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Technical report on the

Kenya Afforestation Decision Support Tool

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DRAFTED BY

Dr. Rekha Warrier and Dr. Patrick Keys

Colorado State University

Executive Summary

Afforestation is a key tool for mitigating climate change and restoring forests to achieve biodiversity and livelihood goals. Kenya's goal of increasing tee cover to 10% of the national land surface by 2030 is also intended for these purposes. This afforestation push is in line with several such initiatives being undertaken on global and national scales (e.g., United Nations Strategic Plan for Forests 2030). Yet, across tropical landscapes tree cover is increasingly characterized by diebacks resulting from direct and indirect climate change impacts such as droughts, fires, and disease. Understanding how future climatic conditions and associated natural disturbance will impact tree cover persistence is key to informing both near-term afforestation efforts and for more accurately tallying long-term benefits that are hoped to be accrued from planting trees. The Kenya Afforestation Decision Support Tool (KA-DST) is an application developed specifically to help explore Kenyan tree cover sensitivity to future climate change and related disturbances. The intent behind developing the application is to enable policymakers and practitioners to appreciate how global-scale drivers of ecosystem change will modulate achievement of national level tree-cover and related climate mitigation and biodiversity goals over the course of this century.

The application hosts results from a total of 156 simulations spanning 4 climate and 3 disturbance scenarios. Taken together the results answer the following question: After Kenya achieves the goal of 10% tree cover by 2030, how will climatic conditions projected to occur beyond this period affect tree-cover persistence?

We used a dynamic ecosystem process model called L-Range and the most recent iteration of the IPCC's future climate change projection data to understand how trees will fare in the years 2050, 2070, and 2100. L-Range is made up of a series of sub-models that can simulate from first principles plant production, plant population change, and nutrient cycling while incorporating monthly data on climate and disturbances such as fire and grazing. We created a spatial dataset that could reasonably represent Kenyan landscapes in 2030 following successful afforestation measures. To create this dataset we loosely followed recommendations outlined in the 'National strategy for achieving and maintaining over 10 % tree cover by 2022' policy document. Using this dataset to represent initial tree cover conditions in 2030, we simulated tree cover change under 4 scenarios of future global development and emissions (Shared Socioeconomic Pathways or SSPs) and associated future global heating levels (Representative Concentration Pathways or RCPs). Together these scenarios represent possible global trends in socioeconomic changes, international relations, and their resulting impacts on the global climate system. For example, the scenario SSP1-RCP2.6 represents a sustainable future world with low levels of inequality and a lower increase in global temperatures. On the contrary, SSP3-RCP7.0 represents a future world with a fractured global order, with high inequality, high rural population growth and significantly higher levels of global heating.

For each future scenario, we ran L-Range using associated projections of future monthly precipitation, and minimum and maximum temperatures for the period between 2030 and 2100. For each climate scenario (SSP-RCP) we also explored 3 scenarios of future fire frequencies (Historic fire severity, Low fire severity, and High fire severity) resulting in a total of 12 scenarios exploring a wide range of possible future impacts. Since, for each climate scenario, climate projections are available from multiple climate models, we repeated the simulations using projections from 13 models that were available across all four climate scenarios.

Our simulations show that after accounting for uncertainties in future socioeconomic scenarios, climate models and disturbance conditions, in the near-term (2050), Kenyan tree-cover change relative to a 2030 baseline will range between -12% (net decline) and 21% (net increase). Similarly, at the turn of the century (2100), Kenyan relative tree cover change ranges between -42 % and 17 %. The most extreme losses in tree cover occur in a scenario with high fire probability and where rapid fossil fuel-based economic growth and emissions (SSP5-RCP8.5) results in a global mean temperature rise of approximately 4.3°C by 2100. While this energy pathway is considered improbable, our results indicate that distinct from global trends, in Kenya, more pronounced climate change can drive larger declines in tree cover. In a scenario consistent with the current global development pathway (SSP2-RCP4.5), if historic fire conditions prevail, Kenya will experience a mean increase in tree cover of 0.96% in 2050. On the contrary, controlling fires yields a mean increase of 1.25%, whereas when fire probability doubles, tree cover increases by 0.21%.

Increases in tree cover in 2050 are driven primarily by increases in deciduous cover, which occur under all scenarios, including when fire severity is high. In the two most extreme climate scenarios (SSP3-RCP7.0 and SSP5-RCP8.5), deciduous tree cover losses occur at the turn of the century irrespective of fire severity. Evergreen tree cover experience declines in all scenarios expect in the near-term (2050) under SSP1-RCP2.6. Loss of evergreen tree cover is most pronounced in the SSP5-RCP8.5 scenario in 2100 when fire severity is higher than historic rates.

In summary, our simulations suggest that in the near-term (2050), regardless of which climate future unfolds, Kenyan tree cover will remain stable or see small increases in extent. Since the model simulates ecosystem processes at coarse spatial scales (100 km2), and processes within individual landscape pixels are spatially inexplicit, land use and land use changes are not accounted for. Consequently, increases in tree cover within any landscape pixel may be best interpreted to mean that tree cover remains stable, since lands may not be available for tree cover expansion to realistically occur. While the model does not accommodate any direct anthropogenic impacts, we may infer these based on available information on how human populations and economic inequality will increase over the century under each climate scenario. Larger increases in rural populations occur in an SSP2-RCP4.5 and SSP3-RCP7.0 world with accompanying increases in inequality. Within these two future scenarios it can be expected that in addition to climate impacts, tree cover may be additionally affected by direct human impacts.

