Methods in Biodiversity Analysis

Species Distribution Modelling of breadfruit (*Artocarpus altilis)*

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Introduction

Breadfruit (*Artocarpus altilis*) is a traditional starch crop which originates from Oceania all the way back from the late 18th century (Ragone, 2018; Zerega, Ragone, & Motley, 2004). Although the origin of breadfruit isn't totally clear, knowing that breadfruit is depending on humans for dispersal, theories that it migrated from eastern Melanesia up to Micronesia is supported by the human migration patterns from Polynesia through Melanesia (Zerega et al., 2004). Breadfruit is a tropical fruit and the breadfruit tree produces fruits from March to June and form July to September (Akanbi, Nazamid, & Adebowale, 2009). The genus Artocarpus belongs to the Moraceae family and include around 50 species which are widely distributed in tropical and subtropical regions (Sikarwar et al., 2014).

Breadfruit could be playing an important role in fighting the world's longest ongoing fight: hunger. Especially with the current rate of population growth in the 21st century, food shortages are forthcoming unless rapid progress is made in terms of food production and security. Many of the countries currently struggling with food shortages and higher levels of undernourishment are suitable for the cultivation of breadfruit (Jones et al., 2011). With this in mind and when comparing the yield and nutritious value of breadfruit against other commonly used staple crops, breadfruit needs to be considered not inferior to other commonly cultivated staple crops (Englberger, Aalbersberg, et al., 2003; Englberger, Marks, & Fitzgerald, 2003). This means that there might be a sustainable solution in fighting hunger and undernutrition by cultivating breadfruit more intensely in the regions in the world that need it, as breadfruit is already naturally occurring in those regions.

Keeping the potential importance of breadfruit in mind, it is interesting to look make a species distribution model (SDM) to see what will potentially happen to the breadfruit tree under climate change scenario's. As breadfruit is well adapted to the wet tropics there are a some important ecological requirements to take into account: warm temperature as it is doing best between 21-32 °C, rainfall between 1525-2540 mm annually and adequate drainage (Jones et al., 2011; Ragone, 1997). Cold temperatures may result in low yield and increased mortality and while it requires relatively high levels of rainfall, breadfruit may survive up to 3-4 months of drought (Jones et al., 2011).

With the help of SDM, the present- and future climate scenario RCP4.5 climate variables are compared to see the effect of potential future climate scenario RCP4.5 on the suitable habitat of breadfruit. From the ecological requirements of breadfruit as mentioned above, it can be expected that when area's with higher temperatures are increasing, the suitable habitat expands also it is expected that precipitation plays an important role. For this, the research question states: Will the suitable habitat of breadfruit increase as consequence of the temperature rise around the tropics according to the RCP4.5 scenario?

Methodology

All steps were performed according to the guidance and manuals of R. Vos & M. van het Zelfde (Vos & Zelfde, 2019). In order to produce and analyze the Species Distribution Model (SDM), the two software programs: MaxEnt & RStudio were used.

First occurrences data of breadfruit was extracted from GBIF.org. The occurrence data of breadfruit retrieved from GBIF.org contained 984 data points of species with coordinates, preserved species were taken into account as the coordinates for this species were retrieved from the location where the specimen was collected.

The data was adjusted by creating a distribution map in GIS followed by taking out data points that didn't occur on land (randomly placed data points in the sea, from which we can be quite certain they are incorrect as the breadfruit tree doesn't grow on open sea without any land), also the data was checked for dubious data points (data points occurring outside the tropical and sub-tropical region).

Environmental data was extracted from worldclim.org using version 1.4 for extracting the bioclimatic variables of the present and the future prediction for the RCP4.5 scenario in a 5 minute resolution for the year 2050. The RCP4.5 scenario assumes global CO_2 emissions will rise for the coming approximately 20 years and will hereafter decline (Thomson et al., 2011). This seems like a realistic scenario as rapidly more awareness is rising for the CO_2 emissions. The benefit of this scenario is also that we can look at the short term effect of climate change, as the higher RCP scenario's assume CO_2 peaks beyond 2050.

