2008). 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. (2015) for the Southeast Asia region. For each model, we then generated climatic data for 2050 and 2070.

Species niche modelling. In this study, we used MaxEnt (version 3.3.3 k; Phillips et al., 2006) to predict the potential distribution of P. nigripes based on the relationship between occurrence localities and climate variables. In order to select the best performance model, we ran 48 combination models by tuning beta regularisation values and feature classes. The regularisation values ranged from 0.5 to 4 with interval 0.5 and the feature classes included L, LQ, H, LQH, LQHP, and

METHODOLOGY

Species occurrence data. We used a total of 472 points (350 points in Vietnam and 122 points in Cambodia; Fig. 1) where black-shanked douces were recorded from previous studies, including those by Nadler et al. (2003), Phan et al. (2005), Hoang (2007), Hoang et al. (2010), Nguyen et al. (2010), Rawson (2010), O’Brien (2014), as well as ourselves. The animals were detected visually at these points during line-transect surveys. To avoid reducing the ability of the model to predict spatially independent data due to spatial clustering of occurrence data, we used the ‘spatially rarely occurrence data’ tool in ‘SDM toolbox’ (Brown et al., 2017) to randomly filter presence localities of P. nigripes. We selected only locations which were at least 1.0 km from other localities, resulting in 169 points for the final model. According to Hoang (2007), the home range size of P. nigripes is approximately 0.3–0.5 km², meaning that a group may live in an area with a radius of 0.3–0.4 km. Therefore, occurrence points recorded at locations that are more than 1 km apart are likely from two separate groups.

We standardised the data points to the same coordinate projection system before exporting the point coordinates as a .CSV file for use by the MaxEnt software.

Climate data. The climate data used to run the model was downloaded from the website, http://www.worldclim.org/ (Hijmans et al., 2005). The spatial resolution of climate variables was 30 arc seconds.

The prediction probability and performance of ecological niche modelling can potentially be affected by the background size (VanDerWal et al., 2009; Barve et al., 2011). Therefore, we defined our background as a bounding box of presence localities and plus additional distance of nearly 200 km, following recommendations for optimal distance of appropriate pseudo-absence points (VanDerWal et al., 2009). We also randomly used 10,000 background points from the buffered area for modelling as per the suggestions of Phillips (2008) and VanDerWal et al. (2009).

We used ENMTools version 1.4.4 (Warren et al., 2008) to calculate the correlation among variables. We then selected only one variable from every pair of variables that had a high correlation coefficient (r > 0.85) (Elith, 2000; Bett et al., 2012). The variables were chosen based on previous studies (Bett et al., 2012; Vu et al., 2020) and our understanding of the ecology of douces. From this process, eight climatic variables were eventually selected to model the distribution of the black-shanked douc (Table 1).

Climate change scenarios. In this study, we used two scenarios: the medium-low greenhouse gas concentration (RCP4.5) scenario and the high greenhouse gas concentration (RCP8.5) scenario (RCP standing for ‘Representative Concentration Pathways’) (Moss et al., 2008). 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. (2015) for the Southeast Asia region. For each model, we then generated climatic data for 2050 and 2070.

Species niche modelling. In this study, we used MaxEnt (version 3.3.3 k; Phillips et al., 2006) to predict the potential distribution of P. nigripes based on the relationship between occurrence localities and climate variables. In order to select the best performance model, we ran 48 combination models by tuning beta regularisation values and feature classes. The regularisation values ranged from 0.5 to 4 with interval 0.5 and the feature classes included L, LQ, H, LQH, LQHP, and
Fig. 1. The 472 points recorded for the black-shanked douc (P. nigripes) that were used in this study. BGM = Bu Gia Map National Park; CYS = Chu Yang Sin National Park; CT = Cat Tien National Park; HB = Hon Ba Nature Reserve; KL-SM = Kalon-Song Mao Nature Reserve; KT = Krong Trai Nature Reserve; NK = Nam Ka Nature Reserve; NN = Nam Nung Nature Reserve; NC = Nui Chua National Park; NO = Nui Ong Nature Reserve; TK = Takou Nature Reserve; VC = Vinh Cuu Nature Reserve.
Table 1. Climate variables used in modelling the distribution of the black-shanked douc.