Detailed methods and results

Methods

L-Range ecosystem model overview

We used L-Range, a localized version of the ecosystem model G-Range (Sircely et al., 2019) to explore future forest cover changes. The model simulates plant population dynamics and biogeochemical cycling within rangelands. It simulates from first principles, plant regeneration, decomposition, competitive interactions between herbaceous and woody vegetation, as well as the flow of nitrogen, carbon, and water through the ecosystem. We used as inputs gridded datasets representing soil texture, distribution of vegetation classes (herbs, shrubs and trees), land use and rangeland type (biome) for Kenya. Each grid cell represents a discrete 'natural' area within which ecosystem processes are simulated in a spatially inexplicit manner. We specified a grid-cell size of100 km2 and restricted our simulations to areas dominated by tree cover, shrub cover, grass cover and agriculture (urban areas, deserts, bare areas, and water-covered areas were excluded). We used bias-corrected, downscaled monthly temperature (minimum and maximum) and precipitation projections from 13 CMIP6 Global Circulation Models (GCMs) as input climate data for L-Range. We obtained climate projections from these GCMs for a historic period (1950-2014) as well as for 4 future (2015-2100) scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0 and, SSP5-85).

Simulating tree cover change

Historic simulations and model evaluations

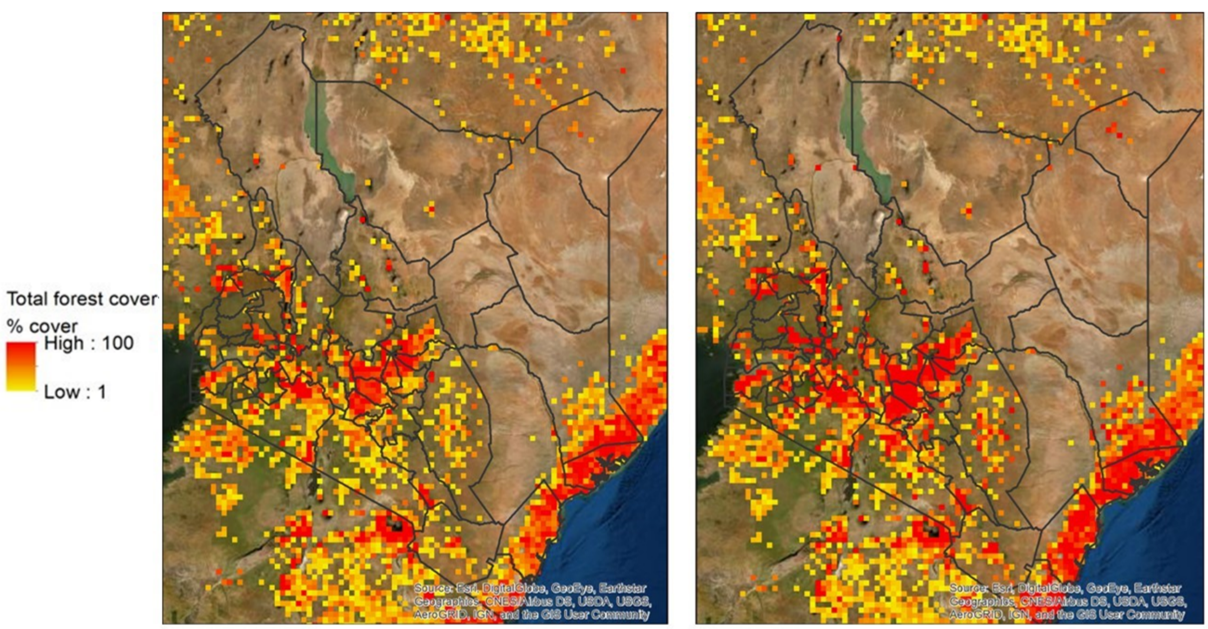
We conducted a 2000-year spin-up simulation using randomized historical climate data (1950 - 2014). We created randomized historic climate data by first creating an ensemble dataset for temperature and precipitation. This was done by averaging monthly projections of these variables across the 13 GCMs. The resulting climate data were then randomized (by year) and repeated to create climate inputs for the 2000-year spin-up. At the end of the simulation, we saved individual rangeland cell characteristics (vegetation cover, carbon pools etc.) to a file and used this as starting conditions for subsequent simulations. For the spin-up simulation we specified vegetation cover for Kenya (tree, shrubs and herbs) using the Consensus Land Cover dataset (Tuanmu and Jetz, 2014), which represents global vegetation cover as it existed between 2000 and 2005. To evaluate model performance and tune input parameters we ran L-Range using the spin-up output as initial conditions and historic climate data from each of the 13 GCMs for the period between 1990 and2014. We compared the mean of L-Range simulated estimates of annual net primary productivity (ANPP) for the 2000 – 2014 period against a validation dataset for the same period (MODIS ANPP). We also compared simulated estimates of above and belowground annual live carbon for the year 2010 against estimates for these variables based on Spawn et al., (2020). We adjusted L-Range parameters and repeated the historic simulations till we obtained a reasonable match between simulated and observed estimates for the three variables.

