Rethinking global carbon storage potential of trees. A comment on Bastin et. al 2019

Shawn D. Taylor[1] *(corresponding author), shawntaylor@weecology.org*
Sergio Marconi[1]

[1] School of Natural Resources and Environment, University of Florida Gainesville, FL, United States

Abstract

In calculating the potential carbon storage potential stemming from global tree restoration Bastin et al. 2019 use two flawed assumptions: 1) that a hectare of additional canopy is equivalent to gaining the full potential of a hectare in carbon stock, and 2) that soil organic carbon (SOC) from increased canopy cover will accumulate quickly enough to mitigate anthropogenic carbon emissions. We use global datasets of tree cover, soil organic carbon, and above ground biomass to estimate the empirical relationships of tree cover and carbon stock storage. A more realistic range is between 71.7 and 75.7 GtC globally, with a large uncertainty associated with SOC. This is less than half of the original 205 GtC estimate, and just around twice the annual anthropogenic emissions globally. While we agree on the value of assessing global reforestation potential, we suggest caution in considering it the most effective strategy to mitigate anthropogenic emissions.

Main

Bastin et al. (2019) (hereafter referred to as Bastin 2019) use a novel machine learning based method to model global tree canopy cover potential. After accounting for current tree canopy cover and areas already occupied by urban and agricultural land they estimate 900 Mha of potential tree canopy cover available worldwide for reforestation. Using biome specific estimates of Tonnes C/ha they calculate the global carbon storage potential of this 900 Mha of tree canopy cover. The Tonnes/C ha-1 values for each biome are derived from average estimates of total carbon storage from two studies of forest (Pan et al. 2011) and tropical grassland (Grace et al. 2006) carbon stock. Thus from their calculation a hectare of restored tree canopy is equivalent to adding a full hectare of carbon stock potential regardless of the vegetation already in place, and results in an overestimate of the global carbon stock potential of restored trees.

To better estimate the relationship between total carbon stock density and tree cover we randomly sampled locations from four global datasets of 1) above ground biomass (Woods Hole Research Center 2019), 2) soil organic carbon (SOC) to 1-meter (Hengl et al. 2017), 3) percent tree cover (Hansen et al. 2013), and 4) the corresponding biome (Olson et al. 2001). We further subset these locations to those within protected areas (Levels I-V, UNEP-WCMC and IUCN (2019)) to minimize the influence of development and better represent the full carbon storage potential. Across all biomes there is already ample carbon stock at all levels of tree cover, and the relationship is weak in several biomes due to the contribution of SOC (Figure 1). The slope of this relationship is a more accurate representation of the potential carbon stock gained with tree cover. For example in Tropical Grasslands Bastin 2019 estimate that an additional 0.5 ha of canopy cover (an additional 50% canopy cover) will add 141.25 Tonnes C. The empirical relationship shows an additional 50% tree cover in this biome means an additional 25.6 Tonnes C/Ha on average. Further, the Boreal Forest and Tundra biomes have a negative relationship between carbon stock and tree canopy cover, potentially resulting in a net carbon source if tree canopy cover was added in these biomes. Applying the updated estimates across all 14 biomes results in 28.4 GtC of potential carbon stock if the additional 900 Mha of global tree canopy potential was realized, and 71.7 GtC if the negative contribution from Boreal and Tundra biomes are removed.

This calculation is further complicated by SOC. SOC makes up the majority of carbon stock in all biomes, and in 7 biomes has no relationship with tree cover ($p > 0.05$, see Supplemental Figure S1). In boreal regions (the biome for 19.8% of the potential canopy area estimated by Bastin 2019) afforestation can cause a temporary increase of greenhouse gas emissions due to quicker SOC mineralization, which can take several decades to recover (Karhu et al. 2011). SOC also forms at rates of less than 0.5 Mg/Ha-1/year-1 in many areas (Trumbore and Harden 1997, Gaudinski et al. 2000, Lichter et al. 2008, but see Shi and Han (2014)) and it is potentially unreasonable to assume increased tree cover would lead to SOC accumulation at a rate quick enough to effectively mitigate carbon emissions (He et al. 2016). To explore the potential carbon storage of increased global tree cover without considering the complexities of SOC we adjusted all estimates by removing the contribution of SOC. For the Bastin 2019 estimates we re-calculated the carbon stock potential minus the SOC fraction using the original sources (Grace et al. 2006, Pan et al. 2011). For our own estimates we considered only above ground carbon and it’s slope with respect to tree cover. With these estimates the global carbon storage potential is 104 GtC using the re-calculated estimates from Bastin 2019, and 75.7 GtC using the empirical relationships from the global datasets.