<table>
<thead>
<tr>
<th>Variables used</th>
<th>Variables omitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO2 = Mean Diurnal Range (Mean of monthly = max temp – min temp)</td>
<td>BIO1 = Annual Mean Temperature</td>
</tr>
<tr>
<td>BIO3 = Isothermality (BIO2/BIO7) (*100)</td>
<td>BIO4 = Temperature Seasonality (standard deviation *100)</td>
</tr>
<tr>
<td>BIO8 = Mean Temperature of Wettest Quarter</td>
<td>BIO5 = Max Temperature of Warmest Month</td>
</tr>
<tr>
<td>BIO11 = Mean Temperature of Coldest Quarter</td>
<td>BIO6 = Min Temperature of Coldest Month</td>
</tr>
<tr>
<td>BIO12 = Annual Precipitation</td>
<td>BIO7 = Temperature Annual Range (BIO5 – BIO6)</td>
</tr>
<tr>
<td>BIO13 = Precipitation of Wettest Month</td>
<td>BIO9 = Mean Temperature of Driest Quarter</td>
</tr>
<tr>
<td>BIO15 = Precipitation Seasonality (Coefficient of Variation)</td>
<td>BIO10 = Mean Temperature of Warmest Quarter</td>
</tr>
<tr>
<td>BIO17 = Precipitation of Driest Quarter</td>
<td>BIO14 = Precipitation of Driest Month</td>
</tr>
<tr>
<td></td>
<td>BIO16 = Precipitation of Wettest Quarter</td>
</tr>
<tr>
<td></td>
<td>BIO18 = Precipitation of Warmest Quarter</td>
</tr>
<tr>
<td></td>
<td>BIO19 = Precipitation of Coldest Quarter</td>
</tr>
</tbody>
</table>

Table 2. The changes in the suitable distribution (unit: km²) of the black-shanked douc (Pygathrix nigripes) under climate change scenarios modelled by the MaxEnt software.

<table>
<thead>
<tr>
<th>Model</th>
<th>RCP</th>
<th>Present</th>
<th>2050</th>
<th>2070</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCESS1-0</td>
<td>4.5</td>
<td>57303.45</td>
<td>32619.51</td>
<td>34476.03</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>4.5</td>
<td>57303.45</td>
<td>31028.67</td>
<td>20540.79</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>4.5</td>
<td>57303.45</td>
<td>32800.14</td>
<td>26720.28</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td><strong>32149.44</strong></td>
<td><strong>27245.70</strong></td>
</tr>
<tr>
<td>ACCESS1-0</td>
<td>8.5</td>
<td>57303.45</td>
<td>35480.43</td>
<td>30571.83</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>8.5</td>
<td>57303.45</td>
<td>23530.50</td>
<td>13735.98</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>8.5</td>
<td>57303.45</td>
<td>23880.42</td>
<td>13808.88</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td><strong>27630.45</strong></td>
<td><strong>19372.23</strong></td>
</tr>
</tbody>
</table>

RESULTS

The predictive model was much better than the random prediction model because all models had AUC_{training} = 0.954 ± 0.002 and AUC_{testing} = 0.948 ± 0.019. Therefore, the modelled distribution of the black-shanked douc was relatively reliable (Elith, 2000; Phillips et al., 2006). In general, the current predicted distribution of the black-shanked douc aligned with the recorded distribution (Fig. 2).

The three variables with the highest contributions in the models were isothermality (31.6%), mean temperature of the wettest quarter (25.7%), and mean temperature of the coldest quarter (16.3%) (Fig. 3).

The simulated distribution under the RCP4.5 scenario suggests that the 2050 range of the black-shanked douc would
Fig. 2. The predicted distribution of the black-shanked douc (*P. nigripes*) generated by the MaxEnt software under the RCP4.5 scenario. BGM = Bu Gia Map National Park; CYS = Chu Yang Sin National Park; CT = Cat Tien National Park; HB = Hon Ba Nature Reserve; KL-SM = Kalon-Song Mao Nature Reserve; KT = Krong Trai Nature Reserve; NK = Nam Ka Nature Reserve; NN = Nam Nung Nature Reserve; NC = Nui Chua National Park; NO = Nui Ong Nature Reserve; TK = Takou Nature Reserve; VC = Vinh Cuu Nature Reserve.
Under the RCP8.5 scenario, the effects of climate change on the potential distribution of the black-shanked douc were more severe than that of the RCP4.5 scenario (Fig. 4). The average of the climatic models showed that 51.78% and 66.19% of the suitable distribution of the species would become unsuitable in 2050 and 2070, respectively. The majority of the potential distribution in 2070 was concentrated in Lang Biang Plateau and Kon Tum Plateau. The area of high suitability seems to increase under the Access1-0 climate model due to the expected change in climate of the Lang Biang Plateau. Almost all current potential distributions in Khanh Hoa, Ninh Thuan, Dong Nai, and Binh Phuoc Provinces are predicted to become unsuitable for the species in 2070 under the RCP8.5 scenarios.

DISCUSSION

Our predicted current potential distribution of the black-shanked douc was in accordance with the locations recorded by Nadler et al. (2003), Phan et al. (2005), Hoang (2007), Hoang et al. (2010), Nguyen et al. (2010), Rawson (2010), and O’Brien (2014). The modelled potential distribution also aligned with the species’ IUCN distribution map (Rawson et al., 2008) and the potential distribution predicted by Bett et al. (2012). The largest area of high suitability was in the southwest of Dak Nong Province and northwest of Binh Phuoc Province, which indicated that the natural forest there might be harbouring an important population of the black-shanked douc. Most of the natural forests outside the protected area system in this area are currently managed by the Thac Mo Watershed Protection Forest and the Nam Tay Nguyen Forestry Enterprise. More survey efforts should be focused on this area to highlight the importance of the primate fauna there in order to support the establishment of new protected areas in the southern part of Dak Nong Province.

