IUCN-SSC SRAS Project 18/29 Summary Report:
The effect of climate change on the distribution of crocodilians in West and Central Africa
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Introduction

Climate can be among the most important determinants in the distribution of species. As such, climate change can impact species' distributions by increasing (e.g. Hickling, Roy, Hill, Fox, & Thomas, 2006) or decreasing (e.g. Meynecke, 2004) available suitable habitat. As ectotherms, herpetofauna are perhaps more sensitive to environmental changes than other species groups, and some studies have shown significant impacts of climate change on amphibian and reptile distribution (e.g. Bickford, Howard, Ng, & Sheridan, 2010).

Crocodiles are large-bodied ectotherms that often function as keystone species in their ecosystems (Ashton, 2010; Mazzotti et al., 2008). To date, no study has as yet examined the potential impact of climate change on any crocodilian species. Within this group, several mechanisms could drive changes in distribution due to climate change. Rising temperatures could have deleterious effects on overall fitness, especially since the majority of ectotherms do not function optimally at the high or low ends of their thermal tolerance (Bickford et al., 2010), instead having thermal optima (Bickford et al., 2010; Ferder & Burggren, 1992). Changing temperatures could furthermore lead to decreased suitable habitat abundance (Gibbons et al., 2000). Besides temperature increases, climate predictions show potential increases of tropical storms and floods. This could impact crocodiles in various ways. Tropical storms might destroy nests by washing away nesting material. Localised flooding is likely to cause egg mortality, erosion of nest banks and altered nest attendance behaviour (Hamann, Limpus, & Read, 2007).

In West and Central Africa, conservative climate change scenarios estimate temperature increases of > 1 C˚ within the next 60 years, and a 5 to 30% change in rainfall, with the predicted changes in rainfall being higher in West Africa than in Central Africa (Hulme, Doherty, Ngara, New, & Lister, 2001). Such changes could potentially lead to changes in crocodile populations and distributions. How species distributions will change is dependent on the ability of the species to adapt and their ability to tolerate changes in temperature and rainfall. West and Central Africa harbour three crocodilian genera: *Mecistops*, *Osteolaemus,* and *Crocodylus*. These genera comprise seven species: *Mecistops cataphractus* and *M. leptorhynchus*, *Osteolaemus tetraspis, O. osborni* and a yet to be named West African species, *Crocodylus suchus* and *niloticus*. These climate change scenarios are likely of particular importance for species like *Mecistops cataphractus* and *O. sp. aff. tetraspis,* which are listed as Critically Endangered (IUCN, 2014) and Endangered (M. Shirley, pers. comm.) on the IUCN Red List, and are more or less forest obligates.

The crocodilians of West and Central Africa vary in their distribution and habitat preference. *Mecistops* and *Osteolaemus* are mainly found inland in fresh water, whereas *Crocodylus* can be found in both inland and coastal areas (Oaks, 2007). *Mecistops* and *Osteolaemus* are frequently observed in forested areas and *Osteolaemus* seems to have a preference for streams and swamps (Waitkuwait, 1986). *Crocodylus* can even be found in desert habitat (Brito, Martínez-Freiría, Sierra, Sillero, & Tarroso, 2011) and its distribution is much wider than those of *Mecistops* and *Osteolaemus*, which suggests that *Crocodylus* has a larger tolerance for a wide variety of climatic conditions. This may mean this genus is more resilient to climate change compared to the other genera.

The objective of this study is to model the potential effects of climate change on the distribution of the three West and Central crocodilian genera. I hypothesized that conservative changes in climate will not lead to changes in the distribution for all three genera, that moderate changes will only lead to changes in distribution for *Mecistops* and *Osteolaemus*, and that extreme changes in climate will lead to a decreased distribution for all three genera.

