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Modeling the carbon dynamics of tropical forest ecosystem in the Amhara Region of Ethiopia

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Abstract

The carbon stored and sequestered in the forest ecosystem is important for the global carbon cycle. The purpose of this study is to adopt the Biogeochemical mechanistic ecosystem model (Biome-BGC) for Ethiopian forests to estimate carbon stocks. Daily climate data, site physical properties and evergreen broadleaved forest (EBF) ecophysiological parameters were used as inputs for the model. For model calibration, above- and belowground carbon, and terrestrial net primary productivity (NPP) were derived from inventory data collected on 156 plots in four natural forest study sites. The model with default EBF parameter was found to be limited in explaining Ethiopian forest ecosystem carbon dynamics. It overestimated stem carbon but underestimate the NPP as compared to the terrestrial results. The default Biome-BGC model simulation considers fully grown or old aged virgin forest but our studied forest sites are highly disturbed and mix of young sapling and old aged trees. Hence, Biome- BGC model was parameterized using thinning intervention and ecophysiological parameters to mimic such disturbed Ethiopian forests.

Keywords: Biomass, carbon, NPP, calibration, Biome-BGC

1. Introduction

Forests are an important part of terrestrial ecosystem since they mitigate the CO_2 concentration effect in the atmosphere. Tropical forests account for 50% (Kindermann et al. 2008) to 67% (Pan et al. 2013) of the Earth's total plant biomass, and store 40% (estimated at 428 Gt of carbon) of the terrestrial carbon (Ashton et al. 2012). Their continuous decline in coverage is a central triggering factor on the current world's climate change. Based on this important role, forest conservation and rehabilitation schemes, such as reducing Emission form Deforestation and forest Degradation (REDD), have been developed. This activity has been gradually extended to (REDD+), which includes forest conservation and sustainable management to effect on carbon stock. Understanding the carbon stock lost to the atmosphere in deforestation and forest degradation, and sequestered through rehabilitation and conservation measures is helpful in carbon balance of the tropical forest.

A number of studies that have been done on East Africa tropical forests mainly focused on livelihoods, species composition, food security and community management (Blackie et al. 2014) but very scarce on carbon stock. Especially, in Ethiopia studies on forest net primary production and carbon stocks are hardly available and are in a piecemeal level. Nowadays, process based ecosystem models like Biome-BGC are increasingly used as tools for simulating forest ecosystem carbon dynamics at landscape levels. Biome-BGC first developed as FOREST-BGC is a widely used as ecosystem process model to simulate carbon, nitrogen, water, and energy in the forest ecosystem (Running & Gower 1991). In this study, we adopted the Biome-BGC model for Ethiopian forests ecosystem carbon stock estimation.

2. Material and Methods

2.1 Study sites

Four natural forest sites, located in the Amhara Regional State of Ethiopia (Figure 1), are used for our study. They are located in wider altitudinal (from 2487m 10 863m a.s.l) and longitudinal (from 11^0 to 13^0 N) gradients representing forests found in different Ethiopian agroecology. All study sites (Metema,Gelawdiwos and Taragedam) but Injibara are owned by Ethiopian Orthodox Tewahedo Church.

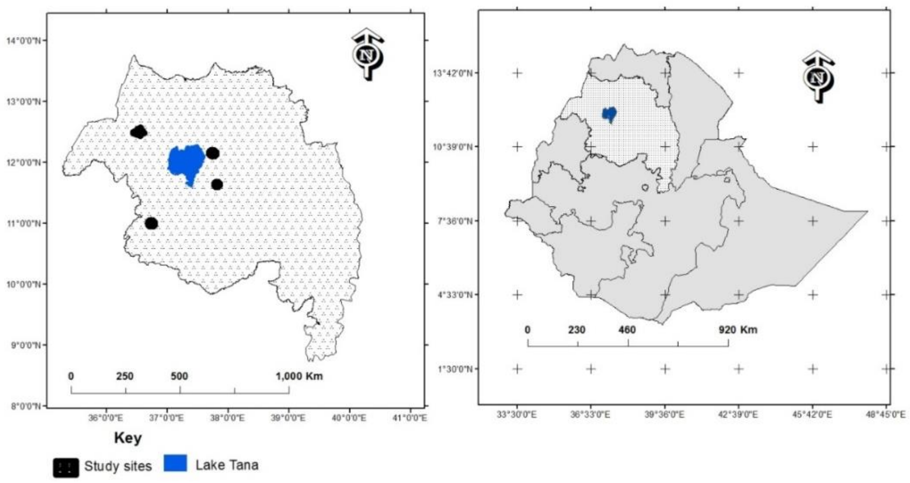

Fig 1. Study sites in Ahmara Region

2.2 Methods

The Biome-BGC (Running & Coughlan 1988) which includes self-initialization (Pietsch & Hasenauer 2006) was used for this study. The model uses daily climate data (daily minimum and maximum temperature and precipitation), soil physical property (effective soil depth, soil texture and aspect), pre-industrial and industrial nitrogen deposition, and EBF ecophysiological parameters to initiate the simulation. Thirty-two years (1979–2010) daily climate data were collected in Ethiopian meteorological stations. Model predicted above - and belowground forest carbon and net primary productivity were calibrated with inventory data collected in 156 sample plots in four study sites.

