Moving towards a climate resilient tea production system in Assam

Tea Research Association, Jorhat, Assam, India

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Tea Research Association
Tocklai Tea Research Institute
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Report of the project on “Moving towards a climate resilient tea production system in Assam”

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Executive Summary

Tea is an important global agricultural commodity, both commercially and culturally. Assam, an agrarian state in northeast India is the largest single tea growing region in the world and the productivity (both in terms of quantity and quality) requires a specific range of enviro-climatic conditions. Precipitation and temperature are two climate factors among others which highly influence productivity. Therefore, water plays a critical role in sustaining future tea production in Assam. In the last decade, the region has been affected by heterogeneous spatio-temporal distributions of precipitation and rising temperatures. This has led to temporally varying drought-like conditions during the tea production season, reducing crop resilience and degrading yield quality. Quantifying regional climate characteristics enables more effective decision-making regarding climate change adaptation, water resources management, and adaptation to sustain (and enhance) future tea crop production. Some recent reports on the effect of changing climate of tea growing region of Assam in the media reflect the urgency of looking into the issue in a more holistic manner and to decide on an appropriate adaptation road map for the future. The present study looks into suitability of tea in the current four tea growing regions (viz. Upper Assam, South Bank, North Bank and Cachar) based on WorldClim data and using selected climate projections from global climate models used in the Fifth Assessment IPCC report. The modelling results show a drastic change in suitability of tea growth in Assam and shifting of tea in new areas of higher altitude in 2050 and 2070 though the adaptation measures that are currently being implemented by the tea growers may compensate the impacts of climate change to some extent, but may not be sufficient to completely negate its impacts. The report concludes that past adaptation only will not work and we need to develop suitable adaptation measures to combat climate change as seasonality of precipitation will be the major bioclimatic factor which will influence the future suitability of tea in Assam.
1. **Project Background**

The major challenges for tea production in Assam are the stresses caused by a significant shift in weather patterns. Frequency of both abiotic (mainly droughts and floods) and biotic (mainly insect, pests and diseases) stresses have increased in the last 30 years. For example, it has been widely observed that precipitation has decreased over Assam and its distribution patterns have significantly changed. Today, the majority of precipitation is concentrating around monsoonal months resulting in periods of very heavy rainfall followed by periods of drought like situations. Frequency of these extreme events have increased in the last 30 years creating new challenges for the tea sector in North Eastern India. Temperature patterns have also experienced an increasing trend. Archived meteorological data from Tocklai Tea Research Institute in Assam indicates that in the last one hundred years the temperature has increased by about 1.4 C. A likely result of this is that the high relative humidity, a key requirement for tea production, has started to show signs of decline in the early tea growing season impacting growth and resulting in crop loss during first flush.

While production is already severely affected in many tea gardens due to a changing climate, concerns are also being raised over quality decline in Assam teas amongst stakeholders. Increased incidences of pests have put further pressure on production expenses by way of increased chemical use. However, recent restrictions on the use of various chemicals (Plant protection code enforcement by Tea Board of India) and increased emphasis on maximum residue limits restrictions by various importing countries have complicated the issue further. Decreasing labour availability (most tea in Assam is hand plucked) has forced gardens to look for mechanical harvesting, where quality is again a major concern. Increasing irrigation demand because of longer rainless periods is increasing costs and thus, while yields are falling, production costs are climbing.

Tea Research Association, India and Ethical Tea Partnership in a joint effort funded by Tata Global Beverages Limited, studied the impact of future climate change on tea growing regions of Assam, India. In the first phase of this study the objective was to map the impacts of predicted future climate in the four tea production regions of Assam: Upper Assam, South Bank, North Bank, and Cachar using existing baseline data and combining this with the most recent IPCC, AR5 predictions to create likely scenarios of future suitability for tea growth in the four regions by 2050 and 2070. This project mapped the suitability of the tea growing regions in 2050 and 2070 using multiple high resolution Global Circulation Models (GCMs) with respect to the present climate status. The preliminary results of the climate modelling were presented and discussed with the stakeholders during a workshop held on 8th April 2016, in Kolkata, India and presented during the TEAM UP India event on 9th April 2016 also held in Kolkata, India.

