The potential impact of present and future climate conditions on the distribution of *Mangifera indica* L. (mango).

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Introduction

Mangifera indica L., also known as mango, is considered as one of the best tropical fruits and is known as the *king of fruits* (Mukherjee, 1972). According to GBIF data over 4476 occurrences with coordinates are available for the mango, with most occurrences in South America, South Asia, and Australia and Oceania (Figure 1 (GBIF, 2013)). This current distribution is in line with the history and the distribution of mangoes. The mango is actively moved for centuries by humans from its centre of origin in Myanmar towards Asia, Middle East, East Africa and South America (Mukherjee, 1972; Rojas-Sandoval & Acevedo-Rodríguez, 2014). The fruit can also be eaten and dispersed by bats, hornbills, monkeys, elephants and raccoons resulting in establishment in natural areas in pan-tropical climates. Due to the movement caused by humans, the mango is widely cultivated for commercial fruit production resulting in naturalized and well adapted mango varieties (Bally, 2006; Rojas-Sandoval & Acevedo-Rodríguez, 2014). Therefore it is justified to wonder about the impact of climate change on mango trees and on the mango production and cultivation (Legave, Normand, & Lauri, 2013). To give insight in the impact of climate change on habitat suitability of the mango, a present (year 1960-1990) and future (year 2050) species distribution model were generated using Maxent and *Mangifera indica* L. sequence data derived from GBIF.

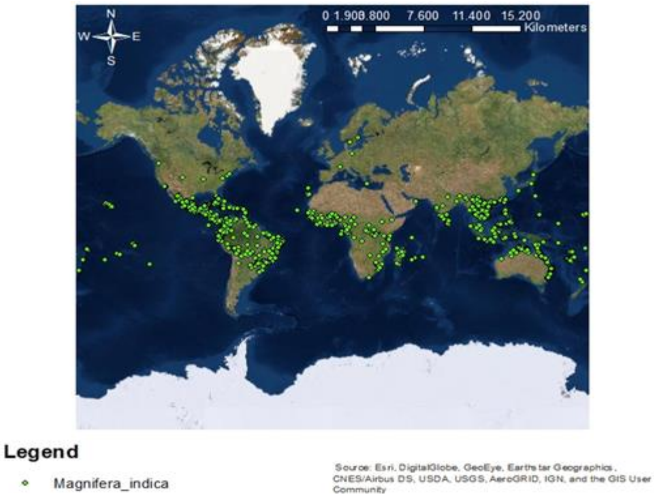

Figure 1: Current distribution of the mango (*Mangifera indica* L.). Mango sequence data derived from GBIF (GBIF, 2013), and visualized with ArcGIS.

Methodology

The potential distribution was estimated with data derived from GBIF for the mango sequences with known coordinates and the Bioclim website for the climate variables (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005; GBIF, 2013). For the present distribution (1960-1990), the bioclimatic variables derived from the generic grid format at 5 minute resolution are used. For the future (2050) distribution, the bioclimatic variables (bi) derived from the representative concentration pathway (RCP) 4.5 from the global climate model HadGEM2-AO at 5 minutes are used (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). The bioclimatic variables with a spearman's correlation lower than -0.7 or greater than 0.7 are selected in the software R. Subsequently, the bioclimatic variables that suits best with the ecological requirements of the mango are selected. The mango requires an average temperature between 15˚C-30˚C. In lower temperatures, the growth will slows down and decreases the fruit quality. Additionally, a distinct dry or cold season stimulates flowering, however, rainfall during flowering reduces the fruit set. Furthermore, the present distribution of the mango is mainly centred towards the equator (Figure 1), therefor it is expected that mean temperatures have a minor effect than fluctuations seasonality (NAFIS, 2014; Bally, 2006). This leads to a subset of bioclimatic variables consisting of mean diurnal range (bio2), temperature seasonality (bio4), annual precipitation (bio12) and precipitation seasonality (bio15). With the created subset, a species distribution model was generated with MaxEnt. The proposed settings in the handout were used to create the present and future species distribution models in MaxEnt. The linear and quadratic features were selected, while the Jackknife function was disabled. The output format was set to logistic and the output file type to asc. Subsequently, the present- and future plots were loaded and plotted in the software R followed by converting the maps to thresholded binary maps using the 'Maximum training sensitivity plus specificity' threshold value (0.320) generated within MaxEnt.

