Impacts of climate change on *Eleusine coracana* based on species distribution models

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Introduction

During the past years it has become clear that climate change is threatening many species survival. Awareness has increased that this will expectedly lead to various critical consequences for humanity. One of the areas this will be noticed in a very direct way, is the agricultural sector which could not only encounter severe economic losses but even threaten the capability to feed human population. It is important to anticipate on the consequences of expected climate changes for currently cultivated crop species so we can anticipate and keep ahead of problems.

One of the cereals widely cultivated is finger millet (*Eleusine coracana*) which is was originally domesticated in East Africa but has gained territory during the past decades en is now also spread across South Asia. The species is favoured in semiarid and tropical areas as it seems to be resistant against agricultural climatic disasters and storage pests[1]. The species is characterised by a short growing season and is capable of being productive even under dry conditions. In India the species is ranked sixth in agricultural production. Furthermore, the species is characterised by several health benefits. It contains no gluten, has high dietary fiber, mineral and vitamin contents[2] and is even claimed to lower the risk for diseases such as diabetes, cancers and cardiovascular disorders[3]. The combination of these traits makes this species of high interest for the agricultural sector with climate change and increasing human population in mind.

Based on the current occurrence data of *E. coracana*, Species Distribution Models (SDMs) can form an important tool to predict consequences of climate change. These models take the current climate conditions of occupied areas into account and prognosticate where species are likely to be able to occur after climate change. This study focuses on predicting how the species *E. coracana* is affected by climate change for the year 2050 under different climate change scenarios: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.0. As *E. coracana* is characterised by high drought tolerance, it is hypothesised that despite area loss at certain places (e.g. too wet areas), the total suitable area will be similar to the current situation or even gain territory. Accordingly to the outcome, it should be considered where it is worth investing in finger millet as an agricultural crop and where it could better be replaced by a more suitable species.

Methodology & Results

As visualised in the flowchart below (Figure 1), several steps are taken to test the hypothesis.
Different computational programs are used as mentioned in brackets.

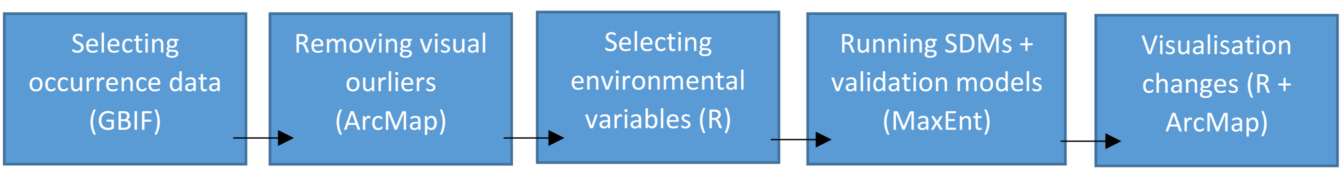

Figure 1. Flowchart steps method

Occurrence data

Occurrence data is retrieved from Global Biodiversity Information Facility website (GBIF[4], retrieved 03-12-2019) by searching for '*Eleusine coracana*'. Next to this, a filter is applied on location, selecting only specimen registered with coordinates, resulting in a total of 6932 datapoints. As this study only focuses on distribution, only the coordinate data is used from this point onwards. By visual inspection in ArcMap, several suspicious datapoints were removed (e.g. in the middle of large lakes), leaving 6874 records worldwide for *E. coracana*. In Figure 2, the remaining datapoints are shown on a global map. With species observation data, often spatial biases are seen with main focus on Mediterranean areas. However, as *E. coracana* is hardly occurring in these areas, this bias is not observed. Other possible biases are not taken into account in this study and based on trait characteristics (e.g. drought tolerance) it is assumed that the occurrence data is accurately reflecting the ecological niche of the species.

