Brief

CGIAR Initiative on Livestock and Climate

Global updated rangeland ecosystem climate change projections through 2050, using evaluated parameters and CMIP6 climate forecasts

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Executive summary

Climate change in rangelands creates uncertainty that hinders the long-term direction of research, land management, agricultural production and policy formulation. The updated rangeland ecosystem projections under climate change use the most recent global climate forecasts (Coupled Model Intercomparison Project CMIP6) with evaluated model parameters for the G-Range global rangeland simulation model to project how rangeland ecosystems may change through 2050. The spatial dataset produced includes several fundamental attributes of rangeland ecosystems, specifically net primary productivity, soil carbon, cover of grass, shrubs, trees and bare soil, and root:shoot ratio on a decadal basis. G-Range was driven by climate inputs produced using MarkSimGCM, specifically CMIP6 from 2001 to 2050, and historical data from 2001 to 2020. These outputs are used as inputs to other models and analyses, or for national to global scale estimates of rangeland ecosystem status, structure and function under climate change, with significant implications for research, land management, agricultural production and policy formulation and implementation.

Introduction

To improve projections of global rangeland ecosystem change that may result from climate change created using the G-Range global rangelands simulation model, projections using validated parameter sets, especially for semi-desert rangelands (Sircely et al. 2019), were generated as driven by the most recent Coupled Model Intercomparison Project Phase 6 (CMIP6). The objectives of the project are to enhance model validation by improving the performance of the G-Range model through validation using historical weather data generated using the same MarkSimGCM software used to create the CMIP6 input data, ensuring its reliability and accuracy in projecting rangeland dynamics. Additionally, the project aims to test the most up-to-date parameter sets for G-Range by integrating and applying the highest standard parameter set available to control changes in ecosystem behaviour in response to climate change, comparing projections from the present day through 2050. Finally, the project will develop a portable dataset that can be easily shared with modellers at the International Livestock Research Institute and the International Food Policy Research Institute (IMPACT model), facilitating collaboration and enhancing the development of Livestock Master Plans across countries.

Methodology

We applied a simulation model to project climate change impacts on rangelands from 2000 through 2050 at 0.5 degree spatial resolution. G-Range is a global model of intermediate complexity with biogeochemical processes coupled with a population model with dynamic cover of herbaceous, shrub, tree and bare soil cover (Boone, Conant and Hilinski 2011, Boone et al. 2018, Sircely et al. 2018). To demonstrate a scenario analysis with G-Range, we downscaled and bias-corrected the latest CIMP6 data from five models. The multi-model ensemble of five GCMs applied here (GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, MRI-ESM2-0, and IPSL-CM6A-LR) has been used as the basis for the current simulation.

We employed a set of monthly weather surfaces comprising monthly precipitation and minimum and maximum temperatures both historical (1991–2014) and future (2014–2050) (Jones and Thornton 2013). Methods of downscaling future projection data and bias correction are detailed elsewhere (Stefan and Thornton et al. 2019). Shared Socioeconomic Pathways (SSP245 and SSP585) from CIMP6 were employed to explore potential future socioeconomic developments and their implications. That said, SSP126 and SSP585 were employed and represent sustainable current trajectory and business-as-usual fossil-fuelled pathways from the lower and higher ends of the spectrum, respectively.

The data were reformatted into GRIDASCII spatial layers for use in G-Range, and then Sim_Parm.grg was edited to point to the new surfaces. Simulations were made at 0.5 degree resolution for both historical and future time horizons as well as the two climate scenarios.

