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Reconstructing pre-agricultural expansion vegetation cover of Ethiopia

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Abstract
Landscape reconstructions can be used to define a reference condition from which to assess the magnitude of land changes caused by human influence. Since the beginning of the last century, the population of Ethiopia has increased drastically with large effects on the natural vegetation and biodiversity. However, the original land cover patterns in Ethiopia have not been precisely mapped, which hinder the identification of the biophysical and socio-economic factors that contributed to the current landscape patterns. The objective of this study was to reconstruct the past century vegetation landscapes of Ethiopia (i.e. vegetation cover before agricultural expansion) and identify which ecosystems have been most affected by land changes. First, the net primary productivity (NPP) was modelled based on the climatic constraints of natural vegetation growth (water availability, solar radiation and minimum temperature) derived from remote sensing and climate data. This analysis showed that water availability is the most critical constraint for vegetation growth for all regions and land cover types in Ethiopia. Then, the past vegetation was mapped based on predicted NPP. Our results show that i) the extent of broadleaved evergreen or semi-deciduous forest, open broadleaved deciduous forest, closed to open shrubland, mosaic forest-shrubland/grassland, sparse vegetation and grassland was 18.8%, 12.4%, 20.6%, 31.5%, and 16.8%, respectively, and ii) current agricultural landscapes were previously covered mainly by broadleaved evergreen and deciduous forest. The least affected by agricultural expansion were sparse vegetation and grassland. Our study provides novel insights on pre-agricultural expansion landscapes in Ethiopia with critical information for scientists and other stakeholders working on the restoration and rehabilitation of degraded areas.

Key words: *Pre-agricultural expansion, remote sensing, Net Primary Productivity, Ethiopia*

Introduction

The rapid population growth observed in the East African highlands during the past century has had implications for land use requirements with subsequent impacts on natural vegetation cover, biodiversity, socio-economic stability and food security (Brink and Eva, 2009).

In Ethiopia, studies estimate that 35–40% was covered by natural forest and 66% of the country was originally covered with forest or woodlands (Britenbach, 1961, Wood, 1990, Kuru, 1990, Yirdaw, 1996). According to FAO (2010), 13 % of the total area of the country (159104 km²) was covered with forests in 1990 and this had decreased to ca. 11 % of the total area (129104 km²) in 2010.

In this research, we aimed to simulate past century natural vegetation cover of Ethiopia and to estimate the extent of natural vegetation cover affected by agricultural expansion.

Study Area

Ethiopia is situated at 34°30'–45 °30' E and 3°30'–15° N covering an area of 1.1 million square kilometer in the northeastern part of Africa (Figure 1).

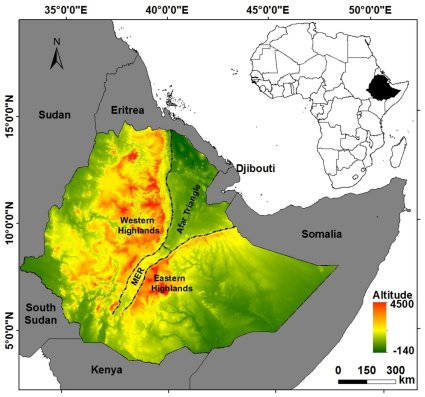

Figure 1. The location map and topography of Ethiopia (DEM: GTOPO30).

The traditional Ethiopian classification of climate (Conway, 2000) is based on altitude and identifies three zones: i) Kolla zone that is below 1800 m asl. with mean annual temperatures of 20–28 °C; ii) Woina Dega zone, 1800–2400 m asl with mean annual temperatures of 16–20 °C; iii) Dega zone above 2400 m asl with mean annual temperatures of 1–6 °C.

Material & Methods

In this research, the net primary productivity (NPP) was modeled based on the climatic constraints of natural vegetation growth derived from remote sensing and climate data. This model was used to simulate productivity of agricultural area in order to identify the original extent of natural vegetation cover.

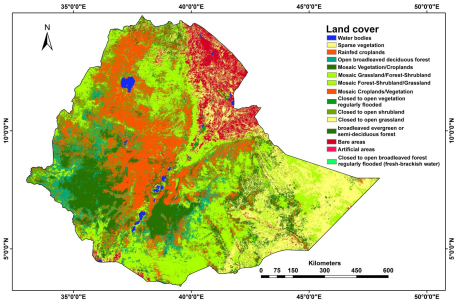

Figure 2. Land cover of Ethiopia in 2009 (FAO, 2009).

Methods

The method was divided in 4 main stages.

1. The natural vegetation was separated from agricultural areas and its net primary productivity (NPP) was characterized based on climatic productivity constraints (Nemani et al., 2003).
2. Random points of natural vegetation cover were created to tabulate the three constraints and NPP.
3. Mltivariate regression was used to assess the relationship between NPP and the climatic variables (water availability, solar radiation and minimum temperature). The relative impact of these variables for NPP of each vegetation cover was determined by standardized coefficients (beta). The model was used for simulating NPP over agricultural lands of Ethiopia
4. The simulated productivity map classified based on threshold in order to show how the natural vegetation affected by agricultural expansion.

Results

Climatic constraints of productivity

The productivity on the highest peaks of mountains, such as the northern part of the Ethiopian highlands and the southeastern part of the country is limited by the minimum temperature. As these peaks are very small in area, the productivity in the highlands is mainly constrained by the solar radiation.

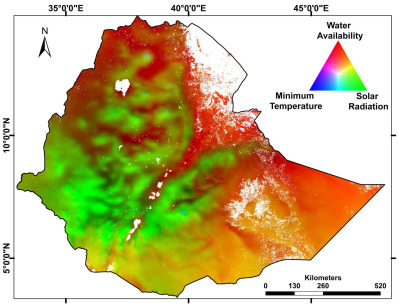

Figure 3. Environmental constraints for vegetation growth in Ethiopia.