2. **Key Objectives**

The key objectives of the project were as follows:

- To map the current suitability of four tea growing regions of Assam (viz. Upper Assam, South Bank, North Bank and Cachar) based on existing baseline data.
To perform suitability modelling using existing database of climate variables (total precipitation, maximum temperature, and minimum temperature) from WorldClim with species distribution model (SDM).

To estimate the hot spots of climate extremities in 2050 and 2070 under four different IPCC AR5 climate scenarios by using suitability modelling of all the four tea growing regions of Assam.

3. Methodology

3.1. Current Climate

Historical climate data from www.worldclim.org was used as the current climate or baseline data (Hijmans et al., 2005). The baseline data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km" resolution). The variables included monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables (Hijmans et al., 2005).

The WorldClim interpolated climate layers were made using:

- Major climate databases compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others.
- The SRTM elevation database (aggregated to 30 arc-seconds, "1 km2")
- The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variate data using thin plate smoothing splines. Latitude, longitude, and elevation were used as independent variables.

For stations having records for multiple years, averages for the 1960-90 period were calculated. Stations having at least 10 years of data were used for the interpolation. In some cases the time period was extended to the 1950-2000 period to include recent available records (e.g. DR Congo) or predominantly recent records (e.g. Amazonia). After removing stations with errors, the database consisted of precipitation records from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations.

The bioclimatic variables within the WorldClim data are derived from the monthly temperature and precipitation values in order to generate more biologically meaningful variables. These are often used in ecological niche modelling (e.g. BIOCLIM, GARP). The bioclimatic variables represent annual trends (e.g. mean annual temperature, annual precipitation) seasonality (e.g. annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year).

The following bioclimatic factors have been taken into consideration:
BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

3.2. Future Climate

In IPCC AR5, four scenarios have been considered which are called representative concentration pathways (RCPs). RCPs are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC (Moss et al., 2014). It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. The AR5 described four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs viz. RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m² respectively). The details of the four RCPs are available in [http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html](http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html).

The data used in this study are climate projections from global climate models (GCMs) freely available from [www.worldclim.org](http://www.worldclim.org). These are the most recent GCM climate projections that are used in the Fifth Assessment IPCC report (AR5). The GCM output was downscaled and calibrated (bias corrected) using WorldClim1.4 as baseline 'current' climate.

The climate projections used in this study have been generated by a method which starts with the projected change in a weather variable (i.e. minimum temperature in June). This is computed as the (absolute or relative) difference between the output of the GCM run for the baseline years (typically 1960-1990 for future climate studies and "pre-industrial" for past climate studies) and for the target years (e.g. 2050-2080). These changes are then interpolated to a grid with a high (~ 1 km) resolution. The assumption made is that the change in climate is relatively stable over space (high spatial autocorrelation).

These high resolution changes are then applied to high resolution interpolated climate data for the "current period" (the WorldClim dataset). This step is referred to as "calibration". Calibration is a necessary step because GCMs do not accurately predict the current climate in all places. Thus direct comparison between observed current climate with predicted future climate is not possible. It is also problematic to compare the response to simulated current conditions with a response to simulated future conditions because the simulated current conditions could be far from reality (Hijmans et al., 2005). For temperature absolute differences are used while for precipitation relative differences have been used because otherwise results can be awkward in areas with strong precipitation gradients.
Figure 1 Flow diagram of the modelling process
The IPCC AR5 is based on 21 global climate models with a resolution of 1km, hence require no downscaling. Moreover, the data is available on a monthly scale thus enabling the present study to be carried out at growing season and dormant season scale. In the Indian context for the temperature variable, the models used were NorESM1-M, CCSM4, MIROC5 and HadGEM2 - ES while for the precipitation variable GFDL-CM3, CCSM4 and HadGEM2-ES were used as the above models individually simulate results which are close to observations either for temperature or precipitation for the India region (Chaturvedi et al., 2012).