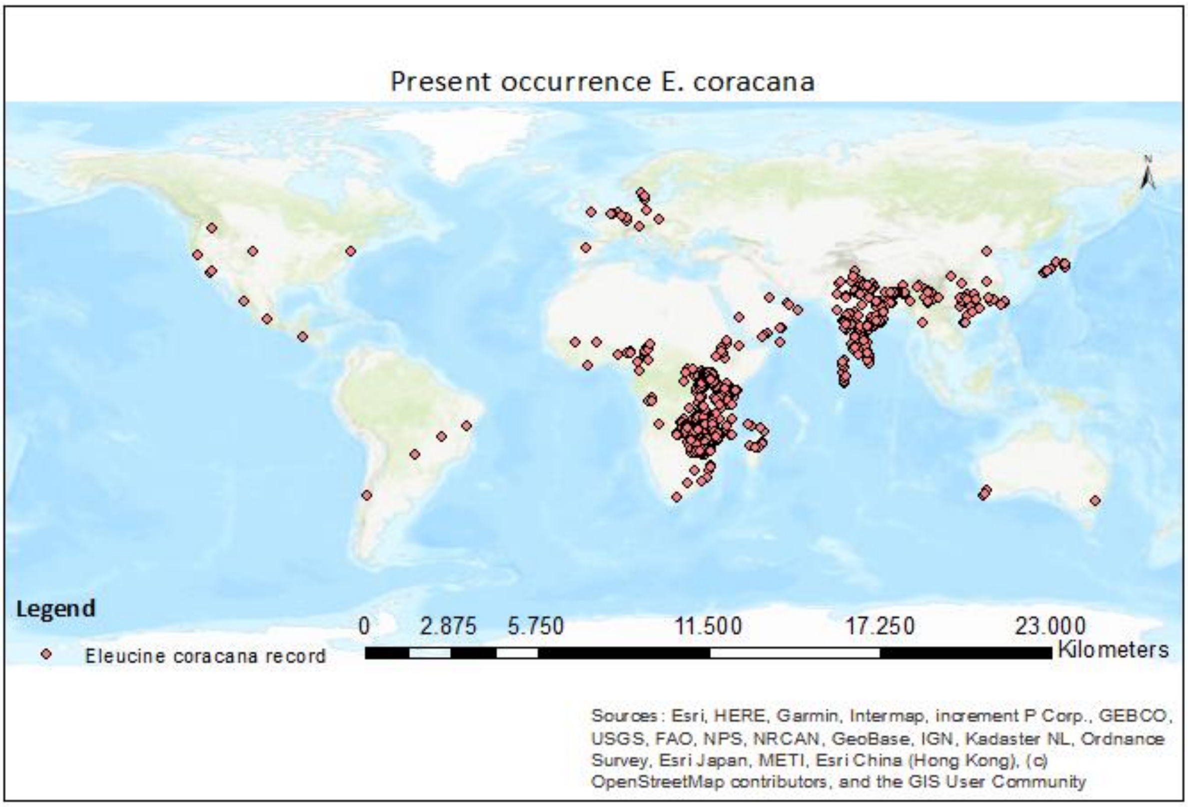

Figure 2. Map present occurence data E. coracana

Environmental data

To see the effect of climate change, different environmental variables are needed to put in the model. Therefor bioclimatic variable data was retrieved from the WorldClim website[5] (retrieved 06-12-2019, Version 1.4). The generic grid format of 5 minutes was chosen (future data: HadGEM2-ES).

As it is known that *E. coracana* has a high drought tolerance, it is expected to be less impacted by precipitation changes then changes in temperature. As it is in general a relatively tolerant species, most decisions for variable selection are based on the statistical analyses. Figure 3 shows the autocorrelation table with Pearson’s pairwise correlations -0.7 < r > 0.7 in red.

	Bio01	Bio02	Bio03	Bio04	Bio05	Bio06	Bio07	Bio08	Bio09	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19
Bio01	1	0,1348185	0,7642530	-0,833693	0,8227622	0,9639218	-0,775738	0,7081637	0,9152447	0,8899313	0,9769929	0,3222884	0,3765569	0,0538103	0,2755527	0,3690022	0,0759263	0,0900111	0,2380079
Bio02	0,1348185	1	0,0622566	0,0485821	0,4156956	-0,030297	0,2669527	0,0981709	0,1221469	0,2462124	0,0674615	-0,505552	-0,381580	-0,467584	0,4468632	-0,399368	-0,483805	-0,440513	-0,398561
Bio03	0,7642530	0,0622566	1	-0,914656	0,3728255	0,8452136	-0,871716	0,5068215	0,7074353	0,4488719	0,8512890	0,5583841	0,5306488	0,2692493	0,1603231	0,5372309	0,2998118	0,2970717	0,4502677
Bio04	-0,833693	0,0485821	-0,914656	1	-0,397743	-0,934553	0,9718177	-0,486488	-0,802933	-0,492204	-0,931622	-0,530449	-0,535591	-0,214784	-0,144006	-0,540393	-0,244233	-0,279460	-0,384173
Bio05	0,8227622	0,4156956	0,3728255	-0,397743	1	0,6603151	-0,291675	0,6277398	0,7467109	0,9740821	0,6951867	-0,059310	0,0345425	-0,186459	0,3311137	0,0169376	-0,180492	-0,232889	-0,017119
Bio06	0,9639218	-0,030297	0,8452136	-0,934553	0,6603151	1	-0,910931	0,6205772	0,9120412	0,7538263	0,9934158	0,4553218	0,4692810	0,1741344	0,1637434	0,4684622	0,2014343	0,1864911	0,3578780
Bio07	-0,775738	0,2669527	-0,871716	0,9718177	-0,291675	-0,910931	1	-0,445564	-0,751438	-0,425016	-0,883388	-0,612515	-0,578736	-0,324223	-0,026657	-0,587365	-0,355716	-0,365468	-0,465226
Bio08	0,7081637	0,0981709	0,5068215	-0,486488	0,6277398	0,6205772	-0,445564	1	0,4238420	0,7012697	0,6461522	0,2455100	0,3338550	0,0038908	0,3523484	0,3186620	0,0193457	0,2130641	0,0732858
Bio09	0,9152447	0,1221469	0,7074353	-0,802933	0,7467109	0,9120412	-0,751438	0,4238420	1	0,7907263	0,9133108	0,2704658	0,2879764	0,0646886	0,1666660	0,2863883	0,0859651	-0,018463	0,2700635
Bio10	0,8899313	0,2462124	0,4488719	-0,492204	0,9740821	0,7538263	-0,425016	0,7012697	0,7907263	1	0,7747084	0,0722537	0,1503746	-0,086729	0,3007835	0,1344201	-0,075962	-0,101659	0,0703441
Bio11	0,9769929	0,0674615	0,8512890	-0,931622	0,6951867	0,9934158	-0,883388	0,6461522	0,9133108	0,7747084	1	0,4141499	0,4503770	0,1189292	0,2295266	0,4473189	0,1447509	0,1603043	0,3073607
Bio12	0,3222884	-0,505552	0,5583841	-0,530449	-0,059310	0,4553218	-0,612515	0,2455100	0,2704658	0,0722537	0,4141499	1	0,8908163	0,6954546	-0,238208	0,9182183	0,7310405	0,7814249	0,7279017
Bio13	0,3765569	-0,381580	0,5306488	-0,535591	0,0345425	0,4692810	-0,578736	0,3338550	0,2879764	0,1503746	0,4503770	0,8908163	1	0,3724420	0,0771547	0,9918874	0,4086247	0,7229998	0,5533845
Bio14	0,0538103	-0,467584	0,2692493	-0,214784	-0,186459	0,1741344	-0,324223	0,0038908	0,0646886	-0,086729	0,1189292	0,6954546	0,3724420	1	-0,539198	0,4088423	0,9935606	0,5431892	0,6493036
Bio15	0,2755527	0,4468632	0,1603231	-0,144006	0,3311137	0,1637434	-0,026657	0,3523484	0,1666660	0,3007835	0,2295266	-0,238208	0,0771547	-0,539198	1	0,0314299	-0,544966	-0,161051	-0,312515
Bio16	0,3690022	-0,399368	0,5372309	-0,540393	0,0169376	0,4684622	-0,587365	0,3186620	0,2863883	0,1344201	0,4473189	0,9182183	0,9918874	0,4088423	0,0314299	1	0,4453092	0,7432164	0,5784680
Bio17	0,0759263	-0,483805	0,2998118	-0,244233	-0,180492	0,2014343	-0,355716	0,0193457	0,0859651	-0,075962	0,1447509	0,7310405	0,4086247	0,9935606	-0,544966	0,4453092	1	0,5652430	0,6771447
Bio18	0,0900111	-0,440513	0,2970717	-0,279460	-0,232889	0,1864911	-0,365468	0,2130641	-0,018463	-0,101659	0,1603043	0,7814249	0,7229998	0,5431892	-0,161051	0,7432164	0,5652430	1	0,3303047
Bio19	0,2380079	-0,398561	0,4502677	-0,384173	-0,017119	0,3578780	-0,465226	0,0732858	0,2700635	0,0703441	0,3073607	0,7279017	0,5533845	0,6493036	-0,312515	0,5784680	0,6771447	0,3303047	1

