Assesment of Carbon Storage for a Conversion Landscape from Forest to Coffee Garden in Gayo Plateau to Mitigate Climate Change

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Abstract: According to CO_2 emission mitigation through REDD scheme, valuing of carbon (C) storage for landscape conversion from forest to coffee in Gayo plateau is important to assess. Vegetation analyses and allometry equation were used to estimate C stock of forest and several ages of coffee plantations and natural forests at Gayo plateau, Aceh. Primary forests contained aboveground C stock higher than secondary forests and coffee plantation both mono-and-poly-culture of shading-tree. The highest value of aboveground C stock was found at tropical broadleaf forests (213.05 ton C/ha or 781.91 ton CO_2e/ha), followed by primary pine forests (160.54 ton C/ha, 589.18 ton CO_2e/ha) and secondary broad leaf forests (104.82 ton C/ha, 384.70 ton CO_2e/ha). Coffee plantations with a poly-culture of shading-tree system have good ability to conserve carbon. The highest value of aboveground C stock of coffee plantation was 70.97 ton C/ha or 260.47 ton CO_2e/ha. The result suggests that to increase C stock of coffee plantation, the selection of shading-tree species is one of important key. The shading-tree of *Persea americana*, *Artocarpus heterophyllus* and *Citrus* sp. have good ability in carbon fixation, while the species also could produce commercial fruits besides coffee bean production.

1 INTRODUCTION

Changes in carbon storage in terrestrial ecosystems as result of human land use and activities have become concern for combating the issues of climate change. Climate change has threatened life on earth, as well known it disturbs the environmental and ecosystem services, patterns of rainfall and seasons as well as all living things. Thus, the world is in a hazardous period. To date, reducing emissions from forest loss and degradations as well as preserving virgin and undisturbed forests will be important key for future actions in mitigating climate change. It means forests become a problem due to forest destruction and loss. On the other hand, forests become a solution for climate change if forests are protected from degradations and human disturbances.

Globally, forest degradation and loss contributed for 1/5 to 1/4 (Allen et al., 2010, Myers, 2007, Santili et al., 2005) of total CO_2 emission annually and are to be one important factors of climate changes as well as global warming. Almost 96% of the emissions from forest loss are coming from tropical developing countries. Some the main activities that are caused by humans are driving forest loss and degradation, including weak land use policies and applications, unsecure property rights, inadequate legislation, commercial farming and logging, and limited capacity to protect and preserving the forests. It also produced seriously impacts of environmental and socio-economic; most of them are disproportionately affected by the poor.

Avoided forest loss activities in mitigating climate change are a competitive, low-cost reduction options. A program of 10% abatement in forest loss in period of 2005 - 2030 could provide 0.3–0.6 Gt $CO_2 \cdot yr^{-1}$ in abatement of emission and a half abatement in forest loss from 2005 to 2030 could provide 1.5–2.7 Gt $CO_2 \cdot yr^{-1}$ in emission abatements (Kindermann et al., 2008). On the other hand, forest conversions in Sumatra are usual to meet international demand for global consumer products. Subsequently, it drives forest loss as well as various social and ecological impacts. As a consequence, farming is greatly relied to be one of the main causes of deforestation. All over the globe, forests are providing way to crops for spices, coffee, oil palm and others. As a study case, forest of Bukit Barisan National Park in Lampung Province in period of

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1972-2006 was loss of 21% (Philpott et al., 2008, Gaveau et al., 2009). Almost of forest conversion (80%) caused by farming development. In the national park, the forest loss agents are farmers who are estimated as many as 15,000 farmers who are currently planting coffee. One of the direct causes is the price of coffee; and the principal causes are conditions of socio-economic and law enforcement. Farmers prefer to grow coffee rather than work elsewhere because rural labor is poorly paid (circa $2 a day). Higher local coffee prices conjoined with cheap labor cost, rather than price of coffee, is the synergistic fundamental cause of forest loss in Indonesia's main coffee production.