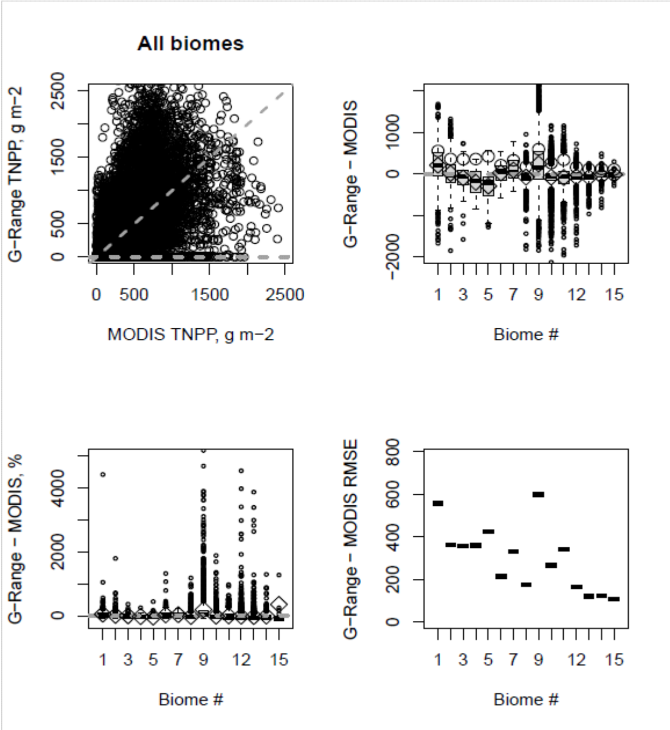
Similar to other models designed to simulate ecosystem dynamics and vegetation changes on continental to global scales (Sircely et al. 2019), the effectiveness of G-Range was evaluated based on its capacity to generate outputs that align with diverse data points collected from various locations and years by comparing the observed data (MODIS) and simulated data from G-Range. Parameters describing ecosystem dynamics (Sircely et al. 2019) were provided to G-Range for 15 biomes (Figure 1). The biomes from Ramankutty and Foley (1999) included (i) Tropical Evergreen Forest, (ii) Temperate Broadleaf Evergreen Forest, (iii) Temperate Deciduous Forest, (iv) Boreal Evergreen Forest (v) Boreal Deciduous Forest, (vi) Evergreen Deciduous Mixed Forest, (vii) Savanna, (viii) Grassland Steppe, (ix) Dense Shrubland, (x) Open Shrubland, (xi) Tundra, (xii) Desert, and (xiii) Polar.

Results and discussion

Model evaluation

Based on the new parameter files employed, G-Range total net primary production (TNPP) and facet cover were generally within the acceptable benchmarks for tolerable model error in terms of absolute and percent different. Interestingly, the validations of the new tested parameter files demonstrated showed close correspondence to the observed data (MODIS), with average TNPP of 357.42 and 385.35 with G-Range and MODIS, respectively, across all biomes. The parameter set used has been evaluated at global and site scales in a published validation analysis and model description (Sircely et al. 2019). The present outputs represent the current state of rangeland ecosystem forecasting under climate change.

Figure 1. Observed and simulated results of G-Range TNPP and MODIS TNPP. For biomes and biome numbers, see Table 1.



Source: Author's creation.

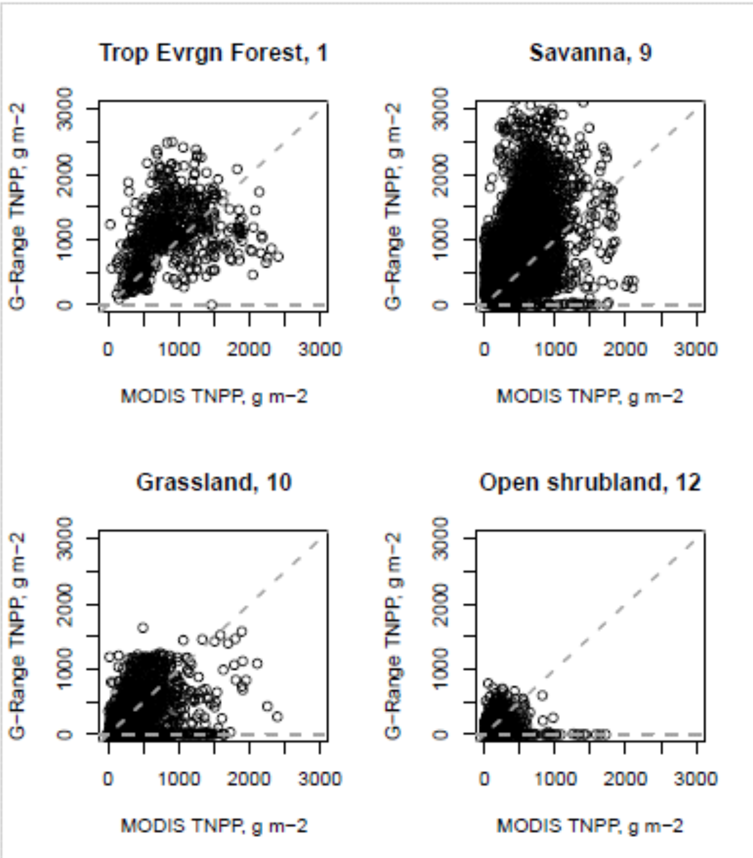


Figure 2. G-Range evaluation using the present parameter set based on historical MODIS TNPP in selected biomes, Tropical Evergreen Forest, Savanna, Grassland and Open Shrubland

Source: Author's creation.