Given the tree diameter at breast height (1.3m) and height, tree biomass was estimated using allometric equation presented by Chave et al. (2005).

$TAGB = \exp(-2.922 + 0.99.\log(DBH^2.H.\varrho))$

Where TAGB is the total above ground biomass in kg/tree; DBH is the diameter at breast height in centimeter; H is the tree height in meter and ϱ = 0.614 is the wood density in g/cm^3 or ton/m3 or Mg/m3.The carbon stock for each tree derived from its biomass with a constant fraction of 0.5 because carbon accounts approximately half of the oven dried biomass (Kajimoto et al. 1999; Lamlom & Savidge 2003).

We run the model using the default tropical EBF ecophysiological parameter for each study forest to predict the above-and belowground carbon and total NPP. Thinning management intervention was used for each study forest according to variations of the stand density index (Gelawdiwos, 3%; Injibara, 6%; Metema 9% and Taragedam, 12%) to calibrate the model results.

3. Results and Discussion

The total aboveground carbon recorded in the study sites ranged from 13.04 ton/ha to 60.42 ton/ha. The mean annual carbon increment of the two study sites (Gelawdiwos 2.11 ton $ha^{-1}yr^{-1}$ and Injibara 1.80 ton $ha^{-1}yr^{-1}$) are within a range of some moist tropical forest growth rates (2.54 ton $ha^{-1}yr^{-1}$in Agro-Forests ; 2.79 ton $ha^{-1}yr^{-1}$ in Managed Forests ; 2.85 ton $ha^{-1}yr^{-1}$ in National Park) (Djomo et al. 2010). However, the two study sites (Metema 0.53 ton $ha^{-1}yr^{-}$ and Taragedam, 0.77 ton $ha^{-1}yr^{-}$) have showed very low annual carbon increment which implied a serious human disturbance or biomass extraction.

The simulated results using the default EBF have depicted higher predictive aboveground carbon stocks than the field inventory carbon stocks (Fig.2 A). Because Biome–BGC simulation accounts fully-stocked old aged virgin forests. As a result the simulated aboveground stock exhibited higher carbon stock than live forest carbon in suggesting strong human management impacts on the study sites. Hence, Biome–BGC was calibrated through EBF parametrization and management/thinning intervention to mimic our current disturbed forest´s carbon stock (Fig.2.B). However, no significant difference has been seen between simulated and observed soil carbon and net primary productivity.

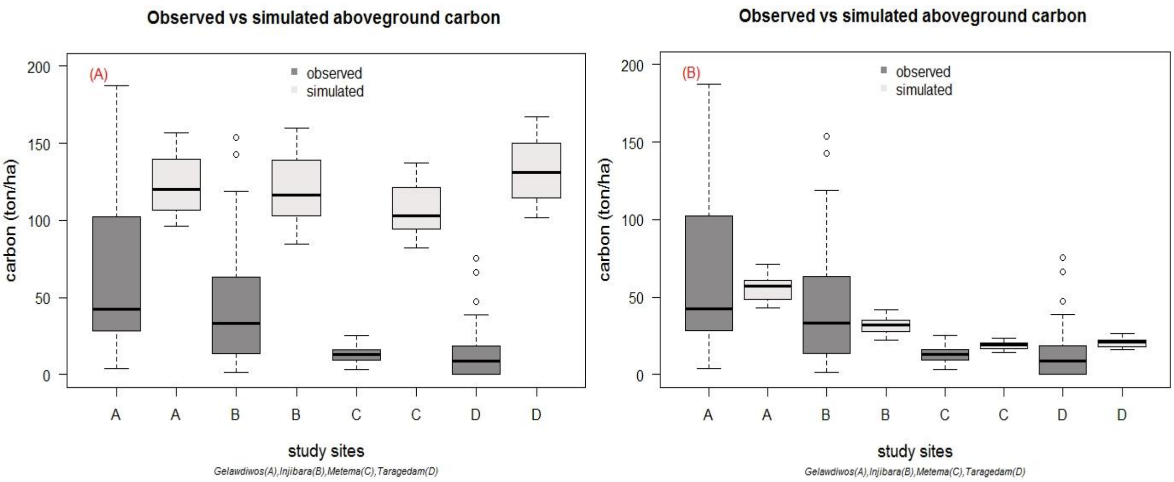

Fig.2: Observed vs BGC-simulated aboveground carbon without (left) and with (right) human intervention

4. Conclusions and Outlook

The whole study sites showed low forest carbon stock which shows high human interference and biomass extraction. The default tropical EBF is less applicable for aboveground carbon stock estimation. With, simple human disturbance intervention it depicts our disturbed forest´s carbon stock and NPP. Once we set the ecophysiological parameter for Ethiopian forest ecosystems based on our studied sites, the next work will be simulating the BGC-model for the whole Amhara region forest carbon stock estimationFurther, studies on developing agro ecological based ecophysiological parameters should be done because Ethiopia has highly diversified forest ecosystem.

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