CARBON STOCK ASSESSMENT FOR A FOREST-TO-COFFEE CONVERSION LANDSCAPE IN KALIKONTO WATERSHED (EAST JAVA, INDONESIA): Scaling up from plot to landscape level

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Summary

The impacts on net sequestration of CO_2 or net release to the atmosphere of CO_2, of a change in land use from natural forest to tree-based agricultural system can be rapidly estimated by measuring the carbon (C) stocks of both land use systems in a Rapid Carbon Stock Appraisal (RACSA). Aim of this study was to assess the aboveground C stocks at landscape level for the Kalikonto sub-watershed (Malang regency, East Java), using land use maps of 1990 and 2005. During that period remaining natural forest was reduced by 2.6% per year and by 33% on aggregate, while the total area of annual crop and of settlements increased by 2.5%/year (aggregate 45%) and 1.1%/year (aggregate 18%), respectively. The area of tree plantations and agroforestry were reduced about 0.6%/year (aggregate 10%). Plot-level measurements of aboveground C stock in June –December 2008 covered the eight land use systems (LUS) most commonly found in the study area: 1) remnant natural forest, 2) bamboo forest, 3-5) 3 types of plantation i.e. pine (*Pinus merkusii*), mahogany (*Swietenia mahogany*) and dammar (*Agathis dammara)*; 6) multistrata shaded coffee with fruit and timber trees, as well as nitrogen-fixing shade trees; 7) simple shade coffee (using *Gliricidia sepium* as shade tree); and, 8) annual cropping systems (vegetable and food crops). The natural forest in Kalikonto area has been severely disturbed as shown by a low aboveground C stock of about 136 Mg ha^{-1}. Aboveground C stock in coffee-based agroforestry systems was lower, at about 44 Mg C ha^{-1}. The time averaged C stock of tree plantations (pinus, mahogany, and damar mostly aged 25-40 years) was estimated to be 85 Mg C ha^{-1}. The estimated time averaged-C stock (above-ground) in annual crops was only 2 Mg ha^{-1}. Extrapolation of C stock at plot level to watershed level were done by multiplying the area of each land cover with its time-averaged aboveground C stock. Within 15 years, C lost for the whole watershed (23810 ha) was estimated to be 27750 Mg yr^{-1} or equivalent to a yearly C loss of 1.17 Mg ha^{-1}. Carbon lost from natural forest was about 0.92 Mg ha^{-1} yr^{-1}, tree plantations lost 0.15 Mg ha^{-1} yr^{-1}. Carbon lost from coffee-based agroforestry systems was relatively small, about 0.03 Mg ha^{-1} yr^{-1}. Planting more diverse shade trees in coffee-based agroforestry system may increase the role of coffee gardens in net C sequestration at the landscape scale.

Introduction

Photosynthesis by all plants growing inside or outside forest implies sequestration of CO_2 from the atmosphere, but night-time respiration releases part of this to the atmosphere and the residence time for C storage in terrestrial vegetation and soil is greater for trees than for non-woody plants. Carbon is released back to the atmosphere by burning and decomposition [6].

Improving carbon stock in landscape can be achieved by moving from lower-biomass land use systems such as annual crops and grasslands to tree-based systems [10]. Agroforestry systems including shaded coffee systems can effectively sequester carbon at levels above those for open (monoculture) coffee systems. A study in Togo found that carbon stocks of shade coffee system (coffee- *Albizia*) were nearly four times those of open coffee system (81 versus 23 Mg ha^{-1}, respectively) [2]. A study in West Lampung (Indonesia) found much lower aboveground carbon stocks in the local multistrata coffee system (shaded coffee with fruit and timber trees, as well as nitrogen-fixing shade trees), of 34 Mg ha^{-1}, compared to 23 Mg ha^{-1} in simple shaded coffee system (mainly *Gliricidia* as shade trees) and only 7 Mg ha^{-1} in open coffee system [16]. Under natural forest, the average C stock in the Lamoung case was estimated at 195 Mg ha^{-1}. The difference between these studies suggest that more data is needed to assess the potential of coffee-based agroforestry system as contributors to carbon sequestration at landscape level. Coffee has a long history of use on Java and remains an important source of income in densely populated Java. Aim of this study therefore was to estimate the changes of carbon stock at landscape level after forest conversion to coffee-based agroforestry system and various competing types of land use systems in the Kali Konto area of E. Java, using a Rapid Carbon Stock Appraisal protocol (RACSA).

Materials and methods

Measurements of aboveground C stock at plot level were made in June –December 2008 in the up-stream parts of the Kalikonto sub-watershed in Ngantang and Pujon sub-districts (East Java, Indonesia) covering a range of land use system (LUS). The eight LUS most commonly found in the study area were : 1) remnant natural forest, 2) bamboo forest, 3-5) 3 types of plantation i.e. pine (*Pinus merkusii*), mahogany (*Swietenia mahogany*) and dammar (*Agathis dammara)*; 6) multistrata shaded coffee with fruit and timber trees, as well as nitrogen-fixing shade trees; 7) simple shade coffee (using *Gliricidia sepium* as shade tree); and, 8) annual cropping systems (vegetable and food crops). Tree diversity varies among agricultural system. About two-thirds of the trees in multistrata-shaded coffee agroforestry were timber trees (mahogany, *Paraserianthes* or *Maesopsis*), 36% were fruit trees (mostly durian, avocado, lansium, rambutan, jackfruit). Shorter-lived non-woody species such as banana and papaya were common as well. Species composition among trees in simple shade coffee agroforestry systems was similar. In the timber plantation system (pine, mahogany and agathis), other plants species were also found such as coffee, durian *Gliricidia*, papaya and banana although at low density (below 20% of total number of trees).

