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Impacts of Climate Change and Human Activities on Global Mountain Grasslands

Insights from the past two decades and future projections

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Introduction

Ecological Importance and Threats to Mountain Grasslands

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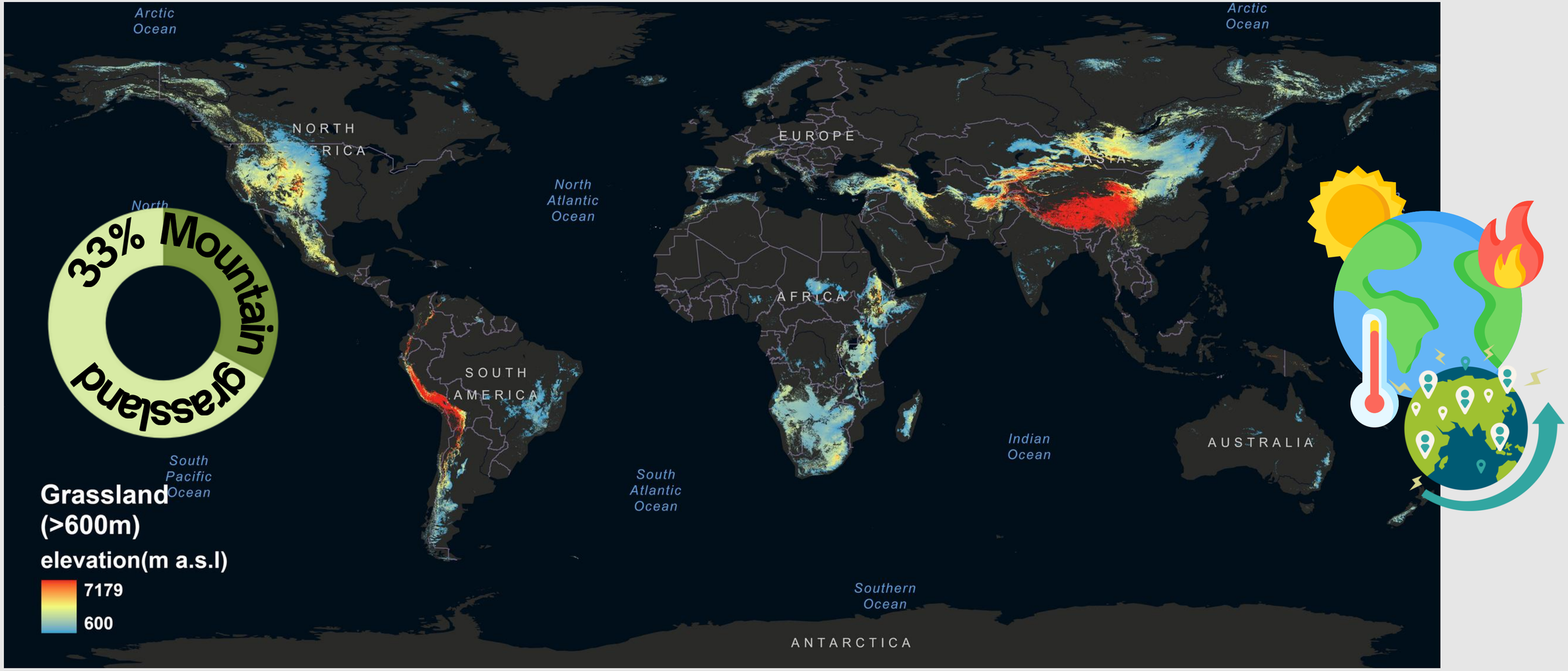

Targeted Mountain Regions Study focuses on grasslands above 600 m a.s.l. across the Alps, Andes, Rockies, Tibetan Plateau, Ethiopian Highlands, and Middle Eastern mountains. (Data source: Straffelini et al. (2024), CATENA)

Data & Method Summary

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Data Sources

- MODIS NDVI – NASA LP DAAC
- ERA5-Land – Copernicus (ECMWF)
- CMIP6 (CESM2, etc.) – ESGF / IPCC
- GMTED2010 – USGS
- Human Modification Index (gHM v1.5, Theobald et al., 2023)

Processing & Analysis

- Resampling & interpolation
- Sen's slope + MK test for NDVI trends
- Spearman correlation (NDVI-climate)
- NDVI + gHM → Disturbance index (R)

Modeling

- RF & XGBoost → Driver analysis
- LSTM → Temporal learning
- Hybrid → Correct LAI (2050)
- SHAP: Variable importance
- Eval: R^2, RMSE, 5-fold CV