Figure 3. Output table Pearsons's pairwise correlations on Bioclimatic variables

Variables with most strong correlations were removed, which led to the following selection of variables: Bio02, Bio05, Bio07, Bio08, Bio15, Bio17, Bio18 and Bio19. Running a multicollinearity test on these variables led to the Variance Inflation Factors (VIFs) as shown in Figure 4, with no VIFs above ten.

Variable	VIF score
Bio02	1.903123
Bio05	2.617256
Bio07	1.847126
Bio08	2.435872
Bio15	1.971414
Bio18	2.092523
Bio17	3.321056
Bio19	2.184513

Figure 4. VIF scores selected Bioclimatic variables

Model settings

Based on the outcomes from the correlation and collinearity test, it is chosen to keep the eight variables from the previous section in the prediction models while running MaxEnt. In total five replicates were performed to receive a reliable average, both for global and clamped area (Area Of Interest).

Model output

The average Arau Under the Curve value (AUC) of all replicate runs is 0.896 (with standard deviation of 0.009). Furthermore, the Receiver Operator Curve (ROC) approximates the predicted omission reasonably. This indicates the models to be reliable and far from random, see Figure 5.

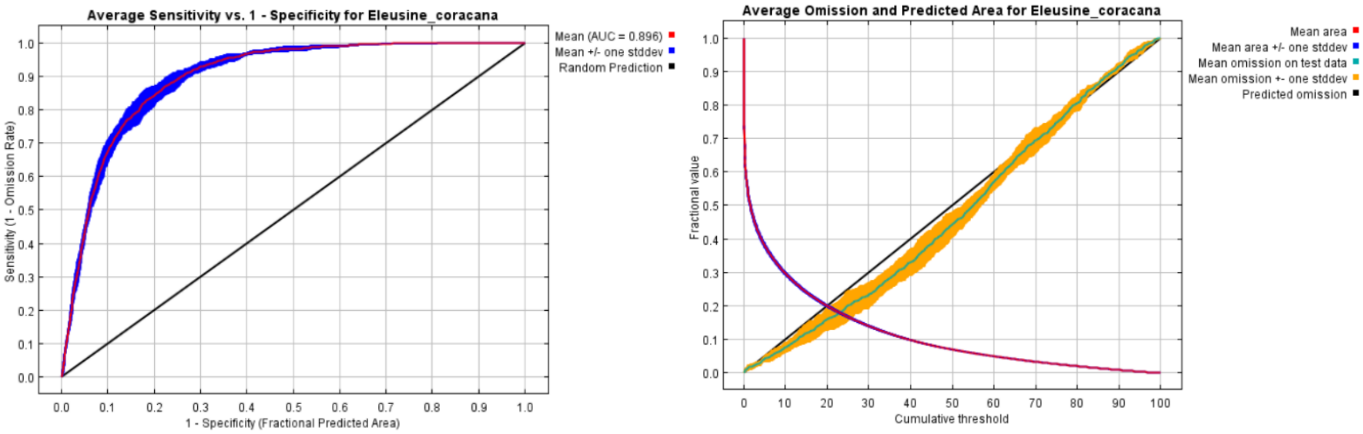

Figure 5. Average AUC (left) and Omission (right) curves

The response curves of the different variables show the strongest contribution for Bio08, followed by Bio07, Bio19 and Bio18 (see Figure 6).