In the present study all the four RCPs of the 5 models were analysed both individually and as an average. In this report the results of the average of the 5 models are discussed of RCP 2.6 and RCP 8.5 as they are the best case scenario and business as usual scenario respectively. The outputs of the individual models are available in Annexure.

3.3 Crop prediction

Climate Envelope Models (CEMs) are generally used to predict species distribution under past present and future climate condition. It is very important to know how any species will perform in a changing climate so as suitable adaptive measures can be taken (Hannah et al. 2002). Similarly, knowledge of past climate condition is essential to describe the present species distribution pattern (Hugall et al. 2002; Peterson et al. 2004; Graham et al. 2006; Ruegg et al. 2006). The CEMs use current geographic distribution of a species to identify its environmental requirements and based on this it predicts the species distribution under a future climate condition.

In this study MaxEnt species distribution models was used to map the future probability distribution of tea in Assam. MAXENT is one of the widely used CEMs which is generally considered to be the most accurate model (Elith et al., 2006). It uses the current geographic distribution of a species (tea in this study) and the corresponding climate responsible for that distribution to predict probability distribution of the same species under changed climate condition. In this case presence of tea (1147 points) in all the tea growing regions of Assam was marked from Google Earth. The 1147 points indicate the current geographic distribution of tea in the current climatic condition. MaxEnt estimates future species distribution by means of measuring the probability distribution of maximum entropy. Entropy is defined as the measure of the level of disorder in a closed but changing system. The information available about the distribution of the species represents as a set of real-valued variables, called ‘features’, and the constraints are that the expected value of each feature should match its empirical average, i.e. the “average value for a set of sample points taken from the current species distribution” (Phillips et al., 2006 pg234). MAXENT weights each environmental variable by a constant similar to logistic regression. The probability distribution are expressed as probability value ranges from 0 to 1, where 0 representing least probability and 1 maximum probability. The program initiates with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution (CIAT, 2011).

3.4 Model boundary conditions

- Temperature, precipitation and 19 bioclimatic variables were used as driving factors in the modelling.
- No clonal variety information were included in the modelling
- No soil information were included in the modelling
- The current practiced adaptation measures were not included in the modelling.
- We assume that the data available for modelling are presence-only, i.e. a set of locations within the landscape of interest, where the tea has been observed.

The sensitivity analysis of the model in predicting the future suitability of a tea growing region was carried out using Receiver Operating Characteristics (ROC) curves or Area Under Curves (AUC) values. The AUC values allow us to compare the performance of one model with another. AUC values ranges between 0-1 and evaluates multiple MaxEnt models. While a AUC value of 0.5 mean random performance of the model, AUC values close to 1 represents better performance of the model. Trends of change in precipitation and other climatic parameters
were statistically derived. Statistical analysis was done to identify the most influential variables deciding on the future suitability of tea in Assam.

3.5 Measure of confidence

Two measurements of uncertainty are computed: (1) the agreement among models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location and (2) the coefficient of variation (CV) among models.

3.6. Environmental factors driving change in suitability

In-built application of the MaxEnt model has been used to identify the most influential variable for future suitability of tea in Assam. While training the model, we can keep track of which environmental variables are making the greatest contribution to the model. Each step of the Maxent algorithm increases the gain of the model by modifying the coefficient for a single feature; the program assigns the increase in the gain to the environmental variable(s) that the feature depends on and represents in percentage at the end of the training process.

To verify this output, Maxent allows alternate estimates of which variables are most important in the model through the jack-knife test. Each variable is excluded in turn, and a model created with the remaining variables. Then a model is created using each variable in isolation. In addition, a model is created using all variables, as before. The environmental variable with highest gain when used in isolation appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted appears to have the most information that isn’t present in the other variables.