Methods

Both literature and on-going survey data in combination with contemporary and historical climate date were used to model how the species distributions are impacted by climate variables. Crocodile occurrence data was obtained from different sources, including published peer-reviewed papers, grey literature (e.g. unpublished reports, survey reports, newsletters, etc.), fieldworker's databases, other databases (e.g. CrocSurveys and CrocBITE), museum records, Google Images, Youtube videos and personal recollections and incidental sightings. I obtained current environmental data from the AfriClim database (available at https://ww.york.ac.uk/environment/research/kite/resources) and climatic scenario data from WorldClim (GCM: NorESM1-M, timeframe: 2070, available at http://www.worldclim.org/CMIP5v1). I developed three scenarios (a conservative, moderate and extreme) to test these effects, using Maxent. The climate scenarios used in this analysis are based on RCP's. RCP's are representative concentration pathways that represent four greenhouse gas concentration trajectories (van Vuuren et al., 2011). In this study scenario 1 corresponds to RCP2.6, scenario 2 to RCP6.0, and scenario 3 to RCP8.5. I used maximum entropy modelling of species geographic distributions in RStudio (version 3.5.1), with default parameters and partitioned the data to training (80%) and testing (20%) of presence points.

The models were tested using receiver operating characteristic (ROC) curves. The ROC curve plots true positive rate against false positive rate (Phillips, Dudík, & Schapire, 2004). The area under the curve (AUC) was used as a measure of the fit of the model. AUC's were obtained for both training and testing, but the latter one was deemed of greater importance as it uses the model to predict the probability of occurrence independent of the model fitting. I used permutation importance as measure of variable contribution, rather than percentage contribution, as permutation importance is independent of the particular path the Maxent code used to obtain the optimal solution.

Results

Mecistops

The model performed well and closely fitted the occurrence points of *Mecistops*, which was confirmed by both training and test AUC values. The training AUC value was above 0.9 and the test AUC value above 0.85 (number of iterations=500, *n* training=75, *n* testing=19).

Examination of the permutation importance revealed that the four most important variables determining the distribution of *Mecistops* in West and Central Africa are mean diurnal range, precipitation of the driest quarter, precipitation of the driest month and annual temperature range.

In contrast with the hypotheses, all three scenarios affect the distribution of *Mecistops*. In all cases predicting potential distribution increases (Fig. 1).

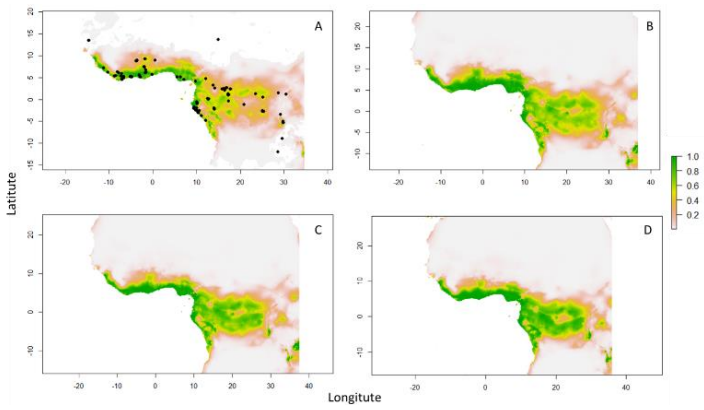


Figure 1: Predicted distribution of *Mecistops* per climate scenario. A: Current distribution of *Mecistops*, including the actual records (filled circles), B: predicted distribution of *Mecistops* under scenario 1 (RCP26, 2070), C: predicted distribution of *Mecistops* under scenario 2 (RCP60, 2070), D: predicted distribution of *Mecistops* under scenario 3 (RCP85, 2070). Colours indicate probability of occurrence.

Osteolaemus

The model performed very well and closely fitted the occurrence points of *Osteolaemus*, which was confirmed by both training and test AUC values. Both training and test AUC values were above 0.9 (number of iterations: 500, N training: 129, N testing: 34).

Examination of the permutation importance revealed that the four most important variables determining the distribution of *Osteolaemus* in West and Central Africa are minimum temperature of the coldest month, annual precipitation, precipitation of the driest quarter and annual temperature range.

All three scenarios affect the distribution of *Osteolaemus*. In all cases predicting potential distribution increases (Fig. 2). This effect is most pronounced in Central Africa. In West Africa, the potential distribution expands with the first scenario, and even though the potential distributions under the second and third scenario are expanded compared to the current distribution, they are slightly more limited when compared to the potential distribution of scenario 1.