A well know Gayo plateau, Aceh is one of the popular producer of the agroforest-based organic coffee, called Gayo coffee for a long time. Gayo refers to one of Acehnese ethnic group that they live on Gayo highlands, spread at three district of Aceh province, i.e. Gayo Luwes District, Bener Meriah District and Central Aceh District, that is situated at northern part of Bukit Barisan Mountains in Sumatra. The Arabica coffee crops situated in contiguous areas of high-storage of forest carbon and high-rich biodiversity of Ulu Masen and Leuser Forest Ecosystems in northern tip of Sumatra. Initially, coffee plantations in the plateau mostly converted virgin forests to coffee garden through slash and burn method in land clearing. Therefore, the objectives of this research were to assess the carbon storage of coffee garden in the study area based on various coffee cultures as well as the carbon storage of virgin and disturbed forests around the coffee plantation in Gayo plateau, and to search opportunities of coffee agroforest system for abatement emission from forest loss.

2 MATERIAL AND METHOD

2.1 Study Site

The fieldwork was carried out at Gayo plateau, Aceh province, distributed at two district, namely Central Aceh and Bener Meriah. The land-use types are natural forests both primary and secondary, and agroforest coffee gardens both monoculture-and-polyculture of shading-tree. There are two forest types at the area, i.e. tropical pine forests and mixed tropical forests (or tropical broadleaf forests). Subsequently, *Pinus merkusii* dominated tropical pine forests in surrounding area. The site elevation ranges from 900 to 1,600 m asl.

2.2 Method

Twenty-four 0.2 ha sample plots were established in coffee garden (12 sampling plots) and natural forests (12 sampling plots). Hairiyah et al. (2001) and IPCC (2006) were used in collecting biomass data collections. All living trees with a stems diameter over 10 cm (big trees) and from 5 to 10 cm (small trees) were measured the stem diameter at breast height (DBH) and the plant species were identified in standard sample plot (20m x 100m) and small sample plot or sub-plots (5m x 40m), respectively. Specimen of each tree species in the sampling plots was collected to identify in herbarium. For the coffee garden, stand age, both coffee plant and shading-tree are based on information from the garden owner.

Tree biomass (W, dry weight) was estimated using the allometry equation of Solichin et al. (2017) for the tropical mixed forests. Allometry equation of Heriyanto et al. (2002) was used to estimate the aboveground of natural pine (Pinus merkusii) forests. For agroforestry plant, such coffee and banana, separate allometric equations from Hairiyah et al. (2001) was used. Total carbon content was calculated from dry weight assuming a carbon content (per unit biomass) of 0.5 (Delaney and Roshetko, 1999.

Undergrowth plants and litters were harvested in 3 units of 1m x 1m sub-plot in each sampling plot and weighted in the field for completely fresh weight. Samples were transported to Research Laboratory of Agriculture Laboratory, Universitas Sumatera Utara. Each sample was dried using a constant temperature oven. Drying took 2 days (85ºC) for leaves and woody biomass under 10 cm diameter, and 4 days (85ºC) for woody biomass over 10 cm of diameter. After measuring dry weight of each sample, completely dry weight (D_w) was calculated based on Heriyanto et al. (2002) Subsequently, organic carbon content of undergrowth plants and litters were analyzed by using the Wakley and Black method (Sulaeman et al., 2005).

3 RESULT AND DISCUSSION

3.1 Composition and Stand Structure

Overall, 64 species were randomly distributed in all sites. Tropical broad leaf forests were recorded as richness with 49 tree species where they were distributed in both primary forests (32 species) and secondary forests (28 species). On the other hand, only one species of tree larger than 5 cm DBH, namely *Pinus merkusii* was found in tropical pine forests both secondary and primary pine forests.

For coffee crop, there were 14 species of shading-tree, which were distributed from one to nine species in each site. All of shading-tree species was different compared than natural forests. The species of *Leucaena leucocephala* was found in all coffee gardens as shading-tree. The local community informed that the species is used to be very popular as shading-tree of coffee garden (distribution [F] 100%). Tropical forest has rich biodiversity (Slik et al. 2015) both plant and animal. As implication, the conversion of tropical broadly forests to coffee garden caused declining tree diversity

Practically, there were two system of shading-tree of coffee garden, i.e. mono-and-polyculture shading-tree. The species of *L. leucocephala* is always used as one of them as shading-tree of coffee garden. Some tree species, such as *Citrus* sp. (F 83.3%), *Persea americana* (F 50.0%) and *Artocarpus heterophyllus* (F 50.0%) were common used as shading-tree which planted together *L. leucocephala*, called polyculture of shading-tree. Gayo plateau is also known as producer of lemon fruit from *Citrus* sp. tree, and avocado fruits from *P. americana* tree. The polyculture system could increase the products as well as income of the farmers from the produced-fruits.