Tree cover sensitivity to climate change and disturbance

We first created a new spatial layer to emulate tree cover across Kenya in 2030 following successful afforestation efforts. This was done by adding tree cover to agricultural and savanna areas in the proximity of existing patches of forest. Using this layer and the randomized historic climate data we conducted another 2000-year spin-up simulation to allow model variables to equilibrate and used the resulting cell characteristics as starting conditions for subsequent simulations. For each of the 4 future climate scenario (SSP1, SSP2, SSP3, and SSP5) we explored three management scenarios:

- Historic fire severity - For each rangeland cell, annual fire probability was set to match historic fire probabilities. This was calculated using a remotely sensed dataset of fire incidences across Kenya for years 2000 -2020 (ESA CCI MODIS).
- Increased fire severity- Annual fire probability for each rangeland cell was set to double the probability.
- Low fire severity - Annual fire probability for each rangeland cell was set to 10% of the historic probability to emulate a scenario of active fire management.

Percent forest cover for current and expanded (2030) cases

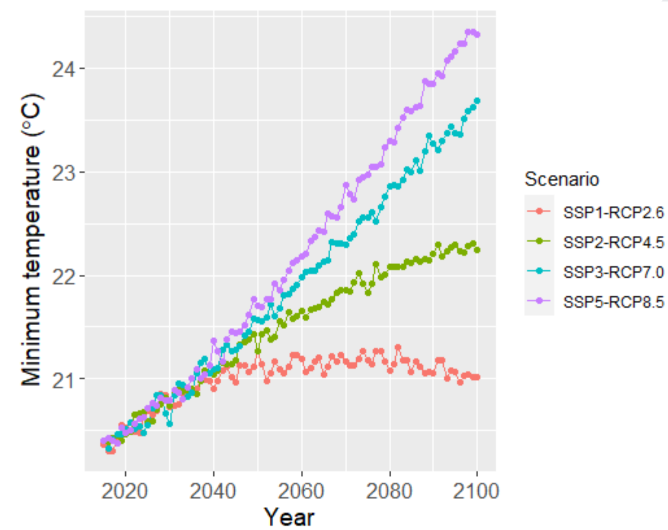


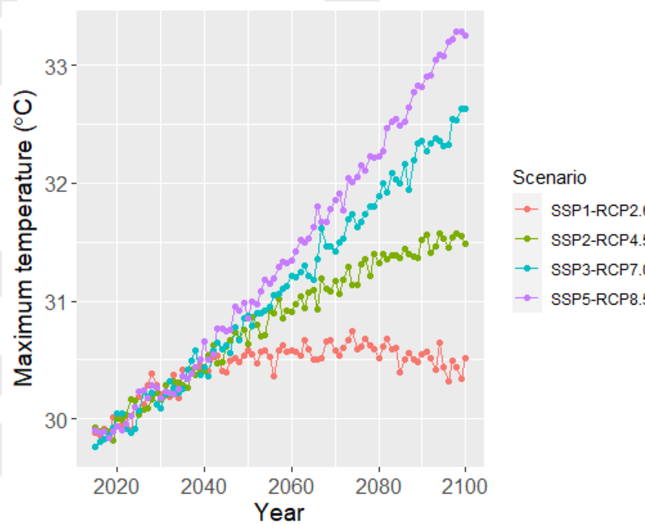
Current tree cover

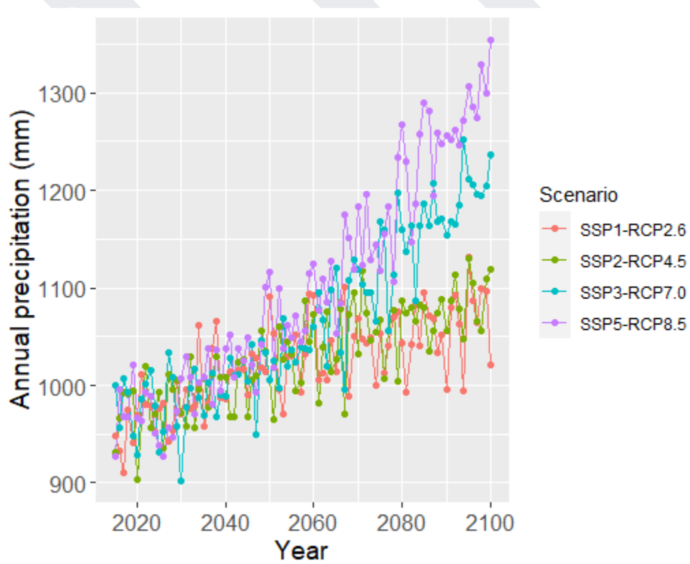
Expanded (2030) tree cover

For each climate-disturbance scenario, we repeated L-Range simulations using climate scenario-specific temperature and precipitation projections for the period between 2030 and 2100, from each of the 13 GCMs. At the end of each simulation, we calculated changes in vegetation cover and carbon pools in the years 2050, 2070 and 2100, relative to their baseline values in 2030 (i.e., the start of the simulation). For each of the 12 climate-disturbance scenarios we summarized estimated changes in variables of interest across the 13 individual GCM runs. In all, we conducted 156 (4 SSPs * 3 management scenarios * 13 GCMs) simulations representing a range of uncertainties associated with future climatic conditions and disturbance regimes.We measured changes in tree cover across all rangeland cells with trees. We interpret this measure as the overall sensitivity of trees across Kenya to climate change. In addition, we measured tree cover changes within cells with at least 30% evergreen or deciduous cover. We interpret this measure as the sensitivity of evergreen or deciduous forest areas to climate change. Finally, we measured changes in tree cover changes in areas that were newly afforested, i.e., areas where we added trees to emulate a successful afforestation scenario.