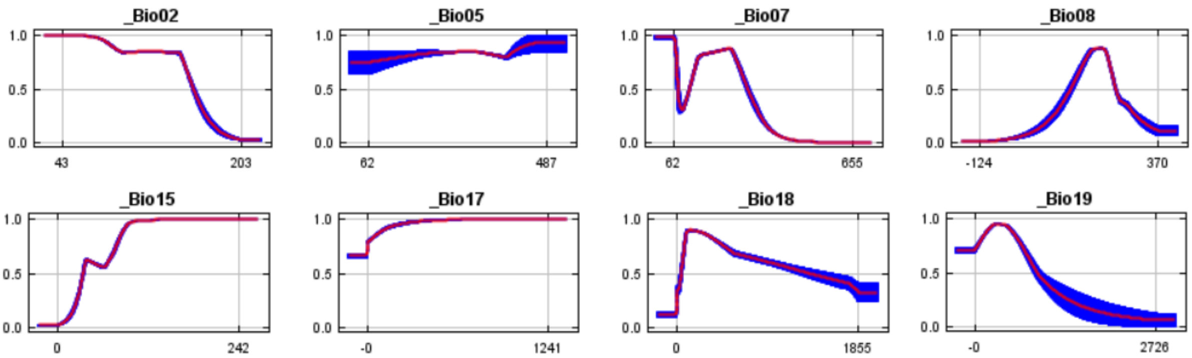

Figure 6. Response curves Bioclimatic variables

Jackknife tests supports Bio07 and Bio08 to be the two variables most important for the model, with addition of Bio15 (see Figure 7 and 8).

Variable	Percent contribution	Permutation importance
_Bio07	46.7	42.5
_Bio08	16.7	14.4
_Bio15	14.5	24.1
_Bio18	13.4	8.9
_Bio19	4.1	2.4
_Bio02	2.9	5.3
_Bio17	1.1	2.2
_Bio05	0.6	0.3

Figure 7. Estimated relative contributions Bioclimatic vairables

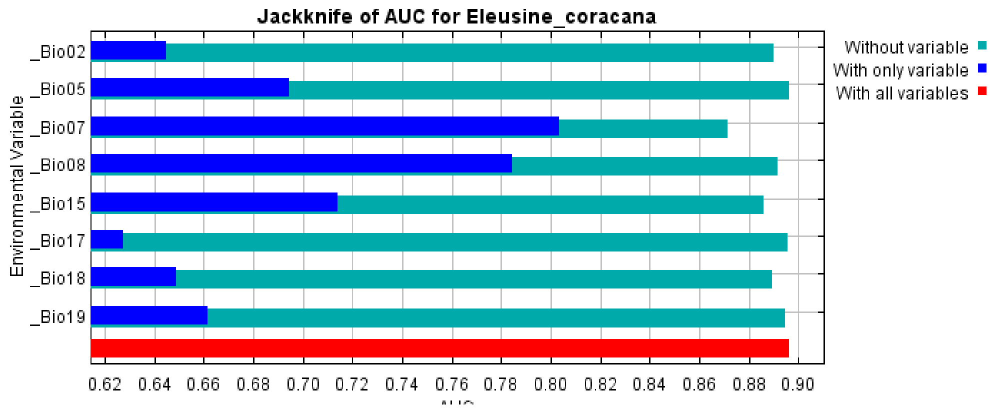

Figure 8. Results Jackknife test Bioclimatic variables

By visual inspection, it is considered that predictions might not be reliable in some areas outside the clamping region. This is mainly formed by the northern area around Greenland and the western part of the Sahara in Africa, see example Figure 9.