Future Scenario

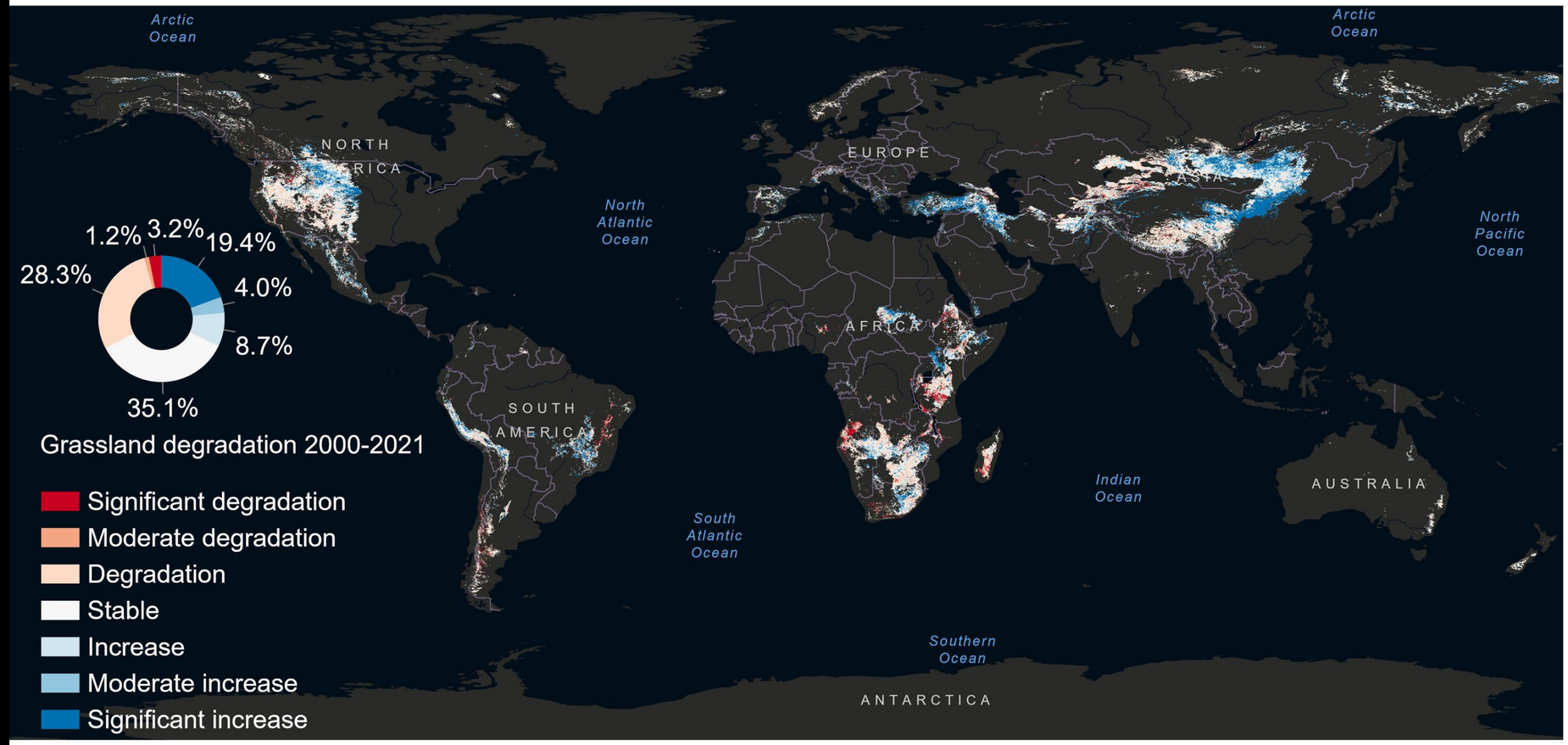
- ΔLAI = SSP5-8.5 – SSP1-2.6 (2050)
- KDE + KS test in ArcGIS
- Regional LAI change mapping