Temporal variability in future climate and tree cover change



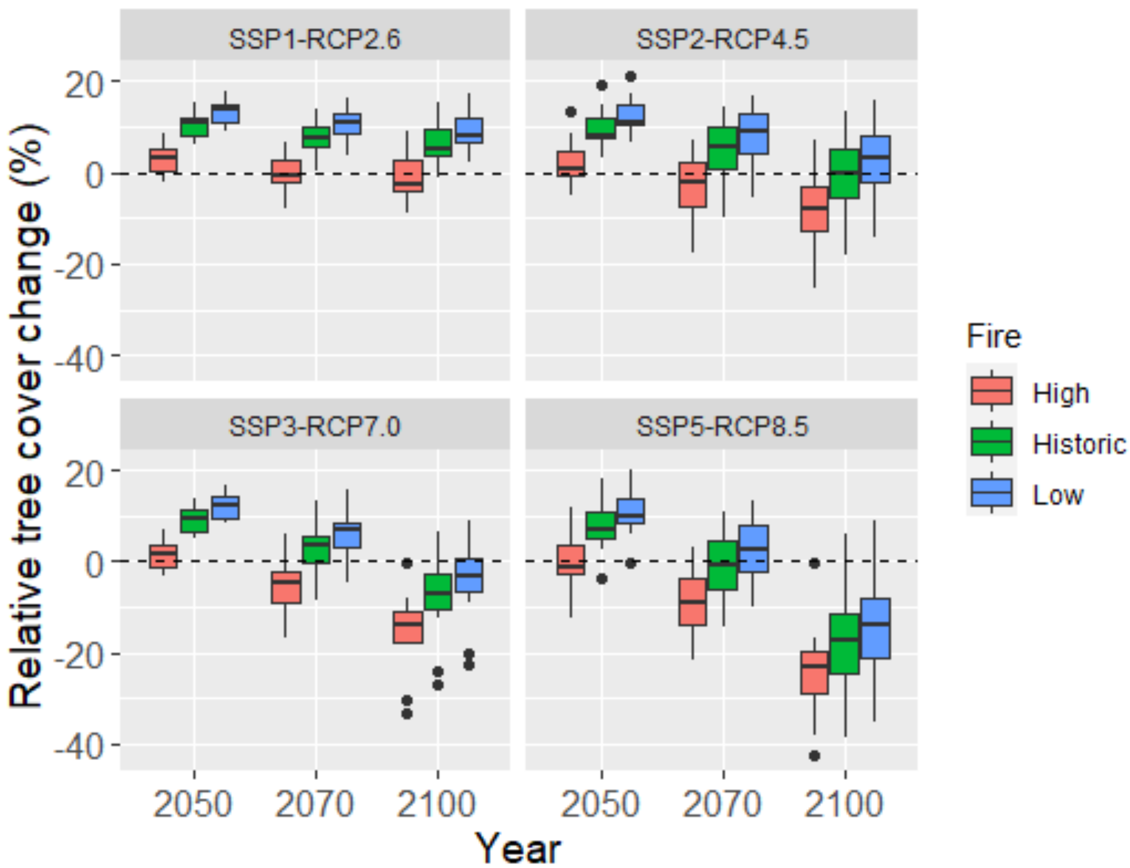




Graphs show temperature and precipitation trends over the rest of the century. Data are downscaled climate projections from the Climate Impacts Lab