4. Results I Climate Change summary of tea production sites

Analysis of the climate variables of four different RCPs were carried out and the general statistics of the best case scenario (RCP 2.6) and business as usual scenario (RCP 8.5) are indicated below:

**General climate statistics:**

- Both minimum temperature ($T_{min}$) and maximum temperature ($T_{max}$) will increase in all major tea growing regions of Assam (irrespective of the climate scenarios). The increase in $T_{min}$ is more than the increase in $T_{max}$. The average increase in $T_{min}$ may reach 1.75°C in 2050 and up to 1.99°C in 2070 considering the best case scenario i.e. RCP 2.6. However if we consider the business as usual scenario (RCP 8.5) the average increase in $T_{min}$ is found to be 3.55°C in 2070 through an increment of 2.5°C in 2050.
- The average increase in $T_{max}$ in all the four major tea growing regions of Assam are 1.34°C and 1.47°C for 2050 and 2070 respectively for RCP 2.6. The same for RCP 8.5 was observed to be 2.18°C and 3.28°C for 2050 and 2070 respectively.
- Total annual precipitation increases in 2050 in all four tea growing regions; however, it reduces in 2070 with respect to 2050 in both the RCPs.

Among the five individual GCMs used in this study, GFDL CM3 gives precipitation prediction closest to observation. The model shows a negative trend in change in annual precipitation in the winter months as well as April and May in 2050. It also shows an increase in precipitation during the monsoon months (Figure 2).

**Seasonal climate statistics:**

Tea in Assam has two distinct seasonal characteristics. December to February is considered as dormant season when there is no production of tea leaves, and March to November is considered as growing season.
Temperature shows an increasing trend throughout the year. The increase in $T_{\text{min}}$ is more than that of $T_{\text{max}}$ both in dormant season in RCP 2.6 and RCP 8.5. (Figure 2 and Figure 5)

The changes in $T_{\text{max}}$ both during growing season from 2050 to 2070 are insignificant, but $T_{\text{min}}$ changes significantly during that period in RCP 2.6 and RCP 8.5. (Figure 4 and Figure 6)

Analysis of seasonal precipitation shows a decrease in precipitation in dormant season in 2050 and 2070 in all four major tea growing regions with respect to the current condition in RCP 2.6 scenario (Figure 7).

The growing season though shows an increase in precipitation in 2050, but decrease in 2070 in RCP 8.5 scenario (Figure 8).

Figure 2 Change in precipitation in 2050 in all tea growing region as per GFDL CM3 model

Regional climate conditions

Cachar

RCP 2.6: The annual $T_{\text{max}}$ increases from 29.69°C to 31°C in 2050 and to 31.20°C in 2070. The annual $T_{\text{min}}$ increases from 19.42°C to 21.23°C in 2050 and to 21.61°C in 2070. Summer (May-June) becomes hotter by over 1°C by 2050 and by around 2°C by 2070. The monsoon (June-Sept) gets wetter by 157 mm by 2050 and 108mm by 2070.

RCP 8.5: The annual $T_{\text{max}}$ increases to 31.86°C in 2050 and to 33°C in 2070. The annual $T_{\text{min}}$ increases to 21.99°C in 2050 and to 23.08°C in 2070. Summer becomes hotter by 1.8°C by 2050 and by over 2°C by 2070. The monsoon gets wetter by 621 mm by 2050 and 211mm by 2070.
Upper Assam

- RCP 2.6: The annual \( T_{\text{max}} \) increases from 27.77 °C to 29.23 °C in 2050 and to 29.27 °C in 2070. The annual \( T_{\text{min}} \) increases from 18.48 °C to 20.21 °C in 2050 and to 20.29 °C in 2070. Summer (May-June) becomes hotter by over 1 °C by 2070. The monsoon (June-Sept) gets wetter by 263 mm by 2050 and 54 mm by 2070.

- RCP 8.5: The annual \( T_{\text{max}} \) increases to 31.86 °C in 2050 and to 33 °C in 2070. The annual \( T_{\text{min}} \) increases to 21.99 °C in 2050 and to 23.08 °C in 2070. Summer becomes hotter by 1.8 °C by 2050 and by over 2 °C by 2070. The monsoon gets wetter by 621 mm by 2050 and 211 mm by 2070.