The data was prepared for use in MaxEnt using RStudio. Most bioclimatic variables were taken out by selecting for autocorrelation and multicollinearity using R. After checking for autocorrelation, using a pairwise correlation test, and for relevance, bioclimatic variables bio3, bio6, bio11, bio14 and bio17 were preselected. After the pairwise correlation test, a multicollinearity test was performed, using the variance inflation factor (VIF) to exclude variables which have a too high statistical dependence. At the end bioclimatic variables bio3 - isothermality, bio6 - minimum temperature of coldest month & bio14 – precipitation of driest month were chosen.

MaxEnt was setup and run according to the manual with the breadfruit occurrence data and the 3 bioclimatic variables mentioned above. The SDM was validated using the Area Under the Curve (AUC) of the Receiver Operator Curve (ROC). At last, change maps were made using R calculating the differences between the habitat suitability between the present and future scenario.

Model performance and output

The Receiver Operator Curve (ROC) gives an Area Under the Curve (AUC) value 0.879. AUC > 0.8 is considered good, AUC > 0.7 considered reliable and AUC 0.5 indicates the model accuracy is not better than random. So this model can be considered to be a good model.

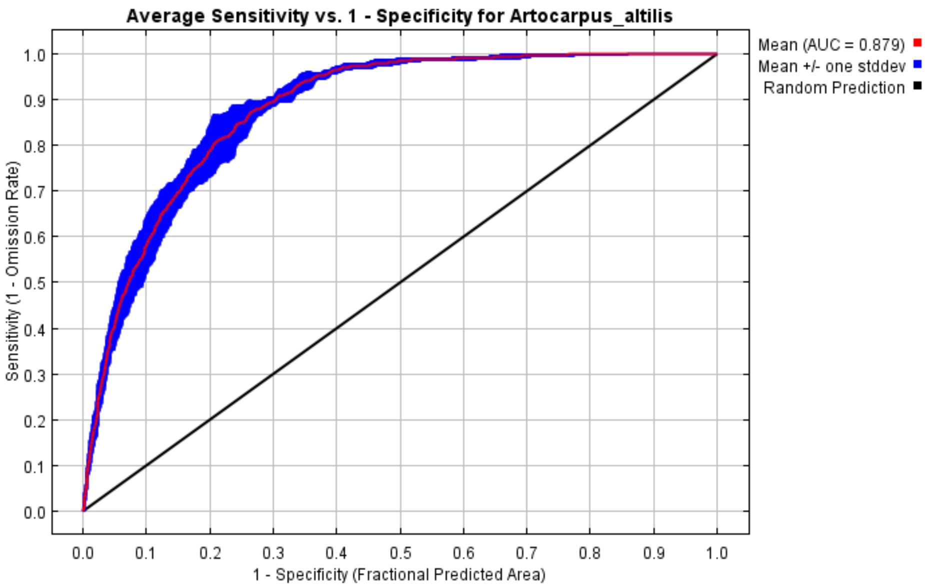

Figure 1: Receiver Operator Curve and Area Under the Curve value

After the calculations of MaxEnt for a maximum training sensitivity plus specificity threshold for each of the 5 replicates, the mean of this 5 thresholds was taken resulting in a threshold of 0.278. This threshold will later also be used for making the change maps in R.