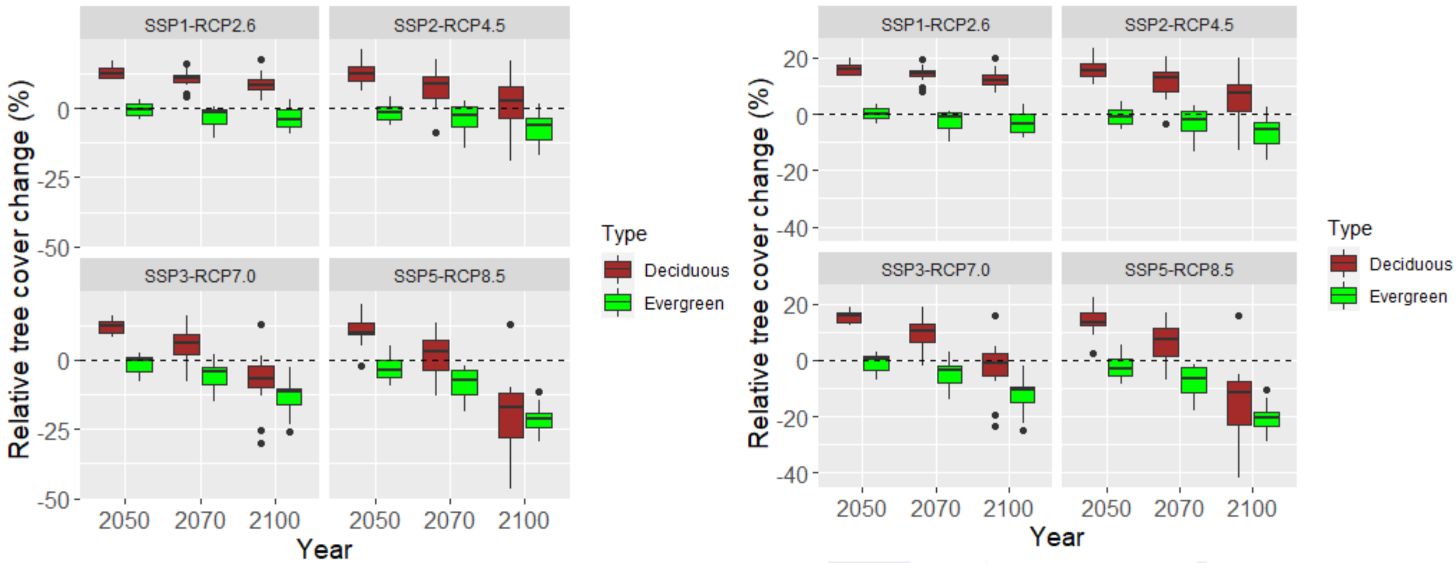
While diverse climate futures are possible, the most recent IPCC climate report prioritizes a handful including the 4 future scenarios that we consider here: SSP1-RCP2.6, SSP3-RCP4.5, SSP3-RCP7.0 and SSP5-RCP8.5. These scenarios together represent a wide range of possible future changes in global development, socioeconomic changes, and climatic conditions. Under SSP1 and SSP2 climatic change progresses apace until mid-century before beginning to stabilize. In the SSP3 and SSP5 scenario on the other hand global emissions continue to rise resulting in a steady rise in global temperatures till the end of the century.

Relative change in tree cover (%) under climate change and disturbance



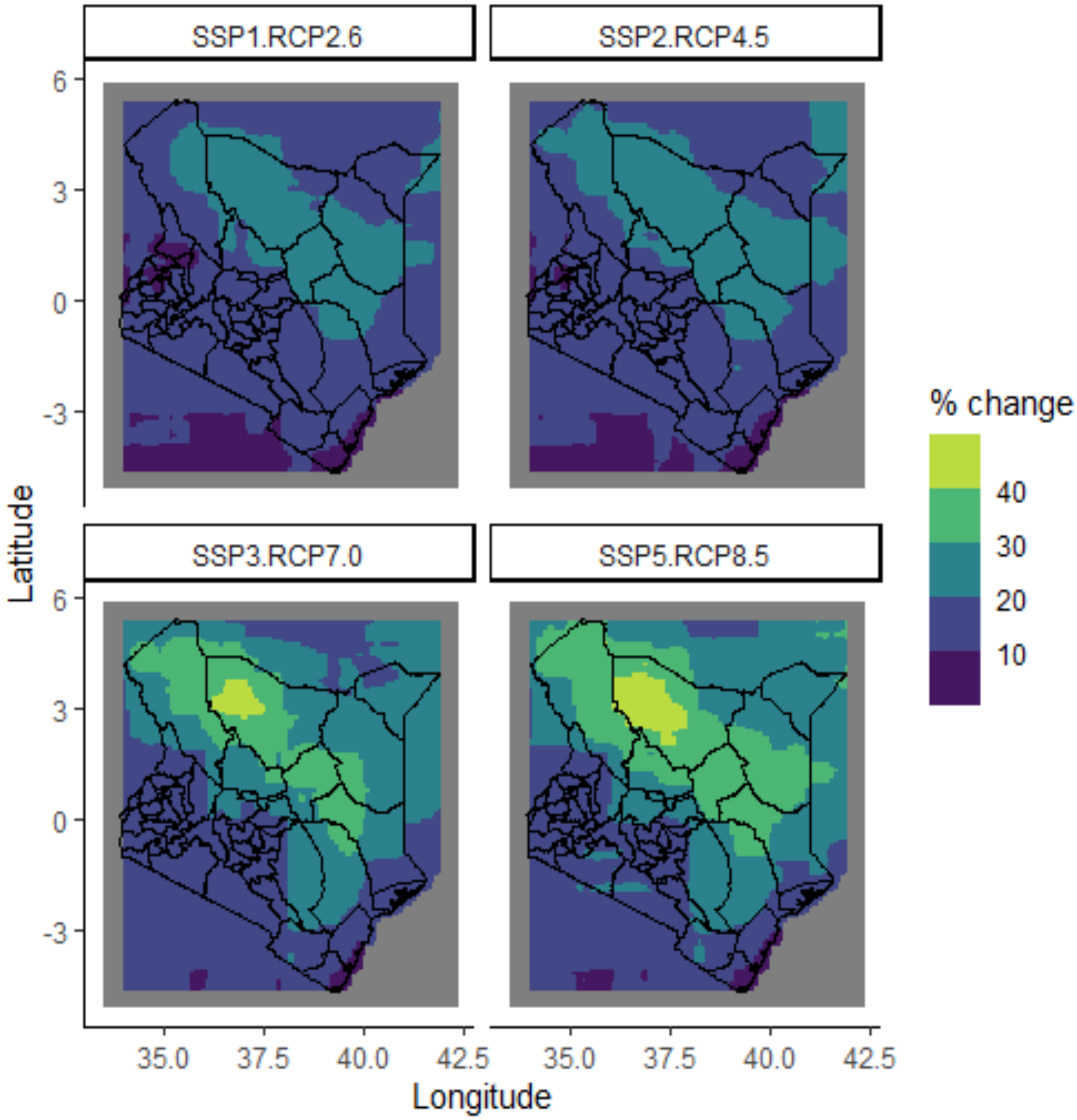
- Starting with 10 % tree cover in Kenya in 2030, increases in cover are apparent under all scenarios in 2050 if fire probabilities are equal to or less that historic conditions.
- Temperature and precipitation changes are the primary drivers of change in cover, with fire modulating the strength of the response.
- Responses are more variable further into the future and under more extreme climate scenarios (SSP3 and SPP5)
- Under the climate scenario that best represents current emissions trajectories (SSP2), tree cover remains stable till the end of the century with modest gains in the near-term
- Largest declines in cover occur at the end of the century when maximum monthly temperatures are approximately 4°C higher that historic conditions (SSP5)