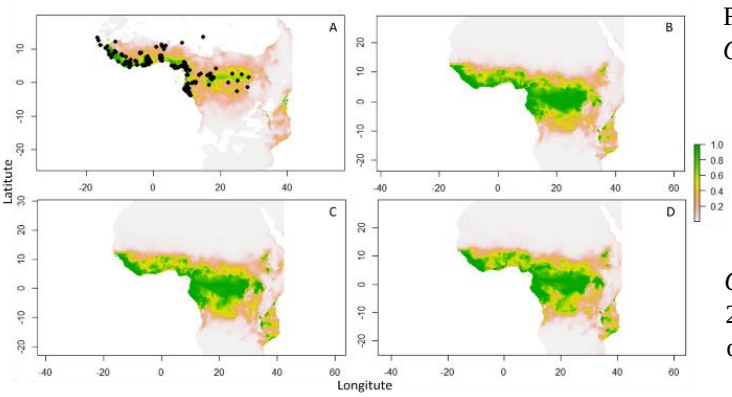


Figure 2: Predicted distribution of *Osteolaemus* per climate scenario. A: Current distribution of *Osteolaemus*, including the actual records (filled circles), B: predicted distribution of *Osteolaemus* under scenario 1 (RCP26, 2070), C: predicted distribution of *Osteolaemus* under scenario 2 (RCP60, 2070), D: predicted distribution of *Osteolaemus* under scenario 3 (RCP85, 2070). Colours indicate probability of occurrence.

Crocodylus

The model performed well and closely fitted the occurrence point of *Crocodylus*, which was confirmed by both training and test AUC values. The training AUC value was above 0.9 and the test AUC value above 0.85 (number of iterations=500, *n* training=130, *n* testing=33).

Examination of the permutation importance revealed that the four most important variables determining the distribution of *Crocodylus* in West and Central Africa are annual mean diurnal range, precipitation of the driest month, minimum temperature of the coldest month and precipitation of the wettest month.

All three scenarios affect the distribution of *Crocodylus*. In all cases predicting potential distribution increases (Fig. 3).

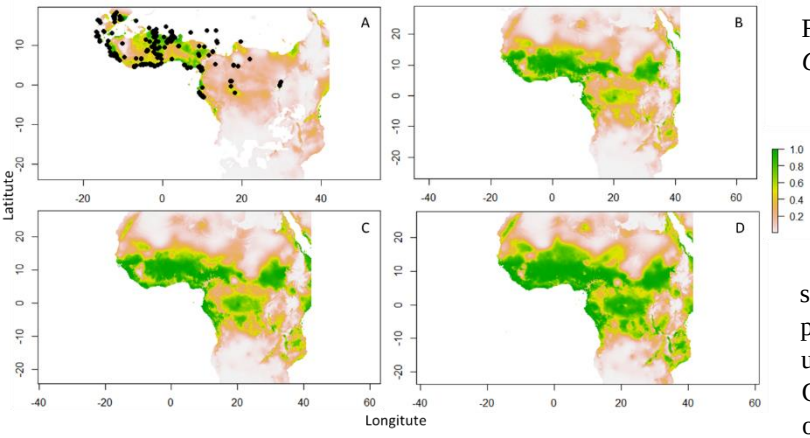


Figure 3: Predicted distribution of *Crocodylus* per climate scenario. A: Current distribution of *Crocodylus*, including the actual records (filled circles), B: predicted distribution of *Crocodylus* under scenario 1 (RCP26, 2070), C: predicted distribution of *Crocodylus* under scenario 2 (RCP60, 2070), D: predicted distribution of *Crocodylus* under scenario 3 (RCP85, 2070). Colours indicate probability of occurrence.

Conclusions

The aim of this study was to model the effect of climate change on the distribution of crocodilians in West and Central Africa. The results show that, contradictory to the hypotheses, predicted climate change scenarios are likely to expand the distribution of all three genera. This effect already occurs under the moderate climate scenario (RCP2.6) and becomes more profound under the extreme climate scenario (RCP8.5). These results must be viewed cautiously, however, as the environmental variables used to describe climatic conditions might not best reflect important processes that could have deleterious effects of crocodilians and their distribution. This could especially be the case for factors such as storm severity and variables that more precisely reflect flooding. The exclusion of these variables from the model could lead to unjustly positive outcomes in terms of distribution change. Additionally, temperature increases did not surpass the critical thermal maxima for the three genera, which could be a reason for the lack of limiting effects on the distribution.

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