Modelling productivity of natural vegetation classes

The multivariate regression shows that the productivity of natural vegetation cover is significantly related ($p<0.001$, $R^2=0.77$) to the water availability. The productivity of each vegetation class was significantly related to the water availability (Figure 4)., (Table 1).

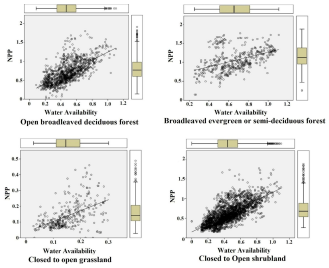

Figure 4. The relationships of NPP and water availability for the natural vegetation classes.

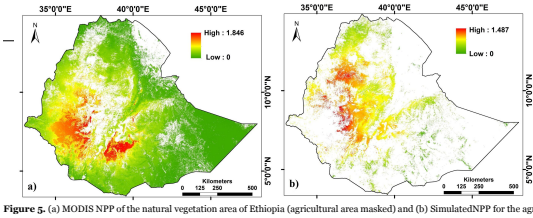

Figure 5. (a) MODIS NPP of the natural vegetation area of Ethiopia (agricultural area masked) and (b) SimulatedNPP for the agricultural area.

Modelling of natural vegetation productivity

From the multivariate regression model, the relative coefficients and intercept were identified in order to formulate NPP validmodel. This model was used for simulating the past natural vegetation productivity in the area covered by agriculture (Figure 5b). Model ation showed that the simulated NPP and original NPP were significantly related ($p < 0.001$ and $R^2 = 0.76$).

Reconstructed natural vegetation of agricultural areas

The simulated NPP map of agricultural land in Ethiopia was classified based on threshold values. in order to reconstruct the original extent of natural vegetation cover classes (Figure 6a). The current agricultural landscapes were previously covered mainly by broadleaved evergreen and deciduous forest, which encompassed 38.9% of the current agricultural land. The least affected by agricultural expansion was sparse vegetation and grassland with 5.7% area. The extent of broadleaved evergreen or semi-deciduous forest, open broadleaved deciduous forest, closed to open shrubland, mosaic forest-shrubland/grassland, sparse vegetation and grassland in Ethiopia was 18.8%, 12.4%, 20.6%, 31.5%, and 16.8%, respectively (Figure 6b).

Discussion

In this study, all the information for mapping the past natural vegetation cover was based on the remote sensing products (NPP, GlobCover land cover, solar radiation, PET) and climate data (precipitation and temperature). Hence, our approach differs from previous attempts to map potential vegetation in Ethiopia (e.g. Friis et al., 2010), which are based on infor-mation from previous literature, field experience, as well as on the analysis of information for about 1300 species of woody plants in the Flora of Ethiopia and Eritrea.

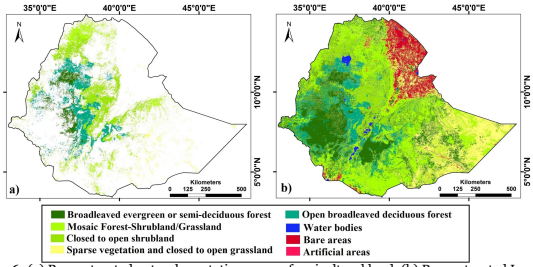

Figure 6. (a) Reconstructed natural vegetation cover of agricultural land. (b) Reconstructed Land cover map of Ethiopia (agricultural areas replaced by its simulated natural vegetation cover).

Conclusion

We reconstructed the past century natural vegetation cover of Ethiopia including the area affected by agriculture. We show that 36.1% and 38.9% of the current agricultural land were previously covered by closed to open shrubland and broadleaved evergreen and deciduous forest, respectively. This encompasses about 75% of the agricultural land. The land cover least affected by agricultural expansion was sparse vegetation and grassland. The map of the reconstructed natural vegetation of Ethiopia could be helpful for decision makers to restore and rehabilitate the major affected areas. Furthermore, it can provide a better understanding of the spatial patterns of the original vegetation and identification of socio-economic factors that contributed for defining the current agricultural landscapes in Ethiopia.

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Table 1. The results of multivariate regression analysis for each natural vegetation class.

Land Cover	Unstandardized Coefficients				Significance (p)			Standardized Coefficients (Beta)		
	WA[1]	SR[1]	Tmin [1]	C[1]	WA	SR	Tmin	WA	SR	Tmin
COG*	1.021	0.000	0.001	-.539	0.000	0.000	0.015	0.649	0.242	0.171
BESDF*	0.561	-4.666E-5	-0.003	1.126	0.000	0.384	0.000	0.395	-0.037	-0.305
COS*	1.033	-5.717E-5	.001	0.188	0.000	0.000	0.000	0.735	-0.053	0.076
MFSG*	1.184	.000	0.001	0.247	0.000	0.000	0.000	0.787	-0.163	0.112
MGFS*	1.521	-2.401E-5	0.000	0.028	0.000	0.435	0.231	0.876	-0.019	-0.033
OBDF*	1.042	-5.728E-5	0.000	0.275	0.000	0.043	0.119	0.669	-0.047	0.037

*COG = Closed to open grassland, BESDF = Broadleaved evergreen or semi-deciduous forest, COS = Closed to open shrubland, MFSG = Mosaic Forest-Shrubland/Grassland, MGFS = Mosaic Grassland/Forest-Shrubland, OBDF = Open broadleaved deciduous forest

[1]WA = Water Availability, SR = Solar Radiation, Tmin = Minimum Temperature, C = Constant

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