The potential present and future distribution

The AUC value of this model is 0.854 (Figure 2), which means that the model is generally accepted as an useful distribution model. However, the AUC value in general, is currently contested since the measured SDM accuracy relies on true absences, which are lacking in most cases and are replaced by pseudo-absences or a background sample (Raes & Aguirre-Gutiérrez, 2018). According to the variable contribution table (Table 1); temperature seasonality (bio4) and the annual precipitation (bio12) has the most influence on the model.

Table 1: Estimates of relative contributions of the environmental variables to the model. Bio4 contributes most to the model followed by bio12. Bio2 = 'Mean Diurnal Range', bio4= 'Temperature Seasonality', bio12= 'Annual Precipitation', and bio15= 'Precipitation Seasonality'.

Variable	Percent contribution	Permutation importance
bio4	55.1	67.8
bio12	37.4	18
bio2	6.2	11.7
bio15	1.3	2.6

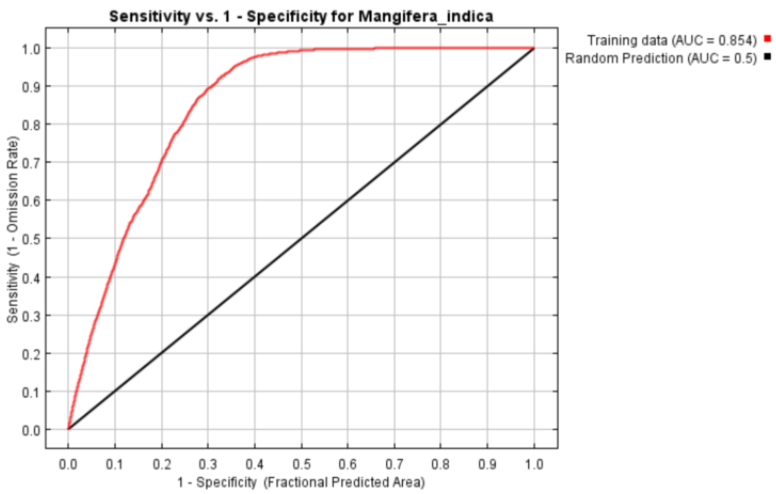

Figure 2: Receiver operating characteristic (ROC) curve with the AUC of the training data (0.854) and the random prediction (0.5).

Based on the selected climatic variables, the present potential distribution of the mango is much wider than its actual distribution. This is probably due to cultivation, which bothers both the amount of offspring and dispersal, and due to its adaptability to a wide variety of climates where it has become naturalized (Bally, 2006). The mango could potentially expand to Chili, Iceland and Scotland (Figure 3). When looking at the potential future global distribution with the climate estimates for 2050, it seems like, at first glance, that there are no huge differences between the present- and future species distribution (Figure 4). However, there are some slightly differences in Africa, South America and Europe. This suggests that climate change in 2050 with the HadGEM2-AO RCP 4.5 scenario has not a high impact on suitable habitats of the mango.

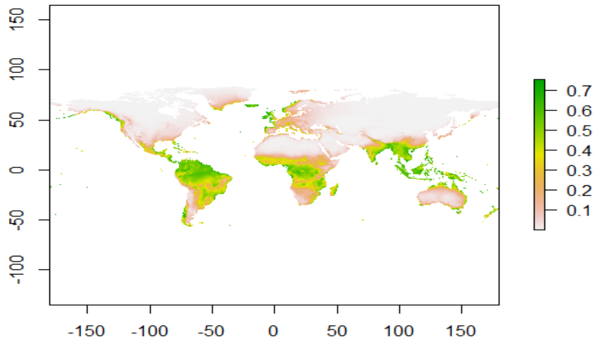

Figure 3: The potential present(1960-1990) global distribution of the mango. Modelled in MaxEnt and visualized with R studio. Green colour represent a high probability of occurrence while red indicates a low probability.

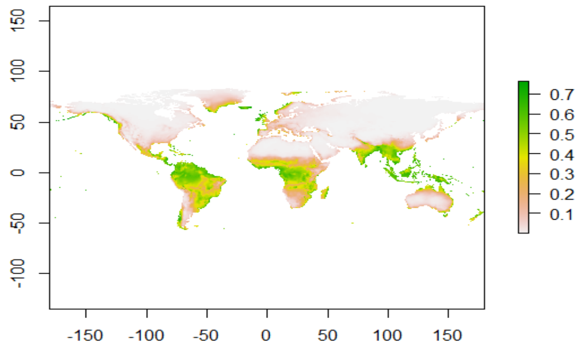

Figure 4: The potential future (2050) global distribution of the mango. Modelled in MaxEnt and visualized with R studio. Green colour represent a high probability of occurrence while red indicates a low probability.