Bastin 2019 state that global tree restoration is “the most effective solution” for mitigating climate change. This conclusion uses simple assumptions which ignore complex carbon dynamics, potential feedback loops, societal costs, and carbon saturation as forests mature (see de Coninck et al. (2018) sec. 4.3.7.2 and references therein). For example afforestation and reforestation is considered a feasible climate mitigation solution only in the tropics since it would reduce albedo in high latitudes (Fuss et al. 2018). Yet, increasing forested areas in the tropics would compete for agriculture and other land use, triggering a number of socio-economic impacts (Fuss et al. 2018). It is also difficult to place the 205 GtC estimate in the context of other mitigation options without a quantitative estimate of the timescale of forest regrowth. Though future studies using more nuanced analysis of carbon uptake could address this (Requena Suarez et al. 2019). Regardless, we show that with more precise estimates using the empirical relationship between tree canopy cover and carbon storage, the global carbon stock potential of restored forests is likely between 71.7 - 75.7 GtC, less than 40% of the original estimate.

		Including Soil Organic Carbon				Without Soil Organic Carbon			
		Tonnes C/ha increase with 1 Ha canopy		Total C Stock potential (GtC)		Tonnes C/ha increase with 1 Ha canopy		Total C Stock potential (GtC)	
Biome	**Potential Tree Cover (Mha)**	**Bastin 2019**	**Current Study**	**Bastin 2019**	**Current Study**	**Bastin 2019**	**Current Study**	**Bastin 2019**	**Current Study**
Boreal Forests/Taiga	178	239.2	-240.4	42.6	-42.8	86.1	45.3	15.3	8.1
Deserts & Xeric Shrublands	77.6	202.4	109.2	15.7	8.5	28.5	76.9	2.2	6
Flooded Grasslands & Savannas	9	202.5	375.7	1.8	3.4	28.6	63.7	0.3	0.6
Mangroves	2.6	282.5	190.5	0.7	0.5	198.9	105.9	0.5	0.3
Mediterranean Forests, Woodlands & Scrub	18.8	202.4	154.6	3.8	2.9	28.5	85.2	0.5	1.6
Montane Grasslands & Shrublands	19.3	202.4	136.9	3.9	2.6	28.5	120.1	0.6	2.3
Temperate Broadleaf & Mixed Forests	109	154.7	1.7	16.9	0.2	80.4	81	8.8	8.8
Temperate Conifer Forests	35.9	154.7	106.6	5.6	3.8	80.4	108.6	2.9	3.9
Temperate Grasslands, Savannas & Shrublands	72.5	154.7	51.1	11.2	3.7	80.4	67.4	5.8	4.9
Tropical Coniferous Forests	7.1	282.5	144.4	2	1	198.9	97.9	1.4	0.7
Tropical Dry Broadleaf Forests	32.8	282.5	171.4	9.3	5.6	198.9	101.8	6.5	3.3
Tropical Grasslands, Savannas & Shrublands	189.5	282.5	137.3	53.5	26	198.9	98	37.7	18.6
Tropical Moist Broadleaf Forests	97.1	282.5	139.5	27.4	13.5	198.9	150.3	19.3	14.6
Tundra	50.6	202.4	-9.9	10.2	-0.5	28.5	38.6	1.4	2
Total				204.6	28.4(71.7[1])			103.2	75.7

Table 1: Estimates of the Tonnes C/ha relationship and per biome estimate of total carbon storage potential using the original estimates from Bastin 2019, estimates derived using global datasets in the current study, and all estimates adjusted to exclude soil organic carbon. The biome specific potential tree canopy cover is from Bastin 2019 Table S2. [1] 71.7 GtC is the global potential is calculated without considering Boreal Forests or Tundra, as these biomes have a negative relationship between total carbon stock and tree canopy cover.