Under the effects of climate change, the distribution range of sensitive species is predicted to move to higher latitudes (Root & Schneider, 2002), shift to higher elevations (Wilson et al., 2005; Parmesan, 2006), or both. The future potential distribution ranges of the black-shanked douc are predicted to shrink toward the centre of the current distribution range. The northern part of the current distribution (Northern Dak Lak Province and Phu Yen Province) almost disappeared from the predicted future distributions. The species did not shift its distribution to higher latitudes, possibly because the provinces in the north of its current distribution range have lower elevations and higher temperatures.
Fig. 4. The predicted distribution of the black-shanked douc (*P. nigripes*) generated by the MaxEnt software under the RCP8.5 scenario.

The areas of high suitability in the current potential distribution range were concentrated in the higher elevations of the Lang Biang Plateau. This area has an average elevation of higher than 1,500 m, with some peaks higher than 2,000 m such as Bidoup, Nui Ba, and Chu Yang Sin. There are two protected areas, Chu Yang Sin National Park and Bidoup-Nui Ba National Park, located in the centre of Lang Biang Plateau, that might still have large areas of suitable climate conditions for the black-shanked douc in 2050 and 2070. Those protected areas lie within the suitable distributions in 2050 and 2070 which were generated by all three models. All three models therefore indicated the long-term importance of these protected areas for black-shanked douc conservation.

About half of the area of the other three protected areas (including the Nam Nung Nature Reserve, Ta Dung National Park, and Phuoc Binh Nature Reserve) would still be suitable for the species in 2070. Most of Cat Tien National Park, Bu Gia Map National Park, Vinh Cuu Nature Reserve, Kalon-Song Mao Nature Reserve, Hon Ba Nature Reserve, Nui Ong Nature Reserve, Easo Nature Reserve, Krong Trai Nature Reserve, and Takou Nature Reserve would be unsuitable for the black-shanked douc in 2070. One of those protected areas, Nui Chua National Park, is now harbouring one of the most important populations of the black-shanked douc, with about 700 individuals (Hoang et al., 2020).

Establishing and maintaining the biodiversity corridors that link severely affected areas to areas less affected by climate change are some of the measures that have been applied (Heller & Zavaleta, 2009). These corridors also help to facilitate gene exchange among populations. Once established, the biodiversity corridors will facilitate the movement of animals and the dispersal of plant species within the distribution areas to ensure their viability. Maintaining biodiversity corridors also helps to better conserve endangered species outside the protected areas. The biodiversity corridors in the region should be designed to connect habitat areas that are expected to be severely affected by climate change, e.g., the forest complex consisting of Bidoup-Nui Ba National Park and Chu Yang Sin National Park. Maintaining the natural forest to create a dispersal route from Cat Tien National Park to Ta Dung National Park and then to Bidoup-Nui Ba National Park would also be very important for long-term conservation efforts of the species, and should be given top priority.

Although the high habitat suitability between the Access1-0 model and the other two models is different, the overall patterns in the shift in distribution of the black-shanked douc in 2050 and 2070 are similar under all climate models. Future potential distribution range predicted by GFDL-CM3 and MPI-ESM-LR models were more conservative than that predicted by Access1-0. Therefore, the areas that fall in the future distribution ranges predicted by all three models should receive the highest priority in the conservation of the species. Specifically, in the context of climate change, higher priority in the conservation of the species should be given to the protected areas in the centre of the species’ current distribution range, especially in the north of Lam Dong, the south of Dak Lak, and the middle of Dak Nong Province. Specifically, Bidoup-Nui Ba and Chu Yang Sin National Parks should receive the highest priority. Our studies indicated that several forested areas, both inside and outside the protected area system, need further surveys in order to gain a fuller understanding of the black-shanked douc langur populations and distribution; this is important to facilitate the establishment of new protected areas or biodiversity corridors in the region.

CONCLUSIONS

We predicted that the distribution of the black-shanked douc would be sharply reduced with 66.19 % of the current distribution lost by 2070 under the RCP8.5 scenario. Under the context of climate change, higher priority in conservation efforts for the species should be given to the protected areas in the centre of the species’ current distribution, especially in the north of Lam Dong, south of Dak Lak, and middle of Dak Nong Provinces. Specifically, Bidoup-Nui Ba and Chu Yang Sin National Parks should receive the highest priority. Our studies indicated that more surveys should be conducted in several forested areas, both inside and outside the protected area systems, in order to gain a better understanding of the black-shanked douc langur populations and their distribution.

ACKNOWLEDGEMENTS

This study was funded by the Vietnam National Science and Technology Program to respond to climate change and for environmental and resource management in the period from 2016 to 2020 (Project Code: BĐKH.38/16–20). We would like to thank several researchers who conducted the wildlife surveys in order to make this study possible. We would also like to thank Greg Nagle, Martin M. Balagat, and Alexa A. Rose Prince-Capone for proofreading this manuscript, and are grateful to the anonymous reviewers for their comments and suggestions to improve the manuscript.

LITERATURE CITED