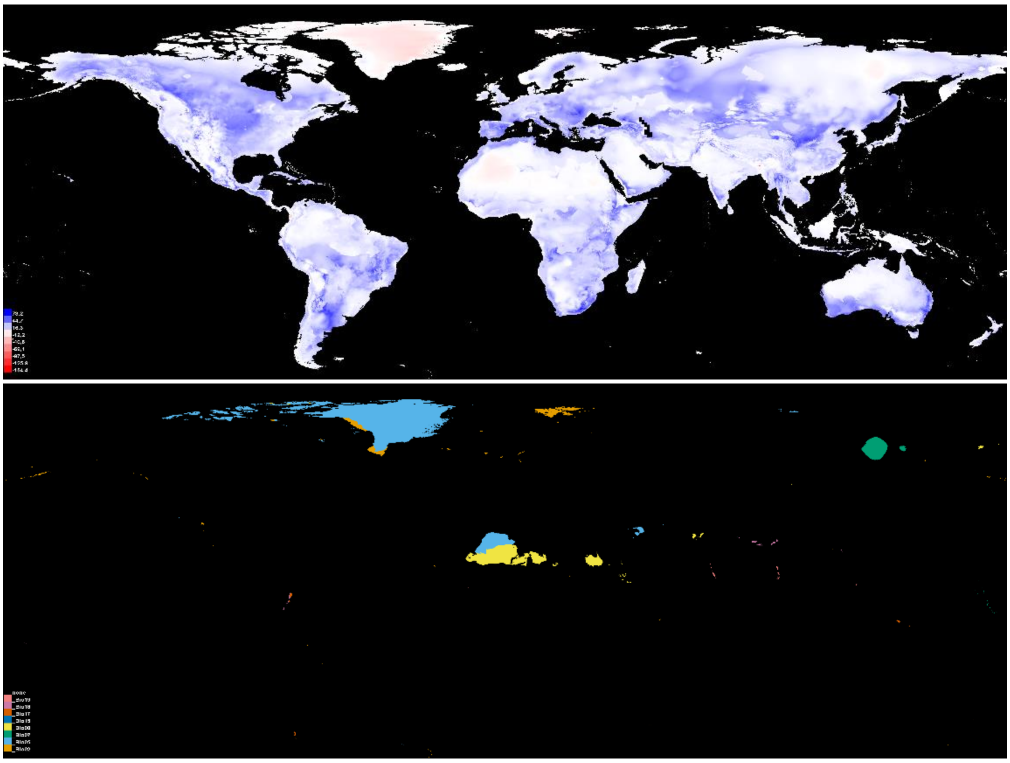

Figure 9. Comparison of the environmental similarity of variables in present occurrence to the environmental data used for training the model (First run, RCP8.5)

SDM projections

SDMs are performed by MaxEnt and visually changed in ArcMap. The resulting maps for predicted suitable areas for both presence and the different climate change scenarios for 2050 are illustrated in Figure 10 and 11. In general a decline in probable suitable area for *E. coracana* is noticed by decrease at the borders of current predicted areas. By focussing on specific areas there can also be difference noticed between the different scenarios. For example Brazil contains more green area with RCP2.6 than in case of RCP8.5. However, the differences can not easily be distinguished with these maps.