North Bank

- RCP 2.6: The annual \( T_{\text{max}} \) increases from 29.19 °C to 30.49 °C in 2050 and to 30.62 °C in 2070. The annual \( T_{\text{min}} \) increases from 19.32 °C to 21.02 °C in 2050 and to 21.27 °C in 2070. Summer (May-June) becomes hotter by over 1 °C by 2070. The monsoon (June-Sept) gets wetter by 49 mm by 2050, but gets drier by 32 mm by 2070.

- RCP 8.5: The annual \( T_{\text{max}} \) increases to 31.3 °C in 2050 and to 32.44 °C in 2070. The annual \( T_{\text{min}} \) increases to 21.73 °C in 2050 and to 22.74 °C in 2070. Summer becomes hotter by 1.8 °C by 2050 and by over 2 °C by 2070. The monsoon gets wetter by 352 mm by 2050 and 63 mm by 2070.

South Bank

- RCP 2.6: The annual \( T_{\text{max}} \) increases from 28.81 °C to 30.13 °C in 2050 and to 30.25 °C in 2070. The annual \( T_{\text{min}} \) increases from 19.01 °C to 20.76 °C in 2050 and to 21 °C in 2070. Summer (May-June) becomes hotter by over 1 °C by 2070. The monsoon (June-Sept) gets wetter by 49 mm by 2050, but gets drier by 32 mm by 2070.

- RCP 8.5: The annual \( T_{\text{max}} \) increases to 30.97 °C in 2050 and to 32.08 °C in 2070. The annual \( T_{\text{min}} \) increases to 21.48 °C in 2050 and to 22.58 °C in 2070. Summer becomes hotter by 1.7 °C by 2050 and by over 2 °C by 2070. The monsoon gets wetter by 403 mm by 2050 and 95 mm by 2070.

Variability among the models

- The coefficient of variation of maximum temperature prediction among the models is 1.86% and that of minimum temperature is 3.023%. As the variability is too low temperature prediction was uniform and thus no outlier was detected.

- The coefficient of variation of precipitation was 8.061%. As the variability is too low precipitation prediction was uniform and thus no outlier was detected though uncertainty is higher in case of precipitation than temperature.
Figure 3 Trend in $T_{\text{max}}$ (A) and $T_{\text{min}}$ (B) in the dormant season under current and future (2050 & 2070) climate condition (rcp2.6)

Figure 4 Trend in $T_{\text{max}}$ (A) and $T_{\text{min}}$ (B) in the growing season under current and future (2050 & 2070) climate condition (rcp2.6)

Figure 5 Trend in $T_{\text{max}}$ (A) and $T_{\text{min}}$ (B) in the dormant season under current and future (2050 & 2070) climate condition (rcp8.5)
Figure 6 Trend in Tmax (A) and Tmin (B) in the growing season under current and future (2050 & 2070) climate condition (rcp8.5)

Figure 7 Precipitation trend in the Dormant (A) and Growing season (B) under current and future (2050 & 2070) climate condition (rcp2.6)

Figure 8 Precipitation trend in the Dormant (A) and Growing season (B) under current and future (2050 & 2070) climate condition (rcp8.5)
5. **Results II Suitability maps of tea production areas**

Currently there are four major tea growing regions in Assam namely Upper Assam (Dibrugarh and Tinsukia district), North Bank (Udalgiri, Darrang, Marigaon, Nagaon, Sonitpur and Lakhimpur district) South Bank (Jorhat, Golaghat and Sibsagar district) and Cachar (Karimganj, Hailakandi and Cachar district) (Figure 9). Based on the current climate condition, the entire South Bank region and parts of Upper Assam and Cachar are most suitable for tea (excellent category) followed by rest of Cachar and Upper Assam and the entire North Bank, which are either good/or very good for tea cultivation. The currently suitability analysed reflects the ground reality as these areas are suitable for tea, at different suitability scales, depending on clonal variety, management practice and type of grower.