TOOLS: Google Earth Engine, ArcGIS Pro, python™

Python packages: NUMPY, PANDAS, SCIKIT-LEARN, XGBOOST, TENSORFLOW/KERAS, SHAP, XARRAY, MATPLOTLIB, SEABORN, NETCDF4

Results

21 Years of Grassland Change



Degraded 32.7%

Stable 35.1%

Recovered 32.1%

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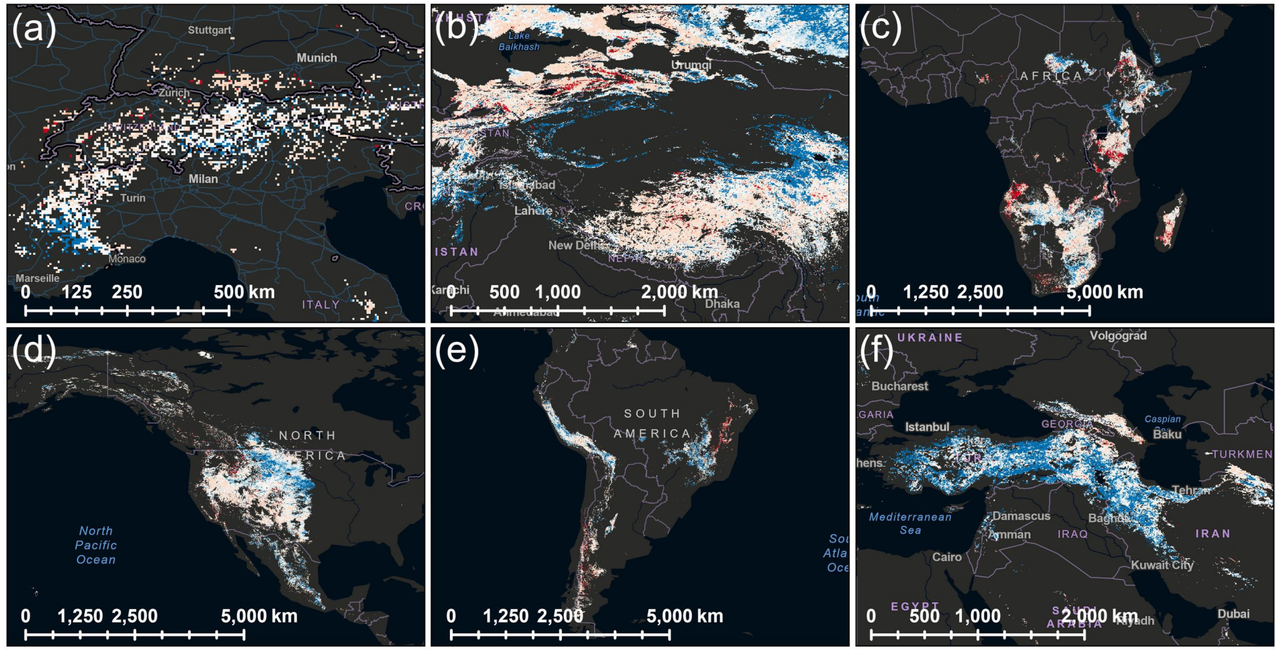
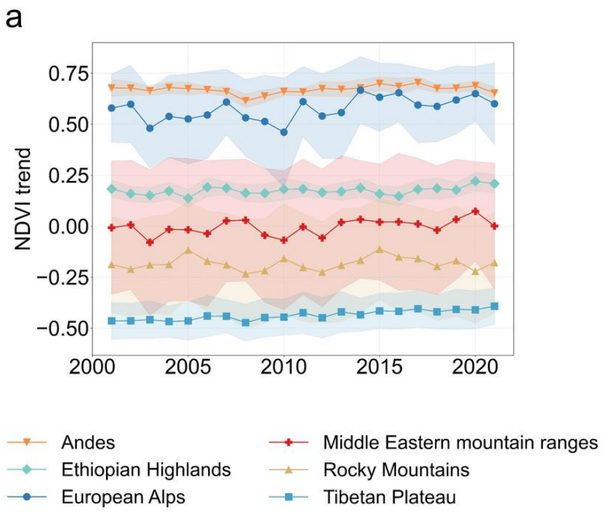


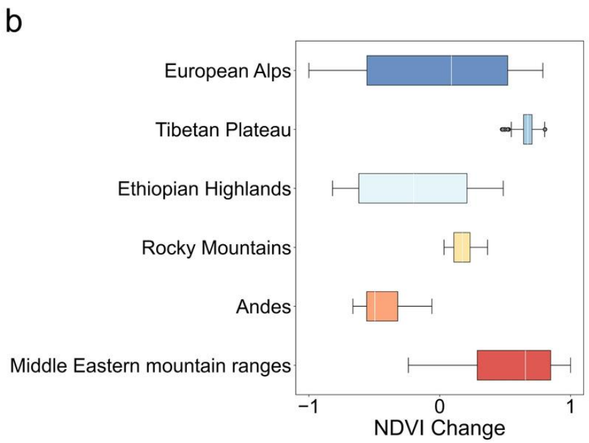
At the regional scale, the *European Alps* (a) and *Rocky Mountains* (d) are dominated by stable or slightly degraded grasslands, whereas *Middle Eastern mountain ranges* (f) mostly show improvement trends.