Density and basal area of trees were increase from secondary forests to primary forests both broad leaf forests and pine forests in study site. Mean density of trees larger than 5 cm DBH in all forest types were range from 349 to 805 stem/ha. The highest density of trees was found in primary broad leaf forests (805 stem/ha) and the lower ~~of~~ density of trees was distributed in secondary pine forests (349 stem/ha). Most part of basal area value in tropical broad leaf forests was contributed by big trees with DBH larger than 100 cm which mean density was 10 stem/ha. Basal area of secondary broad leaf forests and secondary pine forests were only 57.8% and 37.7% of primary broad leaf forests and primary pine forests, respectively. The highest basal area was also found in primary broad leaf forest (35.69 m^2/ha), with a standard deviation of 0.03 and the lower basal was found in secondary pine forests (12.95 m^2/ha).

Density of coffee plant and shading-tree of the coffee garden varied, ranging from 2,100 to 6,000 stem/ha, with an average of 3,367 stem/ha. Subsequently, the shading-tree density ranges from 125 to 1,650 stem/ha, with an average of 580 stem/ha. Therefore, average density of coffee plant: shading-tree ratio was 85:15. Based on the data, some of shading-tree density was larger than density of primary pine forests and secondary forests.

3.2 Biomass and Carbon Stock

Primary forests contained aboveground biomass higher than secondary forests and coffee garden both mono-and-poly-culture of shading-tree. Figure 1 shows the mean of aboveground biomass, carbon stock and carbon dioxide equivalent (CO_2e) at natural forests, both primary and secondary forests. The highest aboveground biomass, C stock and CO_2e were recorded at tropical broad leaf forests, followed by primary pine forests, secondary broad leaf forests, and secondary pine forests. The biomass of understory and litter was only less than 2% of total of aboveground biomass.

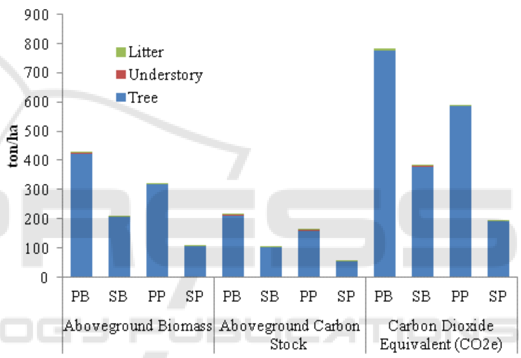

Figure 1: Mean of aboveground biomass, carbon stock and carbon dioxide equivalent (CO_2e) of natural forests at study sites; (PB = primary broad leaf forests; SB = secondary broad leaf forests; PP = primary pine forests; SP = secondary pine forests).

The aboveground biomass of primary forests both broad leaf forests and pine forests at this study site was lower than primary rain forest at Batangtoru, North Sumatra (ranging from 551.8 to 623.0 ton/ha) (Onrizal et al., 2008). While the aboveground biomass of primary broad leaf forests at this study site was higher than Amazon forests, with ranging from 356.2 to 376.6 ton/ha (Fearnside et al., 1999, Nascimento and Laurance, 2002) and similar with tropical Asia (Slik et al., 2013), but the aboveground biomass of primary pine forests at study site was lower than Amazon forests, relatively.