![Current Suitability of Tea in Assam](image)

**Figure 9** current tea growing areas of Assam

The suitability of tea production in Assam in future climate conditions changes drastically over all the major tea growing regions. Based on the climate parameters used in this research it has been observed that tea may not be growing in the areas it is currently growing if no suitable adaptation measures are implemented. In general, a shifting trend of location is observed towards comparatively higher altitude areas of Karbi Anglong and Dima Hasao districts, which are currently not occupied by tea. Tea generally grows in flat lands in Assam where elevation ranges from 90-150m. However, in the future because of an increase in temperature and variability in precipitation, tea may be shifting to comparatively higher lands (350 - 650 m) (Figure 10). This shift is associated with shifting of favourable precipitation and temperature condition in the above regions.
In the best case scenario (RCP 2.6) by 2050, except for some of the places in Upper Assam and Cachar, where average suitability is either marginal or good, other regions can barely support tea growing (Figure 11). By 2070, North bank, South bank and Cachar remain barely suitable for tea, but average suitability in Upper Assam region increases (Figure 12). In business as usual scenario (RCP 8.5) the tea producing area further concentrate in the highly elevated areas of Karbi Anglong and Dima Hasao districts. By 2050 most of the suitable areas of Dima Hasao district will become marginally suitable, but those in Karbi Anglong district suitability will still remain good/very good for tea (Figure 13). By 2070 most of these areas become marginally suitable (Figure 14).
Figure 11 Suitability of tea production in 2050 under RCP 2.6 climate scenario

Figure 12 Suitability of tea production in 2070 under RCP 2.6 climate scenario
Figure 13 Suitability of tea production in 2050 under RCP 8.5 climate scenario

Figure 14 Suitability of tea production in 2070 under RCP 8.5 climate scenario
The measure of agreement of individual models predicting in the same direction as the average of all models at a given location is within 90% - 100% (K-statistics) in tea growing regions.

Table 1  Measure of agreement between individual models predicting in the same direction as average of all models (K-statistics)

<table>
<thead>
<tr>
<th>Model</th>
<th>K -STATS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP 2.6/2050</td>
<td></td>
</tr>
<tr>
<td>CCSM4</td>
<td>95.168</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>93.548</td>
</tr>
<tr>
<td>HADGEM2-ES</td>
<td>94.012</td>
</tr>
<tr>
<td>MIROC5</td>
<td>91.259</td>
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<tr>
<td>NORESM1-M</td>
<td>94.270</td>
</tr>
<tr>
<td>RCP 8.5/2050</td>
<td></td>
</tr>
<tr>
<td>CCSM4</td>
<td>97.186</td>
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<tr>
<td>GFDL-CM3</td>
<td>95.323</td>
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<tr>
<td>HADGEM2-ES</td>
<td>96.83</td>
</tr>
<tr>
<td>MIROC5</td>
<td>93.98</td>
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<tr>
<td>NORESM1-M</td>
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<tr>
<td>CCSM4</td>
<td>94.08</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>92.13</td>
</tr>
<tr>
<td>HADGEM2-ES</td>
<td>93.49</td>
</tr>
<tr>
<td>MIROC5</td>
<td>94.358</td>
</tr>
<tr>
<td>NORESM1-M</td>
<td>100</td>
</tr>
<tr>
<td>RCP 8.5/2070</td>
<td></td>
</tr>
<tr>
<td>CCSM4</td>
<td>98.636</td>
</tr>
<tr>
<td>GFDL-CM3</td>
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</tr>
<tr>
<td>HADGEM2-ES</td>
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</tr>
<tr>
<td>MIROC5</td>
<td>96.504</td>
</tr>
<tr>
<td>NORESM1-M</td>
<td>100</td>
</tr>
</tbody>
</table>

Figures 15 and 17 show the change in suitability of tea in all four regions of Assam in 2050 and 2070 respectively for RCP 2.6 while Figures 16 and 18 show the suitability of tea in the four regionsy for RCP 8.5.
Figure 15 Change in suitability in 2050 (RCP 2.6)

Figure 16 Change in suitability in 2070 (RCP 2.6)
Figure 17 Change in suitability in 2050 (RCP 2.6)

Figure 18 Change in suitability in 2070 (RCP 8.5)
6. Results III Environmental factors which drive the suitability of tea

Initial MAXENT simulation on suitability analysis revealed that in each of the five considered climate models (GCM’s), the bioclimatic variables related to precipitation are of most important in deciding the suitability of tea in the future. The seasonal variability of precipitation is the most influential parameter among all. The contributions (%) of most important bioclimatic variables are given in Table 1 (2050) and Table 2 (2070) in descending order with respect to their contribution.