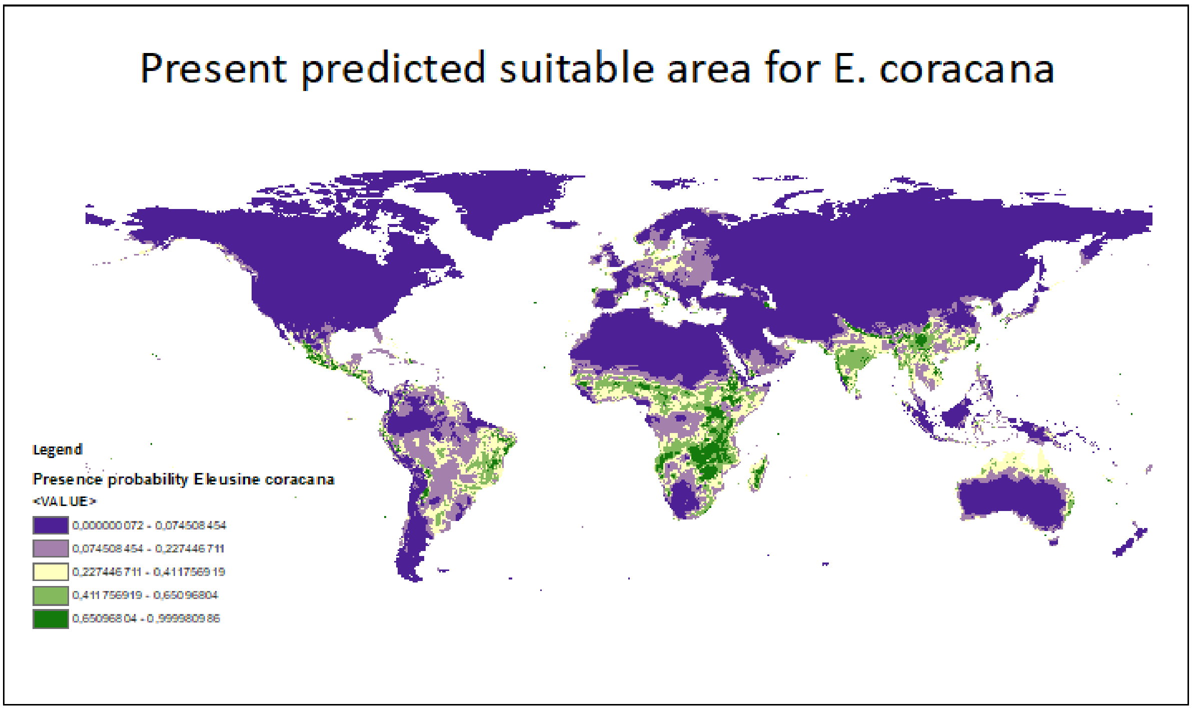

Figure 10. Present predicted occurence area E. coracana

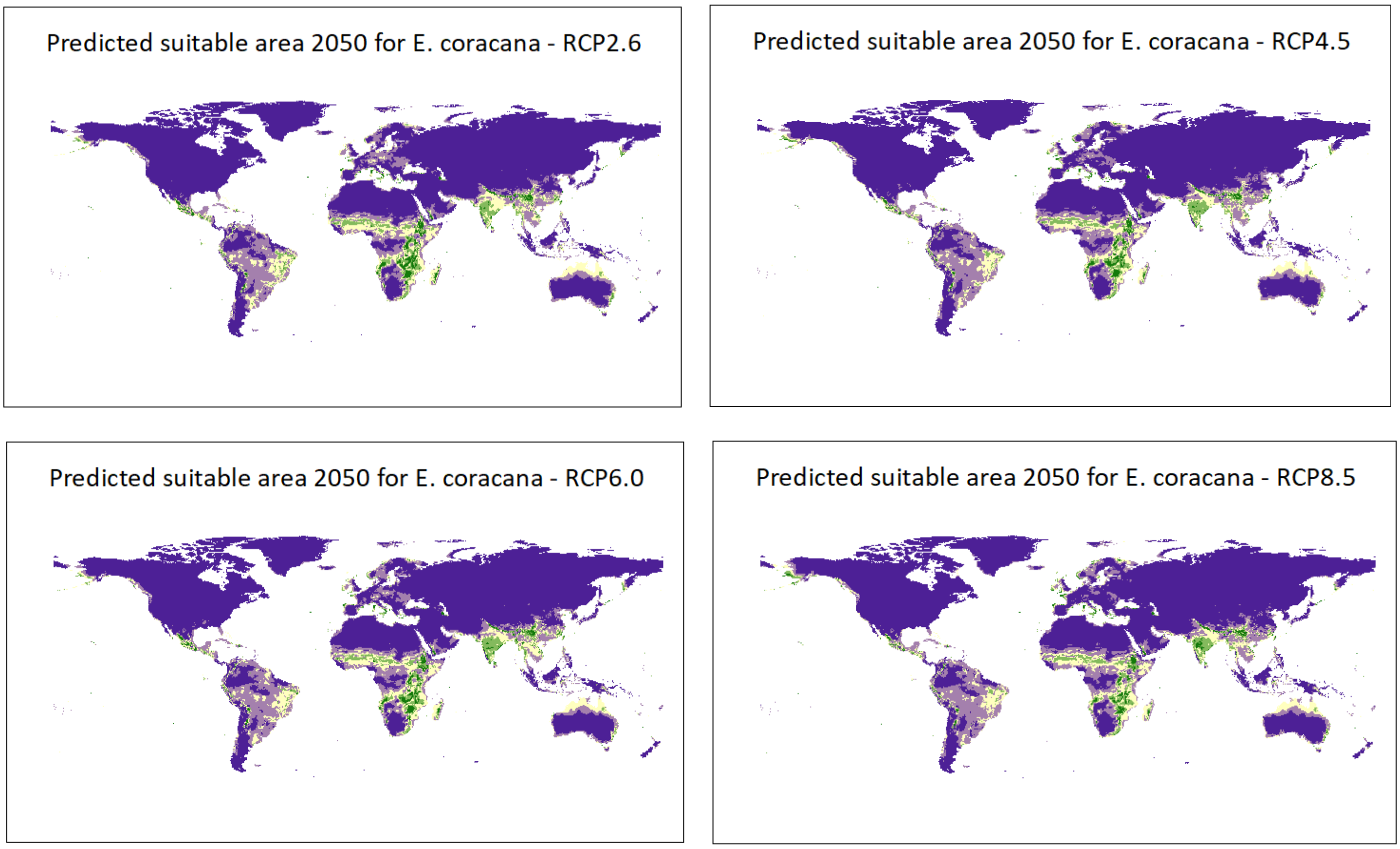

Figure 11. Future predicted suitable area under different climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5)

To get a better insight in the changes, the maps are transformed into change maps with R. Binary maps are created with a threshold of 0.384, based on the average result from the 'Equal test sensitivity and specificity' of the MaxEnt runs. Figures 12 to 15 show the predicted suitable areas for *E. coracana* under the different climate change scenarios. In general the results show a total decrease of suitable area as more places are coloured red then green. Slight differences can be noticed between the different models. The model with RCP2.6 results in more yellow areas in comparison to the other models, indicating that this scenario maintains most suitable areas. With increasing RCPs, more locations seem to be turned into red areas, indicating they are less likely to be suitable in the future. Some areas seem to gain suitable habitat for *E. coracana*, although this is mainly restricted to the northern part of the world outside the present occurrence range. These places are not likely to be reached by natural dispersal and might encounter other ecological constrains.