The aboveground biomass of coffee gardens were depend on the density and age of coffee plant as well as density, age and culture system of shading-tree. However, the aboveground biomass of coffee plants mostly increased from lower stand age into upper stand age. The highest value of aboveground biomass of coffee garden was found at 14 years-old–coffee crop, i.e. 142.91 ton/ha or equivalent to 70.97 ton C/ha and 260,47 ton CO_2e/ha. The biomass of coffee plant : shading-tree ratio at 14 years-old of coffee crop was 11 : 89. Subsequently, the age of shading-tree at the sample plot is mixed age (or uneven age), with stand age of the shading-tree is up to 60 years-old with polyculture system of shading-tree. The shading-tree of *P. americana* and *A. heterophyllus* only composed 11.9% of total density of shading-tree at the plot, but the contribution reached 67.3% of aboveground biomass within the sample plot of 14 years-old of coffee crop. The contribution of *P. americana* and *A. heterophyllus* was larger than the main species of shading-tree, i.e. *L. leucocephala* (9.6% of aboveground biomass), however, it composed 54.9% of total density of shading-tree.

The second higher value of aboveground biomass of coffee garden was placed at 28 years-old coffee crop and 30 years-old shading trees. The aboveground biomass of the crop was 132.12 ton/ha or equivalent to 65.80 ton C/ha and 241.50 ton CO_2e/ha which biomass ratio of coffee plant : shading-tree is 36 : 64.

The third higher value of aboveground biomass of coffee garden was found at the stand age of coffee plant and shading-tree were 10 years-old and up to 30 years-old, repectively. The aboveground biomass at the sample plot C09 was 128.78 ton/ha or equivalent to 64.14 ton C/ha and 235.40 ton CO_2e/ha which biomass ratio of coffee plant : shading-tree is 16 : 84. It should be noted that the aboveground biomass at top three of coffee garden is hinger than secondary broad leaf forests and secondary pine forests around the area.

Based on this study result, the annual C stock increments of coffee plant was average of 0.87 ton C/ha/year, with a standard deviation 0.21. The annual C stock increments of shading-tree were average of 0.92 ton C/ha/year, with a standart deviation of 0.48. Totally, the annual C stock increments of existed coffee garden at the study site was average of 1.72 ton C/ha/years, with a standard deviation of 0.41. On the other hand, the contribution of understory, stump and litter on total of aboveground biomass of the existed coffee garden was only 9.7%, with a standard deviation of 7.6. The understrory, stump and litter contribution on aboveground biomass was an average of 7.5 ton/ha, with a standard deviation of 5.1.

Generally, the biomass ratio of the existed coffee plant : shading-tree was 37 : 63, with a standard deviation of 24. The biomass ratio of coffee plant : shading-tree was opposited on the composition of coffee garden which the ratio of average density between coffee plant : shading-tree is 85 : 15. The data means that the ability of shading-tree on carbon fixation and carbon stock is larger than coffee plant. The result also confirmed that the biomass of polyculture shading-tree is larger than monoculture shading-tree with main species is *L. leucocephala*. Therefore, selection of shading-tree species is a key on carbon mitigation in order to coffee garden.

In Latin America, coffee agroforests have counted a 5-year-old shaded-coffee garden with two common tree species could take up 5.3 ton ha^{-1}. Subsequently, above ground C stocks of coffee gardens with plain shade at Costa Rica are counted around 11 ton per ha (Oelbermann et al., 2004). The ability of coffee agroforest to maintain carbon storability can reach 100 tons/ha and the ability can still be improved if the shading plant is more varied tree species (Hairiah, 2010).

The capacity of coffee crop of Gayo plateau in storing C is similar to previous studies in others tropical areas that the potential C sequestration rates for smallholder, sustainable agroforest systems range between 1.5 to 3.5 ton C/ha/year, or 2.1 billion ton/year globally. An estimation of each hectare of sustainable tropical agroforest could potentially equal of 5 to 20 ha of forest loss (Cacho et al., 2003, Hergoualc'h et al., 2012).

4 CONCLUSIONS

Tree-based land-use systems, such as the shade-grown coffee agro ecosystems particularly in polyculture of shading-tress in Gayo plateau could sequester CO_2 from the air and store it in their biomass. Based on this study, the annual C stock increments of coffee garden was an average of 1.72 ton C/ha/years, with a standard deviation of 0.41. Simultaneously, these coffee agro-ecosystems provide additional services and products to local residents and reduce pressure on existing forests. Therefore, increasing of tree in coffee crops should be a suitable option for climate change mitigation that also provides ecological, economic and social benefits.

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