Grassland degradation 2000-2021

- Significant degradation
- Moderate degradation
- Degradation
- Stable
- Increase
- Moderate increase
- Significant increase

In contrast, the *Tibetan Plateau* (b), *Andes* (e) and *Ethiopian Highlands* (e) exhibit more pronounced degradation.





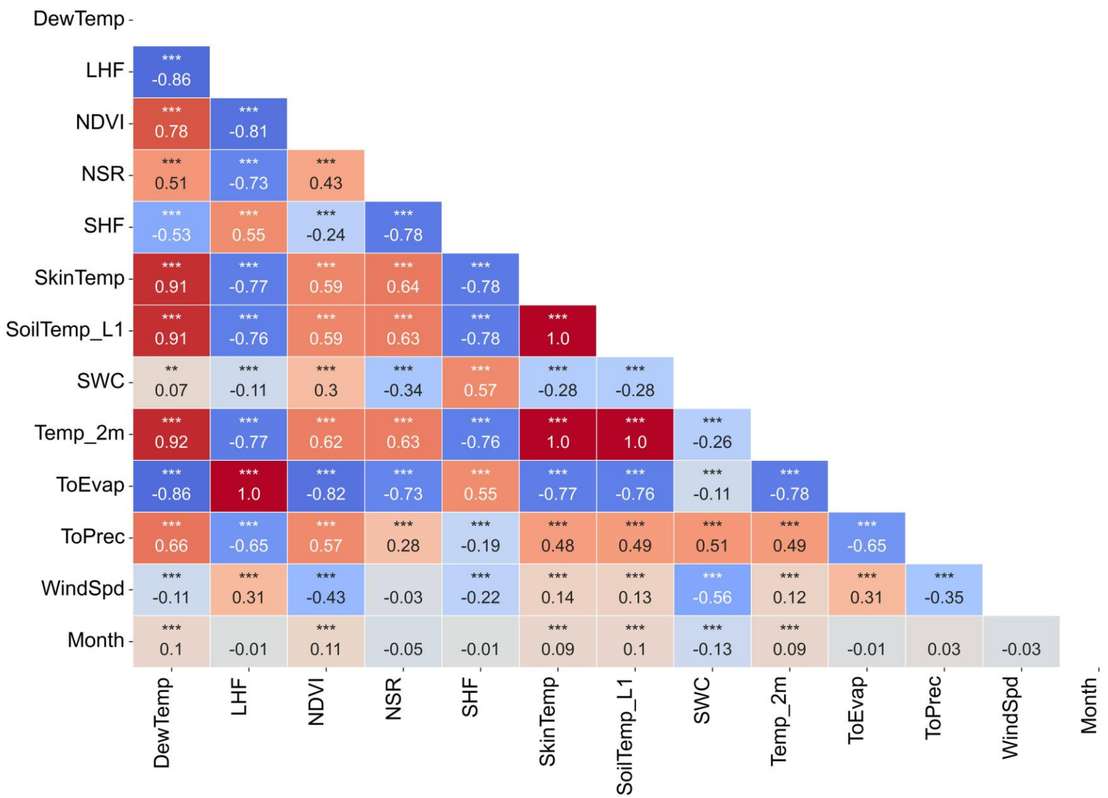
a. NDVI trends (2000–2021) varied among mountain regions:

- Positive and stable: Andes, Ethiopian Highlands
- Positive but variable: European Alps
- Fluctuating around zero: Middle Eastern mountains
- Negative trends: Tibetan Plateau (stable negative), Rocky Mountains

b. NDVI variability:

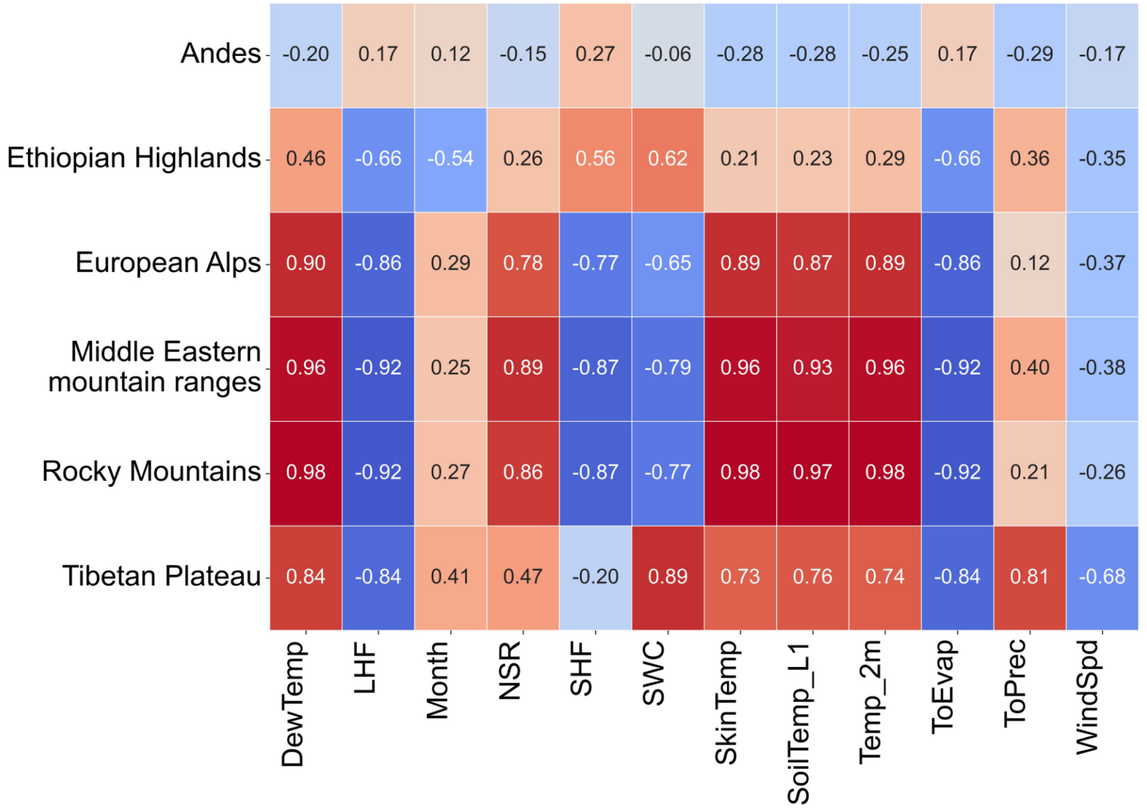
- High: Ethiopian Highlands, European Alps, Middle Eastern mountains
- Moderate: Andes, Rocky Mountains
- Low (stable negative): Tibetan Plateau

What Drives Grassland Degradation?



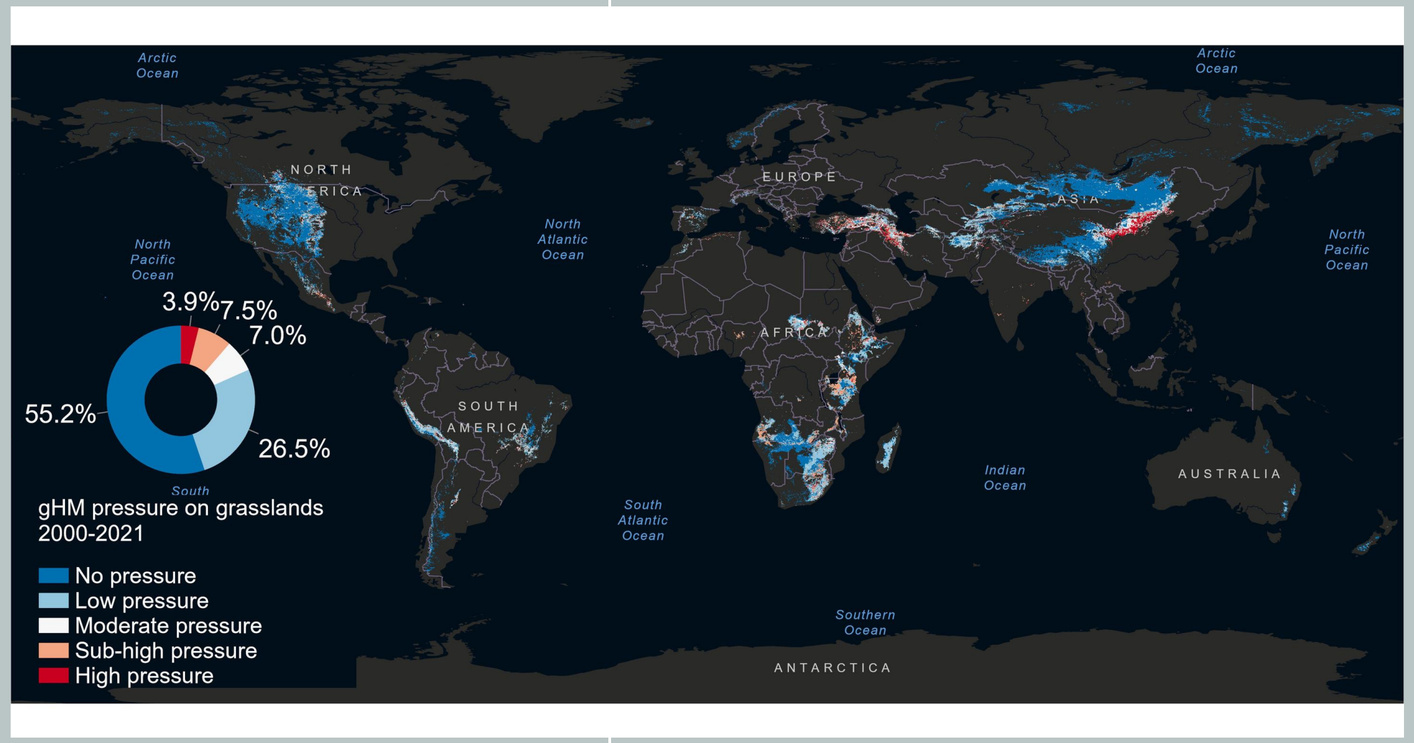
Top Climate Factors:

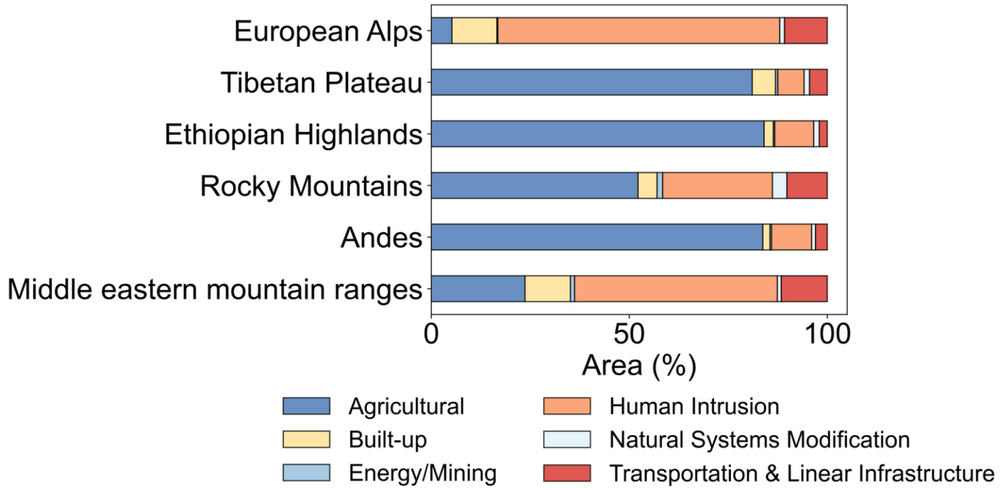
- Dewpoint temperature (+), near-surface air temperature (+)
- Total evaporation (-), latent heat flux (-)

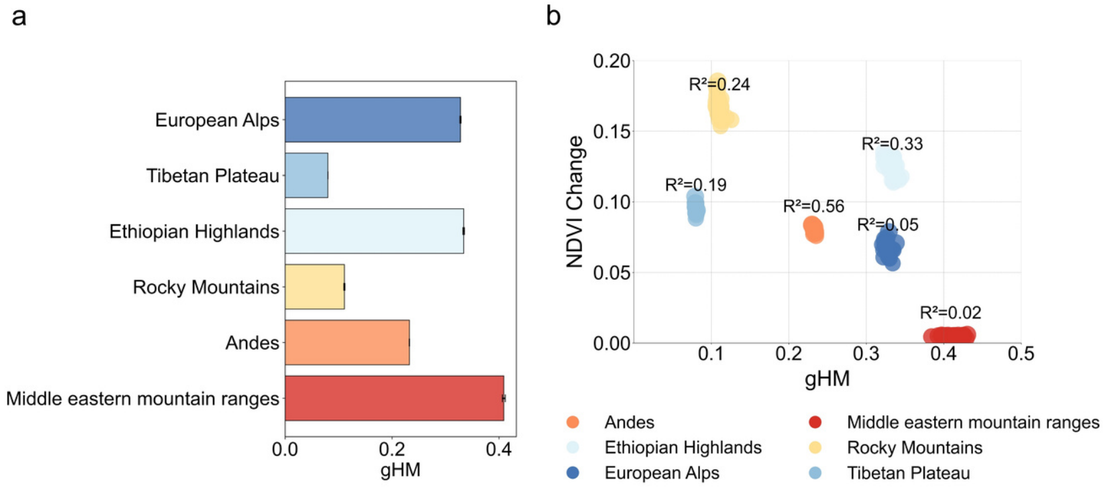


Regional NDVI responses:

- Rocky Mountains and Middle East sensitive to evaporation
- Tibetan Plateau to soil moisture
- Andes show complex, mixed correlations







- High gHM often corresponds to NDVI decline, notably in the Ethiopian Highlands, while the Middle Eastern mountains show improvement despite high pressure.
- NDVI tends to remain stable or improve under low gHM (≤0.2), but declines when gHM exceeds 0.3, with regional differences in correlation strength.
- Agriculture is the dominant stressor in the Tibetan Plateau, Andes, and Ethiopian Highlands, while built-up areas, energy, and mining shape impacts in the Alps and Middle East.

What Will Mountain Grasslands Look Like in 2050?

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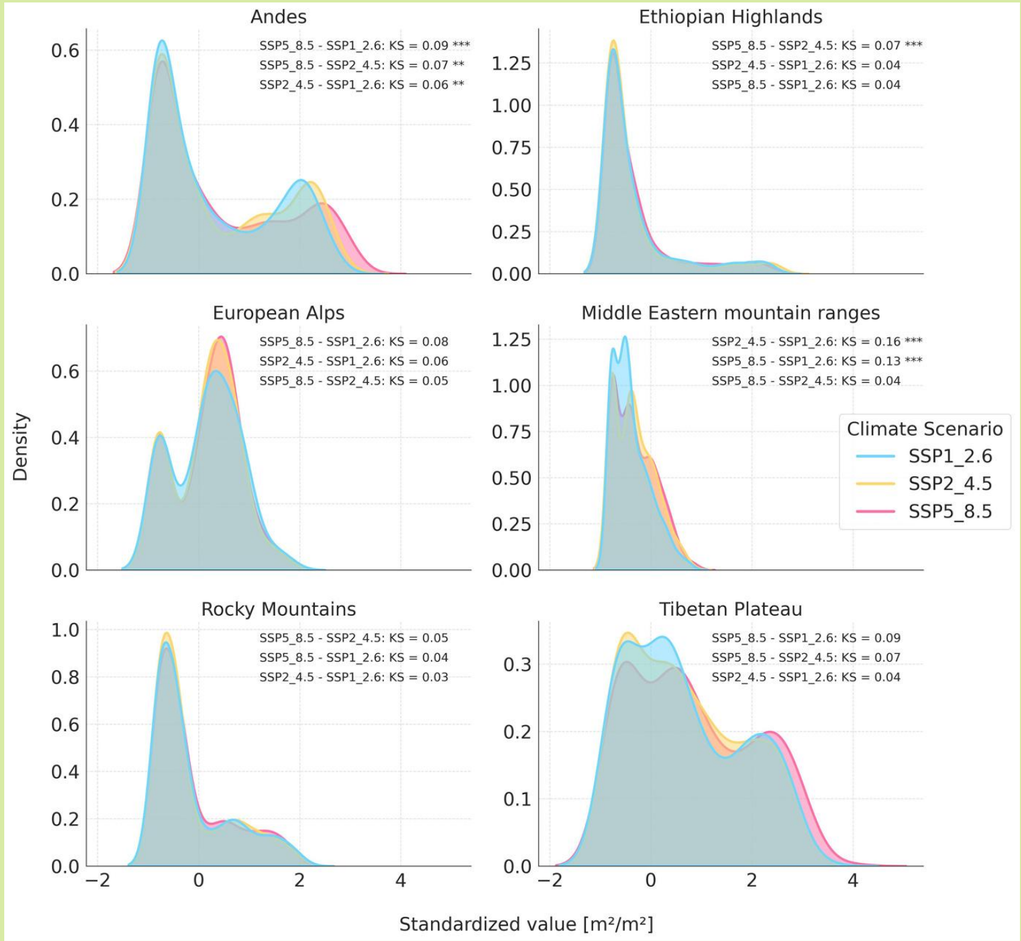
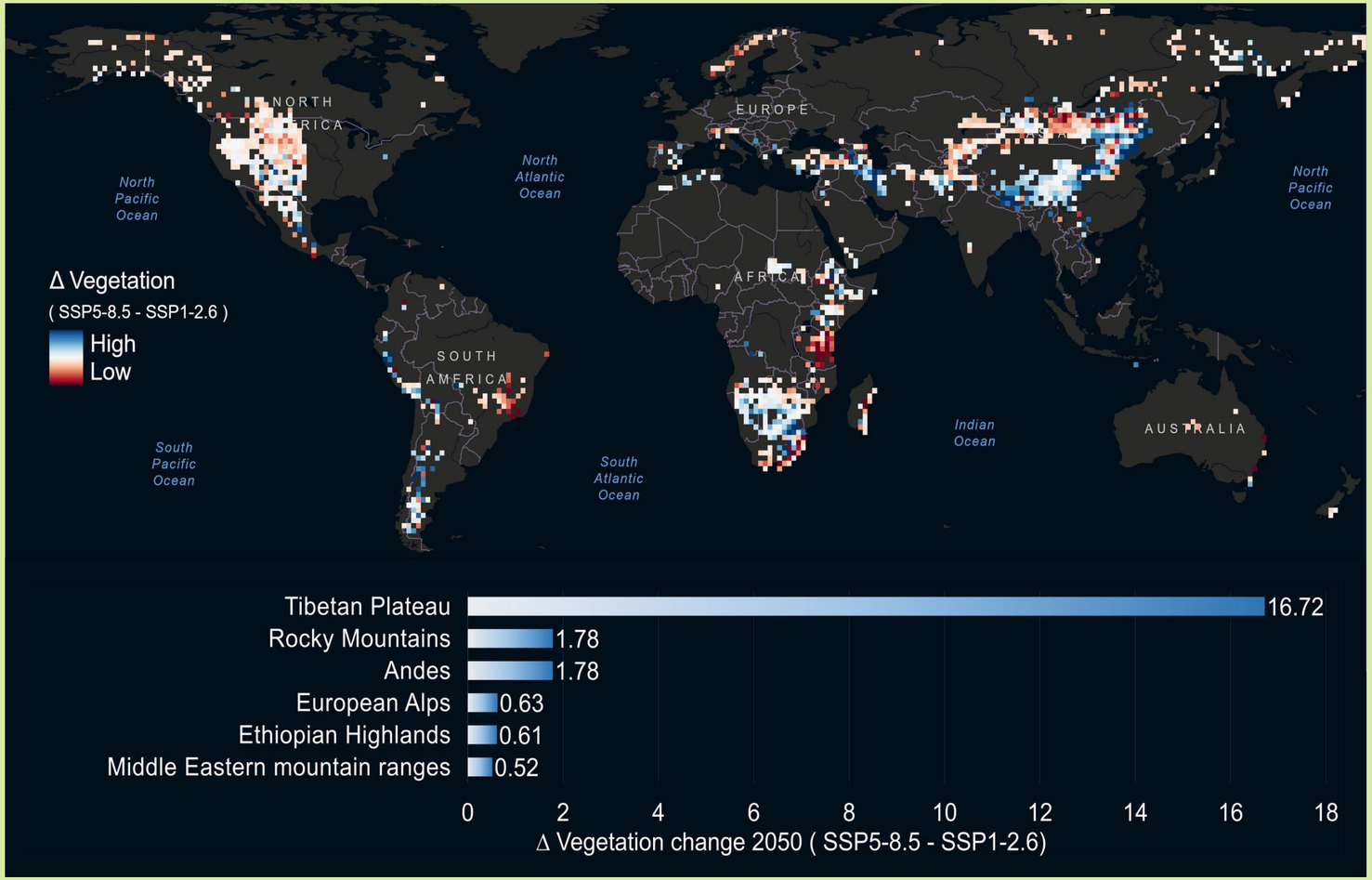
Minimal global change but regional shifts

SSP5-8.5: More spatial heterogeneity in vegetation cover





Conclusions & Conservation Insights

Historical trends (2000–2021): 32.7% of global mountain grasslands have degraded, especially in the Tibetan Plateau, Ethiopian Highlands, and Andes, driven by temperature/moisture stress.

Signs of recovery were observed in parts of the Middle East and Asia, likely due to improved land management and favorable climate shifts.

Future projections (CMIP6): Regional variations dominate — Tibetan Plateau may green under high emissions, while Andes and East Africa show mixed responses.

Model performance: High accuracy, but uncertainties remain due to coarse climate data, limited human pressure detail, and missing ecological feedbacks.

Policy implication: Regional adaptation strategies are essential, combining climate mitigation, sustainable land use, and improved monitoring.

Thanks for your attention