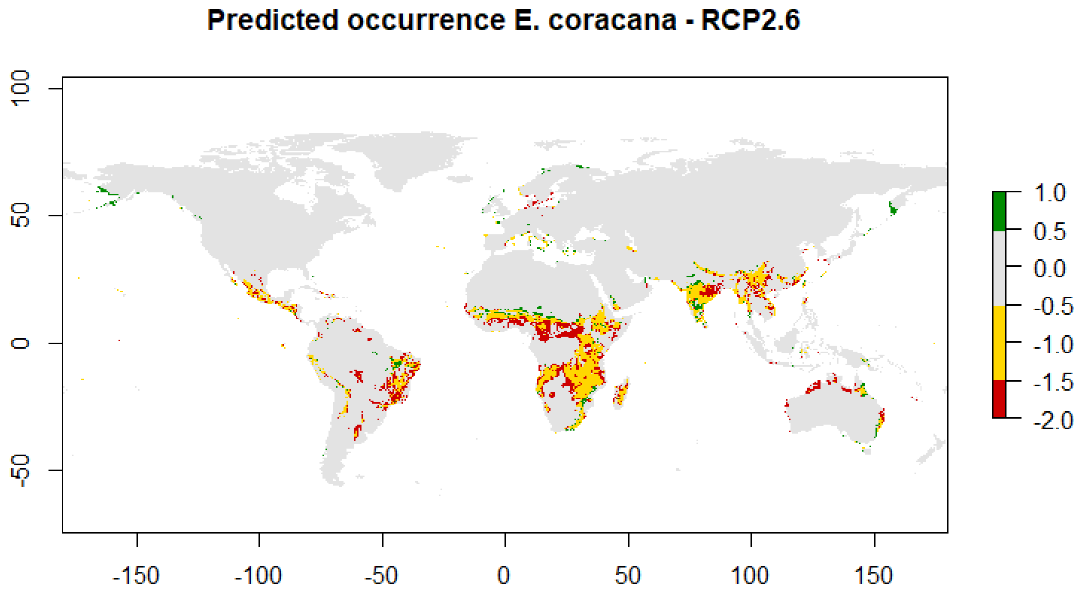

Figure 13. Change map probable suitable areas under RCP2.6

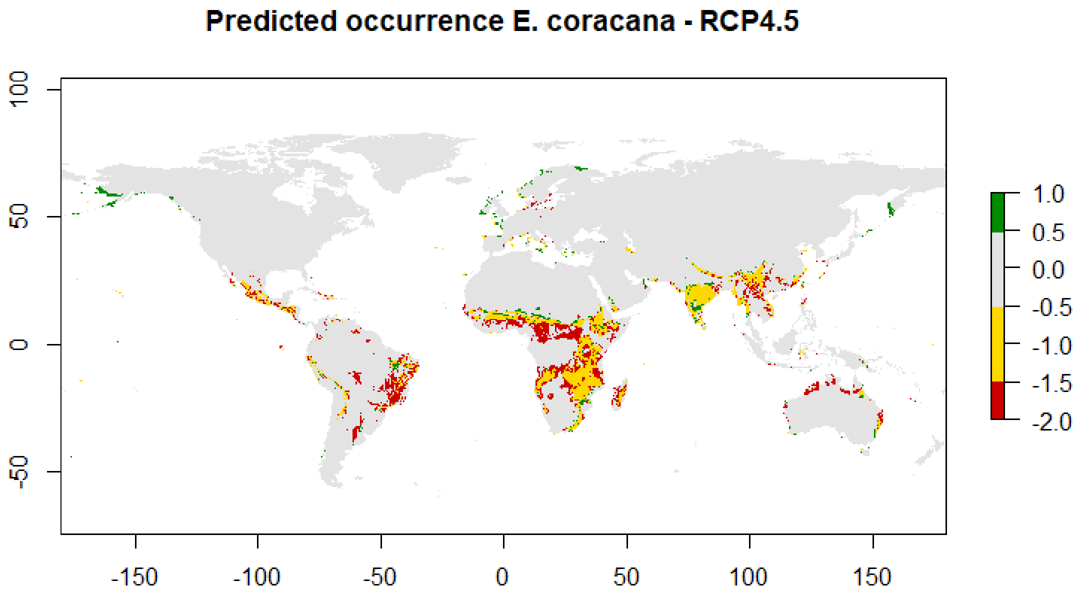

Figure 12. Change map probable suitable areas under RCP4.5

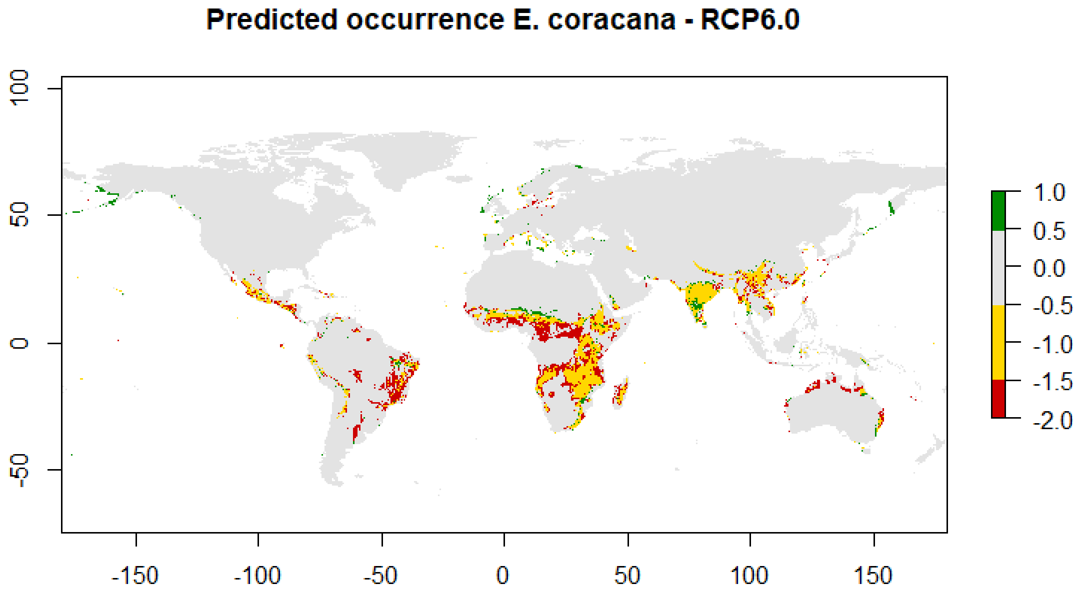

Figure 14. Change map probable suitable areas under RCP6.0

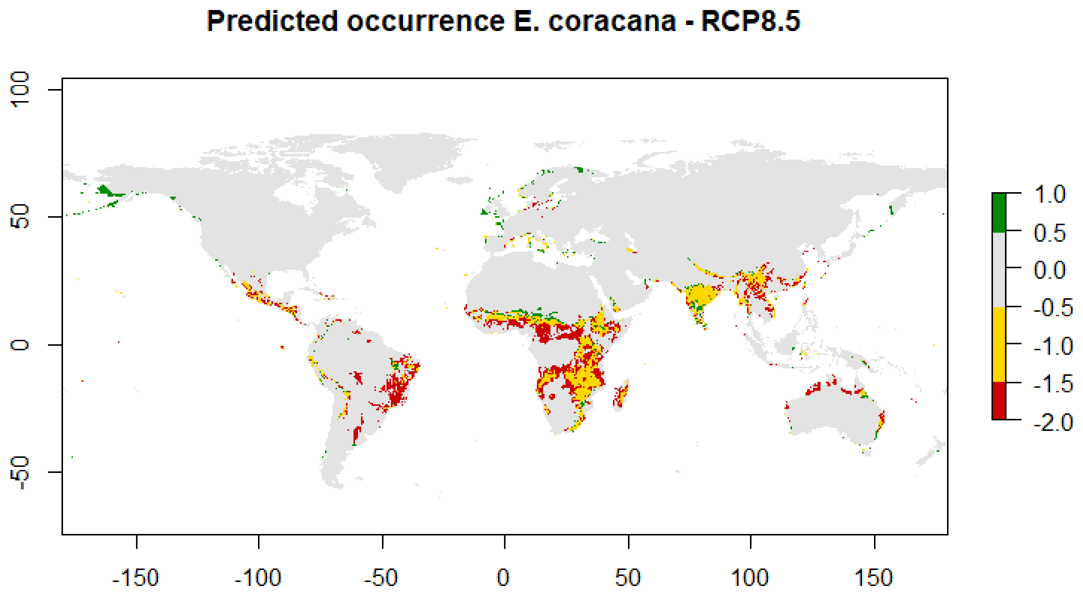

Figure 15. Change map probable suitable areas under RCP8.5

Discussion & conclusion

Based on the present species occurrence data and environmental data chosen for the model runs, it can be concluded that *Eleusine coracana* is most likely to be impacted by the mean temperature of the wettest quarter (Bio08) and temperature annual range (Bio07). Both can be explained by the ecological trait of the species of not being able to survive under extreme temperatures, i.e. too cold or warm periods. It is worthy to emphasize that most bioclimatic variables were chosen based on statistical choices. A more ecological approach based on literature could have led to more useful information about influence of climate change on this specific species. As expected based on literature, the species is less likely to be affected by precipitation changes as it is highly resistant against droughts and occurs in tropic (wet) areas.

As occurrence data for this study is obtained from GBIF with simple filters, it should be considered that data might not be entirely accurate. As it is a crop species we are looking at, the datapoints may represent areas where *E.