Response to future scenario

The thresholded maps are used to calculate the differences between the present and future habitat suitability maps (Figures 5 and 6). As mentioned before but also visible in figure 5, there is indeed a little difference between present and future habitat suitability's. The map in figure 6 shows some mangoes occur in Europe, North America and some islands in the Pacific Ocean while there is no suitable habitat according to the model.

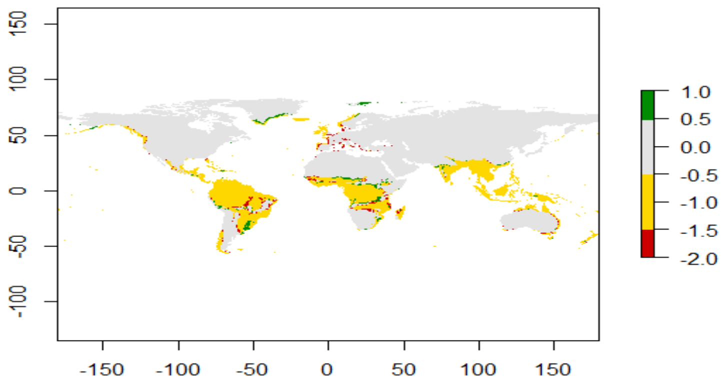

Figure 5: Differences between present (1960-1990) and future (2050) habitat suitability for climatic conditions at global scale according to the model. Grey areas indicates areas that are never suitable, yellow remains suitable, red indicates areas where the suitable habitat is lost and green indicates where suitable habitat is gained.

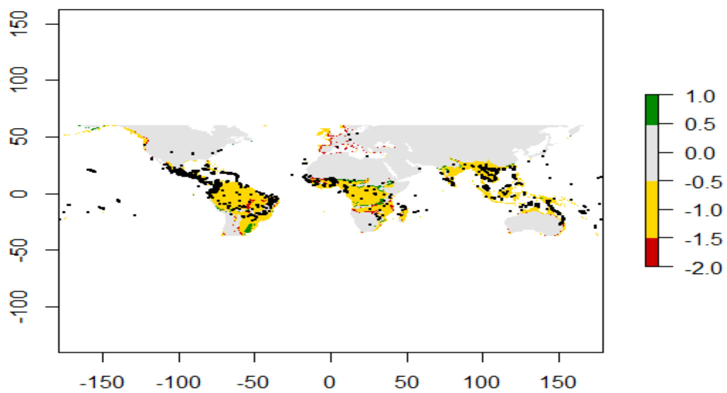

Figure 6: Differences between present (1960-1990) and future (2050) habitat suitability for climatic conditions at occurrence scale according to the model. Grey areas indicates areas that are never suitable, yellow remains suitable, red indicates areas where the suitable habitat is lost and green indicates where suitable habitat is gained.

Biological interpretation

The distribution of the mango within its home range is not expected to change much due to a change in climatic conditions. The climatic conditions become unfavourable in only some places of North America and Europe. However, this has no effect on the growth conditions for the mango, because the mango does not grow there in nature. The mangoes will grow there only in green houses or botanical gardens. Additionally, it is interesting that countries such as Iceland and Scotland have a suitable habitat according to the model. This is probably due to the fact that temperature seasonality and annual precipitation are the main drivers for this model. The duration of drought and extreme temperatures for a longer period are probably more important than temperature seasonality and annual precipitation (Bally, 2006). Additionally, Scotland and Iceland have a different climate, namely a tundra- and sea climate, than the mango actual prefer. The mango prefer pan-tropical climates, so it will probably not grow there in nature. In addition, due to the improvement of cultivating mangoes it resulted in thousand different mango varieties around the world. Therefore, it is possible that mango varieties are well suited for export and able to grow in green houses in other countries (Bally, 2006).

In the end, this is not a very useful model, although it is a very interesting model. The environmental variables that were chosen are chosen with logical thinking and are not supported with empirical data. Additionally, the model has not been verified with a null model and is not tested for pseudo- and background testing. Subsequently, the model has run only once resulting in one model replicate, while it would be better to run the model multiple times to build a consensus model creating a smaller stochastic effect on pseudo absences. Also, the model does not encompass land use changes, biotic interactions or physiological responses of invasive species, which could also have an influence on the distribution of the model. However, when such variables are included it would also increase the complexity of the model.

References

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