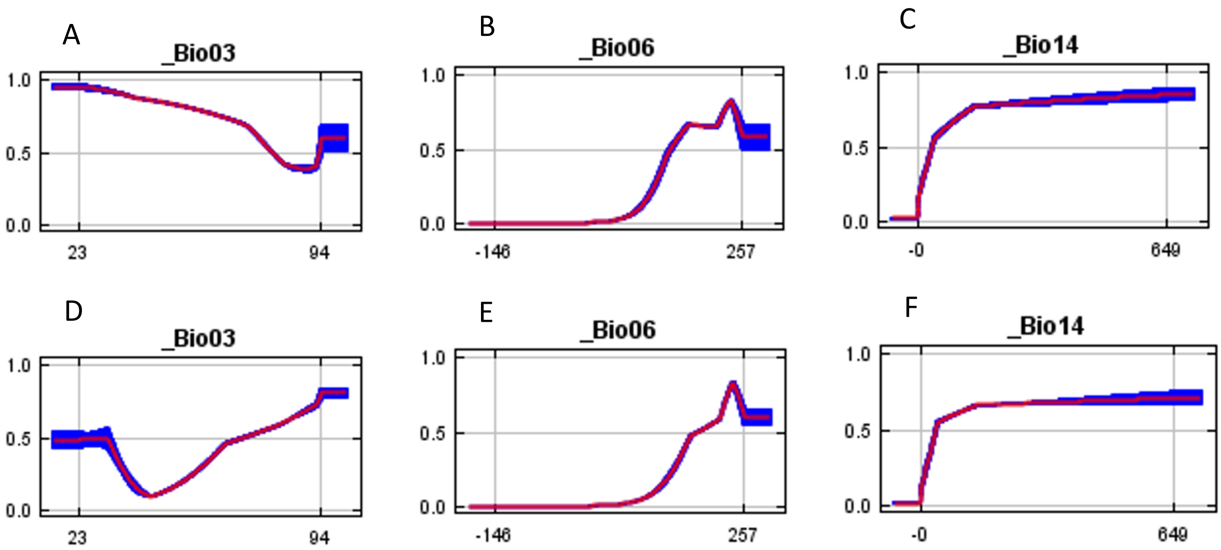

Figure 2: First row (A, B & C): contribution of different variables bio3, bio6 & bio14 relatively to each other in the MaxEnt model. Second row (D, E & F): contribution of different variables bio3, bio6 & bio14 when run separately by MaxEnt.

The curves above show how each variable contributes to the MaxEnt species distribution model. A, B & C (first row) show the contribution of the 3 bioclimatic variables used together in the model and relatively to each other, while D, E & F (second row) show the individual contribution of the variables, separate from each other.

Variable	Percent contribution	Permutation importance
_Bio14	74.4	54.7
_Bio06	18	38
_Bio03	7.6	7.3

Table 1: Jackknife outcome: percentages of contribution of the different bioclimatic variables to the MaxEnt model.

The table above shows the outcomes of the jackknife tests. This table shows us that bio14 contributes the most to the model with 74.4%, this means that 74.4% of the model can be explained by variable bio14. This means that the data of the precipitation of the driest month has the biggest influence. First runner up is bio6 with 18% contribution, which represents the data of the temperature of the coldest month. Last but not least bio3, representing isothermality, contributes with 7.6% to the total model.