Table 2 Contribution of bioclimatic variables for suitability of tea in 2050

<table>
<thead>
<tr>
<th>Variable*</th>
<th>Contribution (%) RCP2.6</th>
<th>Contribution (%) RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio15</td>
<td>21.7</td>
<td>23.3</td>
</tr>
<tr>
<td>Bio19</td>
<td>17.6</td>
<td>18.7</td>
</tr>
<tr>
<td>Bio16</td>
<td>11.8</td>
<td>10.8</td>
</tr>
<tr>
<td>Bio 9</td>
<td>6.8</td>
<td>7.9</td>
</tr>
<tr>
<td>Bio17</td>
<td>7.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Bio 4</td>
<td>6.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Bio 18</td>
<td>6.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Table 3 Contribution of bioclimatic variables for suitability of tea in 2070

<table>
<thead>
<tr>
<th>Variable*</th>
<th>Contribution (%) RCP 2.6</th>
<th>Contribution (%) RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio15</td>
<td>19.9</td>
<td>22.8</td>
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<tr>
<td>Bio19</td>
<td>18.5</td>
<td>20</td>
</tr>
<tr>
<td>Bio16</td>
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<td>10.7</td>
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<td>Bio 9</td>
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<tr>
<td>Bio17</td>
<td>7.1</td>
<td>6.2</td>
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<tr>
<td>Bio 4</td>
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</tr>
<tr>
<td>Bio 18</td>
<td>7.4</td>
<td>6.7</td>
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</tbody>
</table>

Table 4 Changes in the most influential bioclimatic variable from current to 2050 and 2070 climate condition

<table>
<thead>
<tr>
<th>Variable*</th>
<th>Current mean</th>
<th>Change by 2050 (RCP 2.6)</th>
<th>Change by 2050 (RCP 8.5)</th>
<th>Change by 2070 (RCP 2.6)</th>
<th>Change by 2070 (RCP 8.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio15</td>
<td>83.36</td>
<td>-1.769</td>
<td>-1.19</td>
<td>-2.746</td>
<td>-4.24</td>
</tr>
<tr>
<td>Bio19</td>
<td>59.42</td>
<td>5.33</td>
<td>3.08</td>
<td>8.38</td>
<td>13.06</td>
</tr>
<tr>
<td>Bio16</td>
<td>1306.46</td>
<td>-158.29</td>
<td>-173.85</td>
<td>-0.86</td>
<td>-328.89</td>
</tr>
<tr>
<td>Bio 9</td>
<td>180.16</td>
<td>-14.03</td>
<td>-22.68</td>
<td>-15.77</td>
<td>-33.46</td>
</tr>
<tr>
<td>Bio17</td>
<td>53.85</td>
<td>3.72</td>
<td>3.51</td>
<td>8.99</td>
<td>10.93</td>
</tr>
<tr>
<td>Bio 4</td>
<td>4028.94</td>
<td>1.62</td>
<td>256.04</td>
<td>145.42</td>
<td>182.3</td>
</tr>
<tr>
<td>Bio 18</td>
<td>1134.43</td>
<td>92.81</td>
<td>92.81</td>
<td>23.71</td>
<td>-220.26</td>
</tr>
</tbody>
</table>

Variables*

Bio15 = Precipitation Seasonality - coefficient of variation
Bio19 = Precipitation of coldest quarter
Bio16 = Precipitation of wettest quarter
Bio 9 = Mean Temperature of driest quarter
Bio17 = Precipitation of driest quarter
Bio 4 = Temperature seasonality
Bio 18 = Precipitation of warmest quarter

7. Conclusion

The present study concludes that seasonality of precipitation will be the main factor which will influence the suitability of tea in the current tea growing regions of Assam. There will also likely be a decrease in precipitation during the 1st and 2nd flush period, which may have an adverse effect on the production of the premium tea. Increase in precipitation during the monsoon months (June, July and August) may lead to waterlogging / flooding.