Biome-level responses to climate change

Baseline values and mean changes in ensemble results are presented for 15 global rangeland biome responses under SSP585 scenarios in 2050 (Table 1). Overall, we showed that the mean global TNPP may decline by 15 g C m^{-2} year $^{-1}$ under SSP585. The analysis of biome changes between the baseline period of 2001–2010 and the projected future horizon of 2041–2050 reveals significant variations across ecological categories. For instance, rangelands in Tropical Evergreen Forest areas show a notable decline of 26.65%, along with declines in Tropical Deciduous Forest rangeland productivity, suggesting likely impacts from climate change.

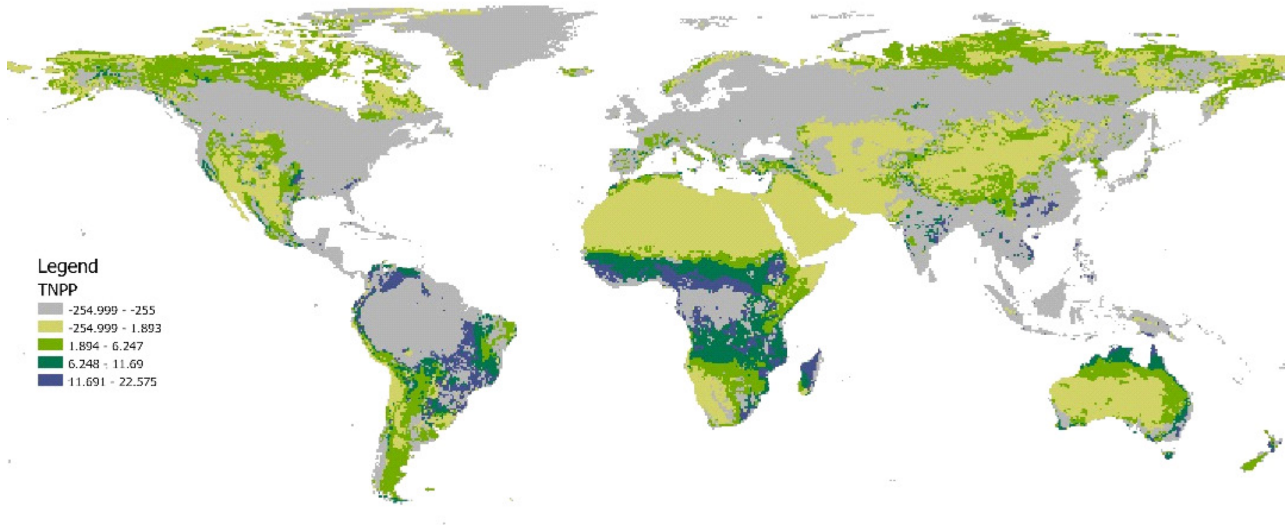
The stable values observed in Dense Shrubland and the slight decrease in Open Shrubland (or semi-desert) highlight the potential resilience and stability of certain ecosystems or regions less strongly affected by climate change (Hussein et al. 2024) or benefitting from CO_2 'fertilization' effects. Conversely, biomes such as Boreal Deciduous Forest zone rangelands exhibited a dramatic increase of 371.76%. This growth may indicate a shift in ecological dynamics, possibly driven by changing climate conditions that favour deciduous boreal forests. Similarly, rangelands within the biomes Temperate Evergreen Forest and Temperate Boreal Evergreen Forest showed substantial increases of 88.67% and 5.13%, respectively, which could reflect alterations in temperature and precipitation patterns that benefit rangelands within these forest zones as shown in Table 1.

Table 1. Biomes with baseline TNPP (2001–2010) and projected future conditions (2041–2050) under SSP585 scenarios

Biome	Biome	Historical 2001–2010	Future 2041–2050
1	Tropical Evergreen Forest	223.06	163.6
2	Tropical Deciduous Forest	268.59	228.38
3	Temperate Broad Leaf Evergreen Forest	288.01	302.74
4	Temperate Evergreen Forest	158.38	298.75
5	Temperate Needleleaf Forest/Woodland	103.23	140.08
6	Boreal Evergreen Forest/Woodland	65.82	149.89
7	Boreal Deciduous Forest/Woodland	79.29	374.43
8	Evergreen/Deciduous Mixed Forest/Woodland	39.94	62.85
9	Savana	129.56	149.77
10	Grassland Steppe	22.07	20.68
11	Dense Shrubland	57.44	57.53
12	Open Shrubland	15.33	12.35
13	Tundra	20.58	31.81
14	Desert	0.44	0.76
15	Polar	49.56	64.77

Source: Author's creation.