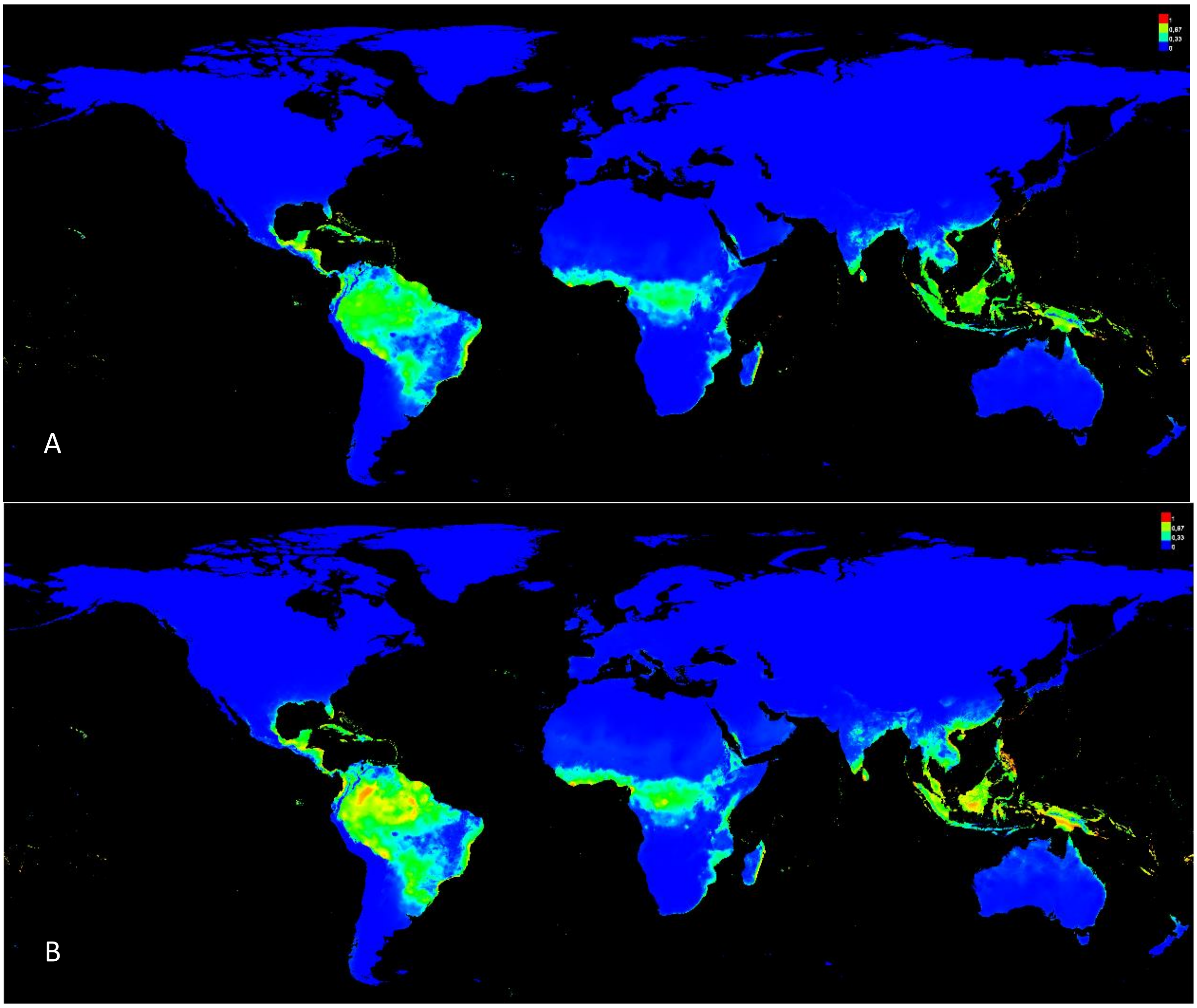

Figure 3: Projection of species distribution model in MaxEnt. A: present climate conditions. B: future RCP4.5 climate conditions.

The maps in figure 3 are projections of the model made by MaxEnt. Map 3A represents the present climate scenario, whilst map 3B represents the future climate scenario. The warmer areas show areas with better predicted conditions for the breadfruit species. These maps indicate a larger geographical habitable area and better conditions for breadfruit in the RCP4.5 climate scenario.

Below, the extra change maps computed by R are shown. Figure 4 shows the suitable habitat for breadfruit under the present climate conditions. Figure 5 shows the suitable habitat under future RCP4.5 conditions. Notable is the expansion of the area as confirmed by figure 6 as where the green areas are areas added to the present area in a future scenario and red means a decline.