Change in cover relative to 2030 baseline in areas with >30% evergreen and deciduous trees under historic (left) and low (right) fire intensity scenarios



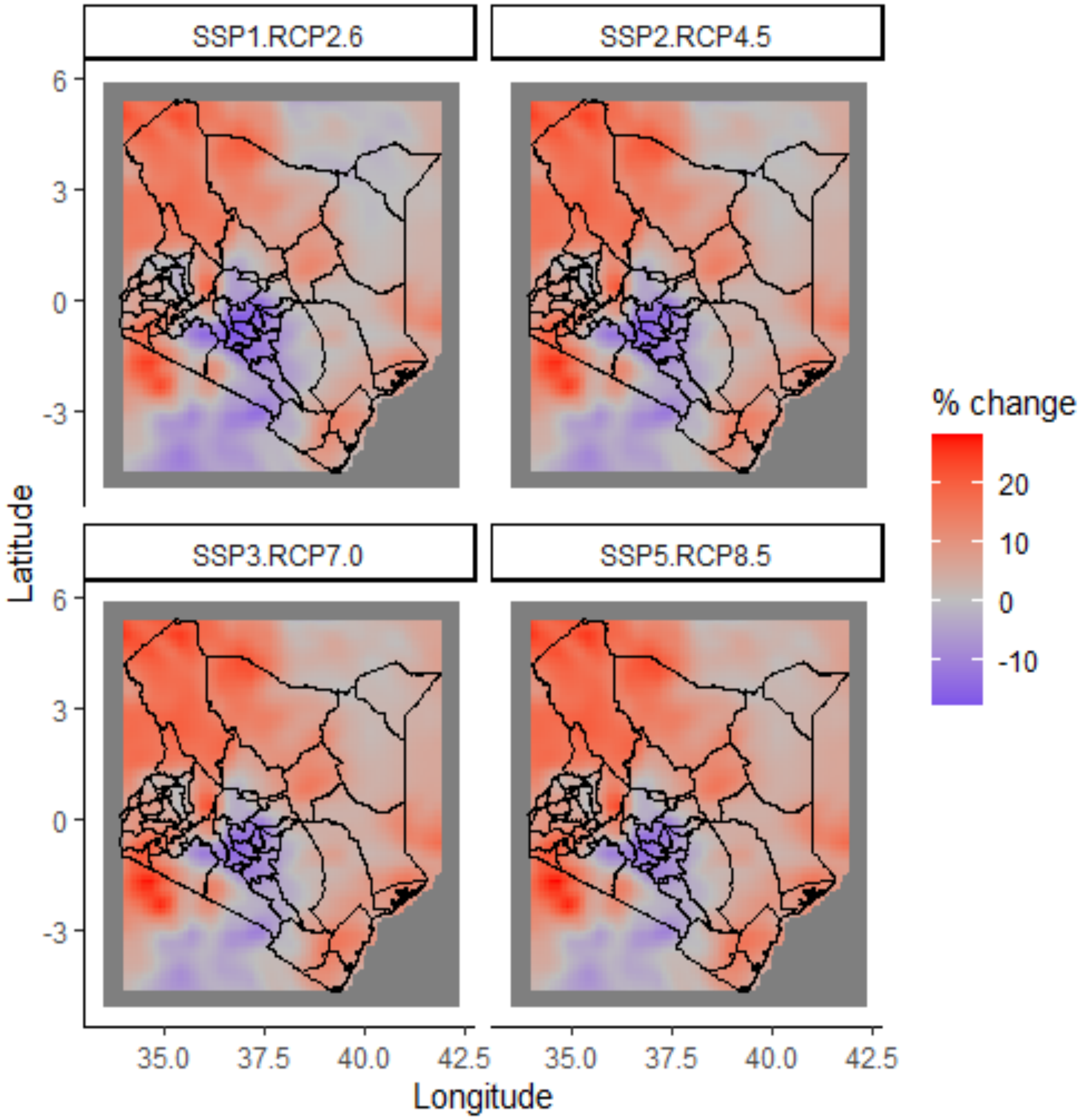
- Historically as well as in the 2030 enhanced tree cover scenario tree cover in Kenya is dominated by deciduous trees.
- Increases in tree cover under all scenarios are driven by increases in deciduous tree cover.
- Evergreen tree cover remains largely stable except towards the end of the century under high emissions scenarios (SSP3 and SSP5)
- Deciduous tree cover areas experience larger gains under all future climate scenarios if fires are controlled.