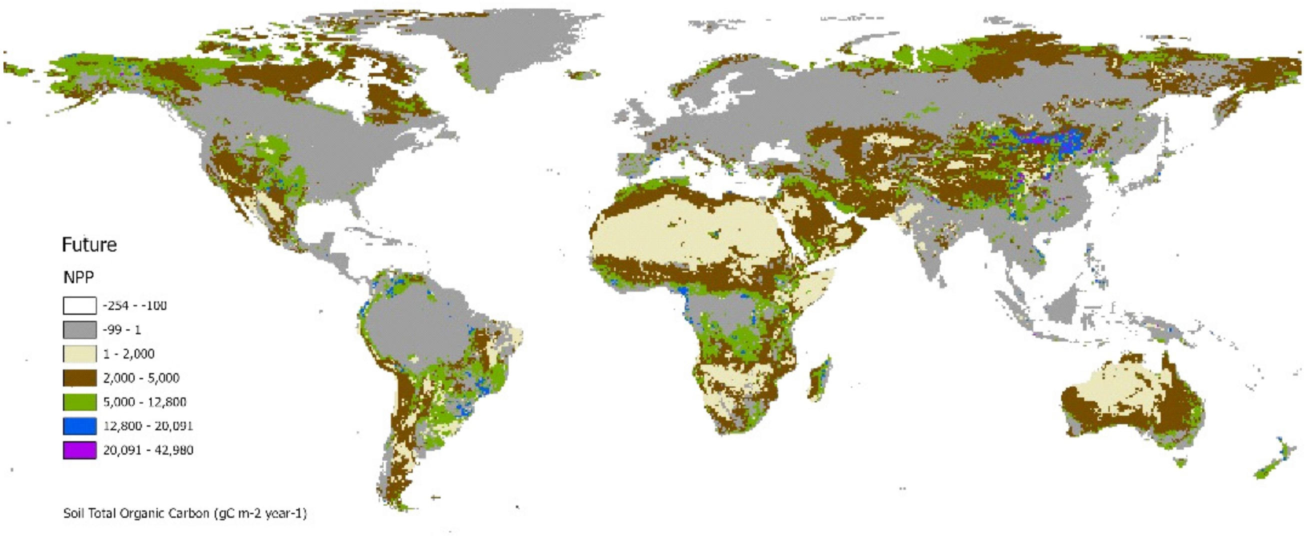
Figure 3. Ensemble simulation results for differences in annual total net primary productivity



***Note:** TNPP; above- + below-ground) of rangelands from 2001–2010 and their change in 2050 under emissions scenario RCP 8.5. Grey indicates non-rangeland areas that were not simulated.*

***Source:** Author's creation*

Figure 4. Ensemble simulation results for soil organic carbon stocks to 60 cm depth in rangelands as simulated in 2041–2050 under emissions scenario RCP 8.5



***Source:** Author's creation.*

Conclusion

These decadal changes underscore the complex interplay between environmental factors and biome resilience. The increase in productivity of rangelands within boreal, evergreen conifer, and other temperate biomes shows a strong beneficial response to warming climates. In contrast, the declines in the productivity of tropical rangelands raises concerns about the reduction of livestock- and rangeland-based livelihoods, ecosystem services, biodiversity loss and habitat degradation (Boone, Conant and Hilinski, 2011). Overall, these findings emphasize the need for adaptive management strategies that consider the projected shifts in biome functionality, ensuring conservation efforts align with ecological trends to mitigate adverse impacts on biodiversity and ecosystem services where climate change may create opportunities, as opposed to tightening constraints.

The updated rangeland ecosystem projections under climate change use the most recent global climate forecasts (CMIP6) with evaluated model parameters for the G-Range global rangeland simulation model to project how rangeland ecosystems may change through 2050. The parameter set used has been evaluated at global and site scales in a published validation analysis and model description, and the present set of outputs represents the current state of the art of rangeland ecosystem forecasting under climate change. The spatial dataset produced includes fundamental ecosystem attributes such as net primary productivity, soil carbon, cover of grass, shrubs, trees, and bare soil, and root:shoot ratio on a decadal basis. The G-Range global rangelands model driven by climate inputs via MarkSimGCM from CMIP6 from 2001 to 2050 and historical data from 2001 to 2020 provides outputs used as inputs to other models and analyses or for national to global scale estimates of rangeland ecosystem status, structure and function under climate change, with significant implications for research, land management and agricultural production, and policy formulation and implementation.

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