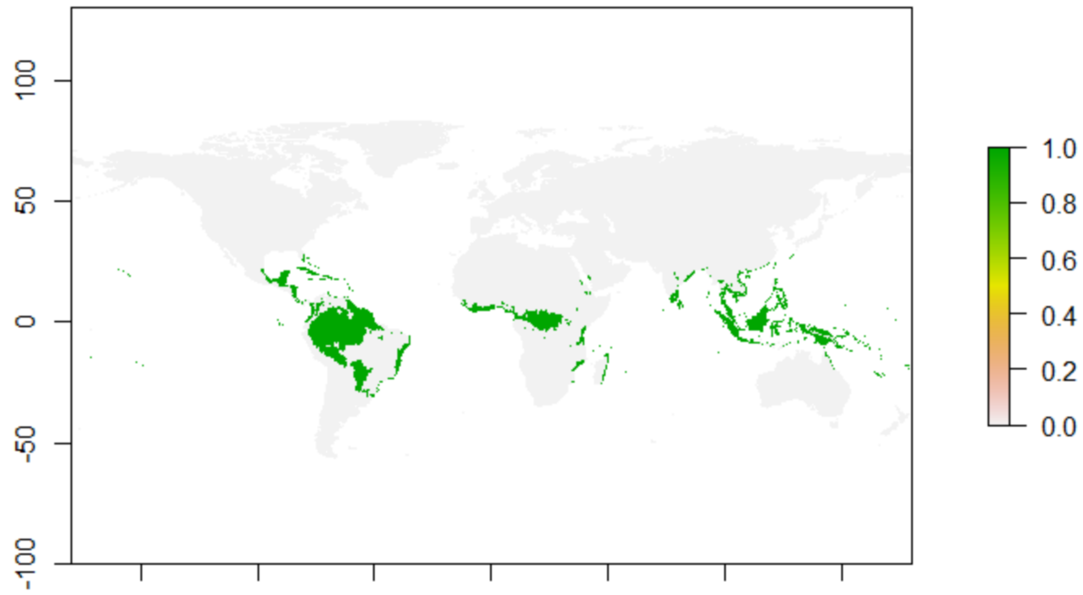

Figure 4: Suitable habitat for breadfruit under the present climate conditions according to threshold in R.

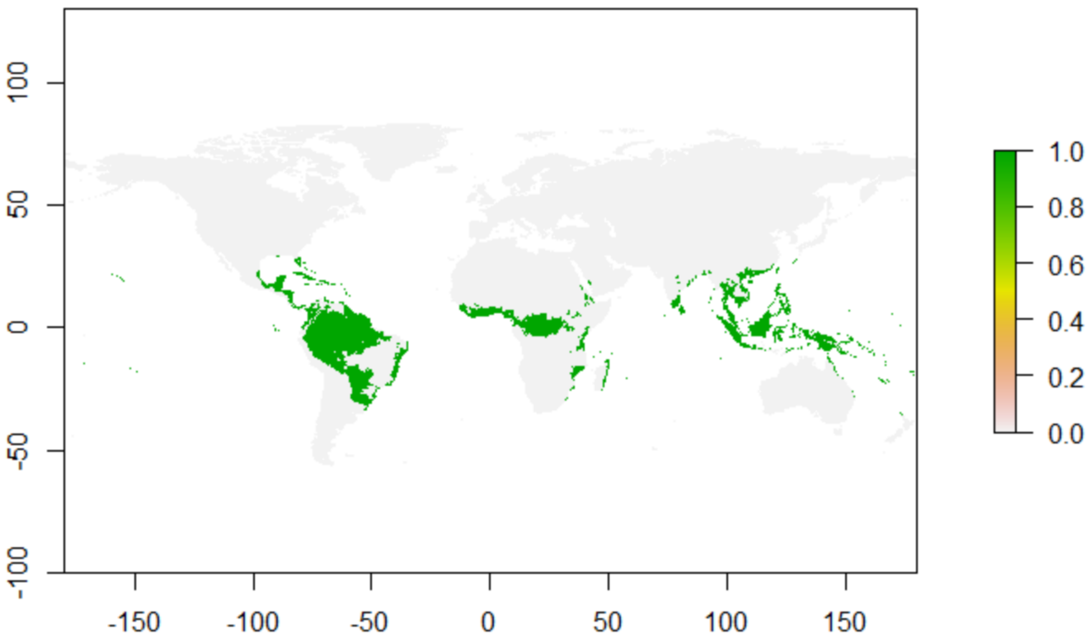

Figure 5: Suitable habitat for breadfruit under future RCP4.5 climate conditions according to threshold in R.