Spatial variability in future climate precipitation changes



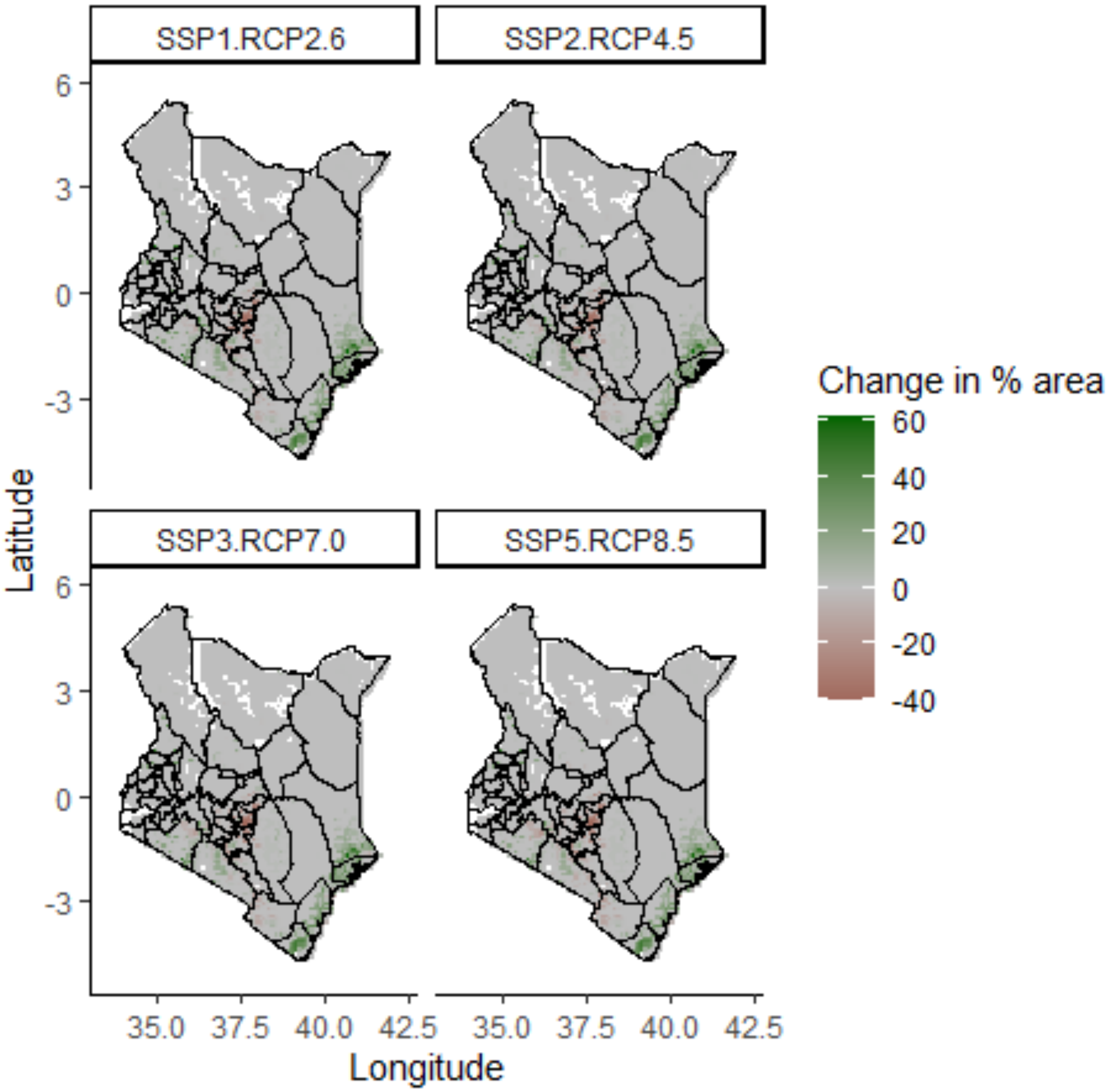
Percent change in mean annual precipitation in the 2030-2100 period relative to precipitation trends in the 1950-2014 period. Increases in precipitation are apparent across Kenya under all climate scenarios with a pronounced north-south gradient.