* coracana under natural conditions might not have been able to grow. Due to agricultural interests, influences such as irrigation systems may create a bias. Next to this, there might also be species included that are not currently growing in the area. For example 'Preserved specimen' were also included en could be dry specimen from collections only. Furthermore, for a large part of the data the basis of the record was marked as 'Unknown' but were too many to remove from the data set. By visual inspection several points were found in the middle of large lakes and therefore removed. However, this could also be an indicator for inaccurate data, e.g. by imprecise coordinates. Further research should focus on more accurate (natural) occurrence data.

The report shows global probability predictions and is not clamped into a specific region, as present occurrence data almost encompasses the entire world. As a consequence some areas outside the current distribution range are predicted to be suitable despite it is not likely for *E. coracana* to reach these areas by natural distribution. However, by human introduction these areas are possibly suitable for the species in the future and could be considered for agricultural purposes. Nevertheless, other ecological factors and invasion risks should be researched beforehand.

In general all climate change scenarios are expected to lead to the same conclusion: suitable area for *Eleusine coracana* is predicted to decline by 2050 due to bioclimatic variable changes. A buffering effect seems to occur as areas seem to decline at the borders but remain suitable at the core. As these results contradict the expected response of the species bases on biological and ecological traits, it should be considered to do further research on the potential of *E. coracana* as crop species.

References

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