The current suitability shows that the south bank region, parts of Upper Assam, and Cachar are the suitable regions (very good and excellent suitability) while North bank region and some areas of the other 3 regions are comparatively less suitable (good suitability / marginally suitable).

In the best case scenario (RCP 2.6) by 2050, except for some of the places in Upper Assam and Cachar, average suitability is either marginal or good, while other regions can barely grow tea. By 2070, North bank, South bank and Cachar remain barely suitable for tea, but average suitability in Upper Assam region increases.

In business as usual scenario (RCP 8.5) the tea producing area further concentrates in the highly elevated areas of Karbi Anglong and Dima Hasao districts. By 2050 most of the suitable areas of Dima Hasao district will become marginally suitable, but for those in Karbi Anglong district suitability will still remain good/very good for tea. By 2070 most of these areas become marginally suitable.

More emphasis is required on water resource management at watershed level. This research must extend to whole of North East India including North Bengal to locate new areas of tea suitability. New adaptation techniques need to be explored which would be more contemporary with the future climate conditions.

8. Limitations

Models are very powerful tools to represent natural processes. Often models are the only means we have to extrapolate to large spatial scales or predict the future. However, all models have some limitations in the form of input data or boundary conditions.

- In this research we have used presence-only data for sample (i.e. the geographical locations of places where tea currently growing), but prevalence is not always identifiable with presence-only data (Elith et al. 2011).
- Apart from temperature and precipitations and their derivatives (bioclimatic variables), other important factors such as humidity, solar radiation, day light hours and soil properties were not included in the modelling because of lack of data.
- No adaptation techniques currently used by the tea growers were considered in the modelling. Likewise, the clonal varieties currently used by the tea growers were also excluded from the modelling due to lack of continuous data.
- Statistical models such as MaxEnt do not describe “cause and effect” relationship between parameters and response (Guisan and Zimmermann 2000; Pearson and Dawson 2003; Kearney and Porter 2004). For example, the model predicts the future sustainability of tea based on the current climate condition especially precipitation and temperature. Tea may well adapt to a different combination of precipitation and temperature. But, in modelling if this new combination appears in any part of the tea growing area, model incorrectly classify that area as unsuitable.
- Logistic output which was opted for during modelling in MaxEnt is based on strong assumptions on the values of probability of presence at ‘average’ presence locations
- The model could not be evaluated for the future prediction as there is no observed data as available for current climate.
- Often models are biased and underestimates range size under future climate (Thuiller et al. 2004).
9. **Recommendations**

Based on the findings of the study, it is essential to point out the future course of action for sustainable growth of tea in the major tea growing regions of Assam. The framework for future needs should include the following:

- More research and simulation studies into tea future suitability using multiple variables.
- More emphasis on water resource management at watershed level.
- This research must extend to whole of North East India including North Bengal to locate new areas of tea suitability and places where tea is likely to migrate and feasibility of those areas to grow tea.
- Exploring the ensemble of all the models to arrive at a definitive conclusion.
- New adaptation techniques need to be explored which would be more contemporary with the future climate conditions.

10. **References**


Richard Moss; Mustafa Babiker; Sander Brinkman; Eduardo Calvo; Tim Carter; Jae Edmonds; Ismail Elgizouli; SeitaEmori; Lin Erda; Kathy Hibbard; Roger Jones; MikikoKainuma; Jessica Kelleher; Jean Francois Lamarque; Martin Manning; Ben Matthews; Jerry Meehl; Leo Meyer; John Mitchell; NebojsaNakicenovic; Brian O’Neill; Ramon Pichs; KeywanRiahi; Steven Rose; Paul Runci; Ron Stouffer; Detlef van Vuuren; John Weyant; Tom Wilbanks; Jean Pascal van Ypersele& Monika Zurek (2008). *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies* Geneva: Intergovernmental Panel on Climate Change. p. 132.