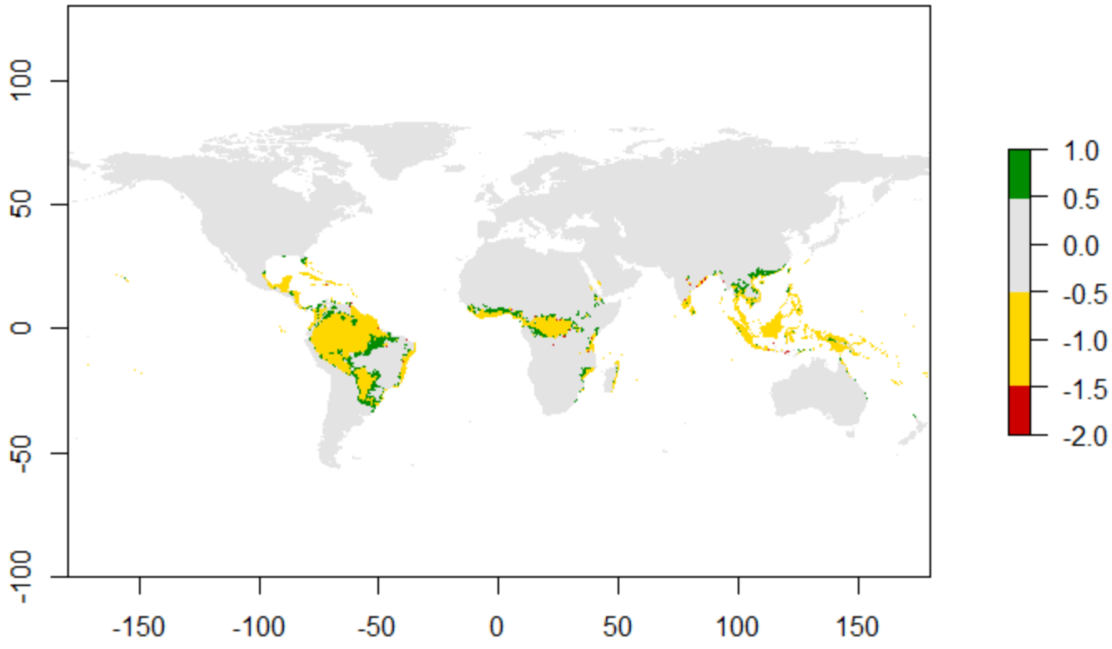

Figure 6: Change range map where green represents the gained-, red the lost- and yellow remained suitable habitat area in the future RCP4.5 climate scenario opposed to the present conditions. Grey area is area that was never suitable.

Discussion & conclusion

According to the model the suitable habitat for breadfruit increases under RCP4.5 climate conditions. However, it has to be taken into account that this model is limited in a sense that only abiotic factors are taken into account. In reality biotic factors and accessibility of an area are playing an important role.

In the model output it seemed that precipitation (especially drought) played an important role in the model for determining the suitable habitat. This was surprising as breadfruit trees can survive up to 3-4 months of drought. The expectation that cold would have the largest influence seemed to be untrue, which seems odd when keeping in mind that cold temperatures can cause lower yield and increased mortality.

This model was only run for the future RCP4.5 climate scenario. Since there is a notable effect of increasing suitable habitat under these conditions it might be interesting to look at other future climate scenario's as well.

For this model the 3 bioclimatic variable bio3, bio6 & bio14 were used, however, the outcome for this model might be totally different when run with different bioclimate variables. Also biotic factors such as soil quality and amount of sun hours were not taken into account (they were not available). It is therefor better to make multiple models under different conditions and compare them to find the best one.

Besides the limitations of the model, breadfruit grows pretty well in the tropic regions and might expand its habitat in the future under the RCP4.5 climate conditions.

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