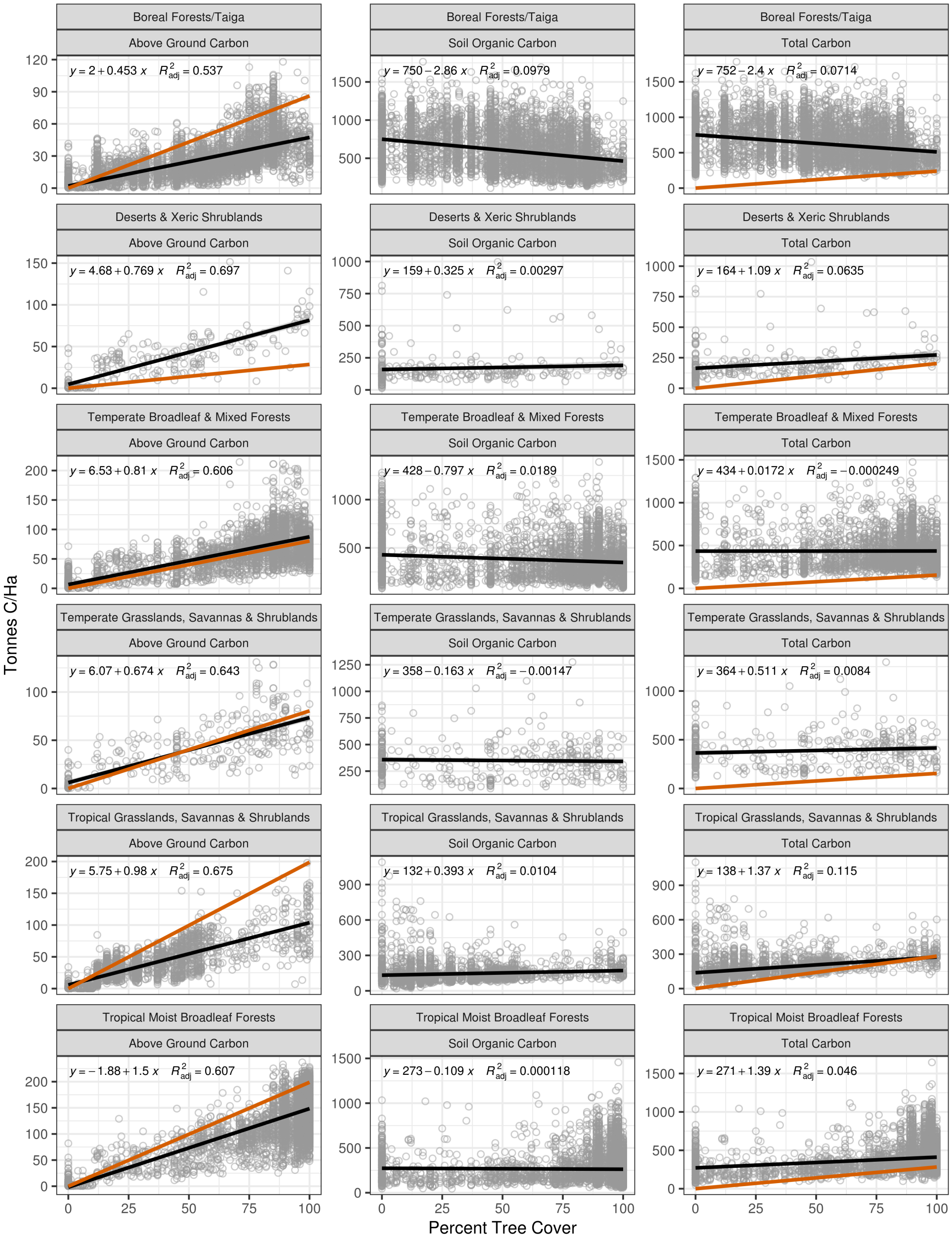

Figure 1: The relationship between carbon stock and tree cover for 6 of the 14 global biomes using global datasets (black regression line and grey points). The red lines for Total Carbon indicate the assumed increase in Tonnes of C/Ha for every increase in tree cover in the original analysis, while the red lines in Above Ground Carbon represents the original estimates minus the fraction of soil organic carbon. The global datasets were randomly sampled for land points within protected areas globally and querying the above ground biomass, 1-meter soil organic carbon, percent tree cover, and the corresponding biome. Above ground biomass was converted to carbon stock by multiplying by 0.5. Total carbon is above ground carbon plus soil organic carbon for each queried point. Note the difference in scales of the y-axis. See Figure S1 for relationships of all 14 biomes.

Supplemental Material

All code and extracted data is archived on Zenodo (https://doi.org/10.5281/zenodo.3364028). Supplemental Figure S1, carbon stock relationships for all 14 biomes, is available on the online version.

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