Spatial variability in future climate temperature changes



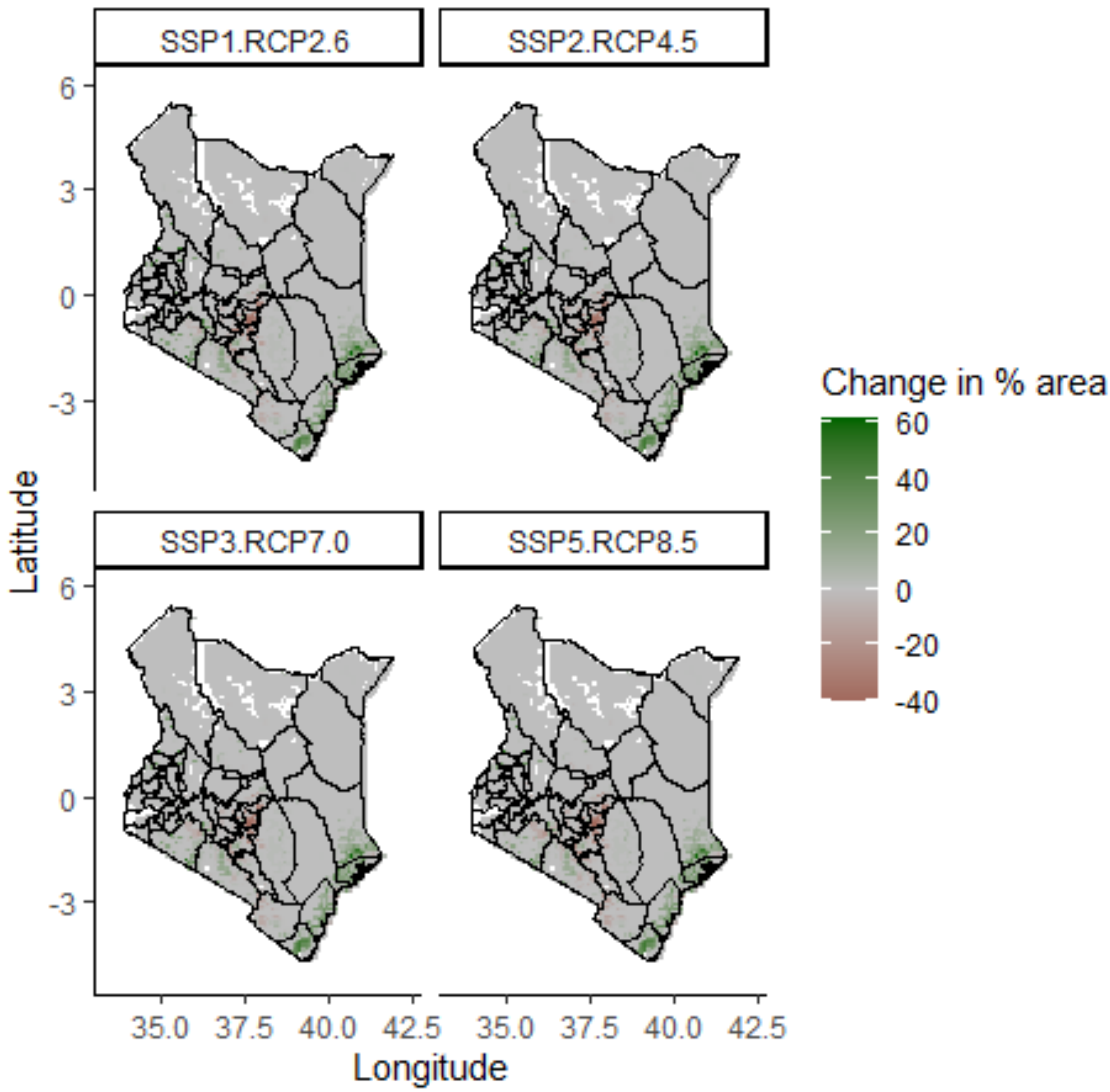
Percent change in mean annual precipitation in the 2030-2100 period relative to precipitation trends in the 1950-2014 period. Increases in precipitation are apparent across Kenya under all climate scenarios with a pronounced north-south gradient.

Potential tree cover change by 2050



- Maps show change in tree cover in 2050 relative to a 2030 baseline
- In the near-term (2050) tree cover gains occur primarily along the coast and in the southern counties.
- Cover losses are concentrated in areas within and near Embu County.

Potential tree cover change by 2100



- Maps show changes in tree cover extent in 2100 relative to the 2030 baseline.
- Tree cover gains are less pronounced along the coastal areas.
- Tree cover losses occur in the highlands as well as in the southern counties in the high emissions scenarios (SSP3 and SSP5)

Data used in this analysis

Dataset	Source	Link
L-Range Inputs		
Biome Classification	Global Potential Vegetation Dataset (Ramankutty and Foley 1999)	Biomes
Landcover	ESA CCI-Land Cover - S2 Prototype Land Cover 20m Map Of Africa 2016	LandCover
Tree-Shrub-Herb Cover	Global 1-km Consensus Land cover	TreeShrubHerb
Soil Characteristics	Regridded Harmonized World Soil Database v1.2	Soils
Downscaled Climate Projections	CIL Global Downscaled Projections for Climate Impacts Research	ClimateProjections
Fire Probability	European Space Agency - Climate Change Initiative (ESA CCI)	Fire
Validation		
Net Primary Productivity	MOD17A3HGF.061: Terra Net Primary Production Gap-Filled Yearly Global 500m	NPP
Live Carbon Density	Global Aboveground and Belowground Biomas Carbon Density Maps	LiveCarbon
Population Change		
Future Population Projections	Global 1-km Downscaled Population Base Year and Projection Grids Based on SSPs, v1.01 (2000-2100)	PopulationProjection

Contact information

Please contact Dr. Patrick Keys (patrick.keys@colostate.edu) with any questions regarding this report.