Landsat images for 1990 and 2005 were interpreted according to a detailed classification legend and compared at post classification stage [18]. Plot-level carbon stock measurements followed the RaCSA (Rapid Carbon Stock Appraisal) protocol of ICRAF [5] which is similar to the Winrock methodology [8]. Four carbon pools were assessed: above- and below ground biomass of trees and understorey vegetation, necromass and soil organic matter. All trees were measured in plots of 40 x 5 m^2, with unbderstorey and soil samples nested within the plot. Trees with a diameter greater than 30 cm diameter were sampled in plots of 20 * 100 m^2. Tree diameter at breast height (dbh) was used as basis for allometric biomass equations [11] [4] as shown in Table 1. A default assumptions of a 4:1 shoot:root ratio was used [9] to estimate root biomass. Biomass and necromass data were converted to C by assuming a plant C content of 0.46 [4].

Table 1. Allometric regressions for estimating tree biomass of common trees grown in agroforestry and plantation system

Tree species	Equations	Source
Branched tree	$Y = 0.11\ \rho\ D^{2.62}$	[7]
Pruned coffee	$Y = 0.281\ D^{2.06}$	[1]
Banana	$Y = 0.030\ D^{2.13}$	[1]
Bamboo	$Y = 0.131\ D^{2.28}$	[12]
Paraserianthes falcataria	$Y = 0.0272\ D^{2.831}$	[13]
Pinus merkusii	$Y = 0.0417\ D^{2.6576}$	[19]

Note: Y = aboveground biomass, kg/tree; D = dbh= tree diameter, cm; H = tree height, cm; ρ = wood density, g m^{-3} can be accessed at: http://www.worldagroforestry.org/sea/Products/AFDbases/AF/index.asp

Understorey vegetation was sampled destructively in ten 0.25 m^2 quadrat samples; total fresh weight was measured and subsamples were collected for determining dry matter content. Diameter and length of dead wood was measured within sampling plot and converted to volume on the basis of a cylindrical form; three apparent density classes were used for stagtes of decomposition. Surface litter (including wood < 5 cm diameter) of each land use was measured by taking litter samples down to the surface of the mineral soil in ten 0.25 m^2 samples and sub samples were taken for dry matter content. Soil samples were collected (composite from 10 sample points) for the 0-5, 5-10, 10-20 cm depth zone below the litter layer, for analysis of texture (sand, silt, clay), pH (1N KCl), pH(H_2O), C_{org} (Walkey and Black), N_{tot} (Kjeldahl).

For estimation of carbon stock at landscape level, the time-averaged C stock of tree-based system was derived from the life cycle of the system [17]. Net CO_2 emissions was estimated by combining the vector of time-averaged C stocks for all land use classes used with the matrix of land cover change [18][5], and converting from C to CO_2 units.

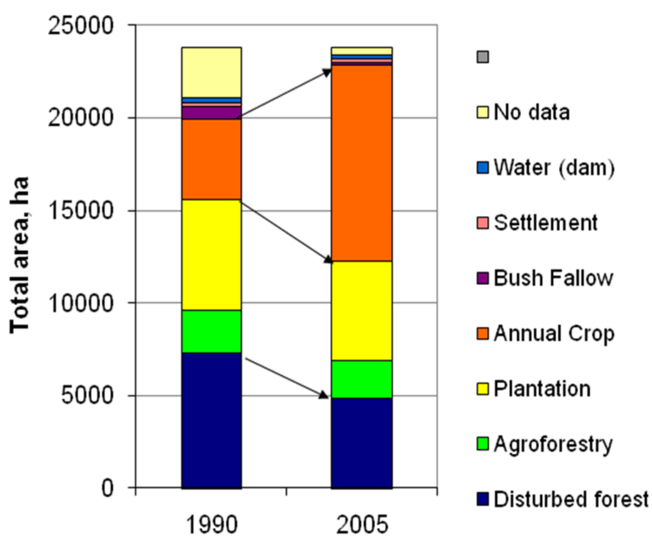

Figure 1. Land cover changes in Kalikonto sub-watershed based on analysis of land cover maps 1990 and 2005

Results and discussion

Land cover changes

Between 1990 and 2005 land cover change in the Kalikonto sub-watershed was substantive (Fig. 1): the remaining natural forest was reduced from 7270 ha to 4852 ha, or by 2.6% per year and by 33% on aggregate. The total area of annual crop and of settlements increased by 2.5%/year (aggregate 45%) and 1.1%/year (aggregate 18%), respectively. The area of tree plantations and agroforestry were reduced about 0.6%/year (aggregate 10%).

Carbon stock of each land use system

The natural forest in Kalikonto area has been severely disturbed shown by a low total C stock of about 161 Mg ha^{-1}. The total C stock in coffee-based agroforestry systems was lower, ranged from 99 to 111 Mg C ha^{-1} (Figure 2 and Table 2).

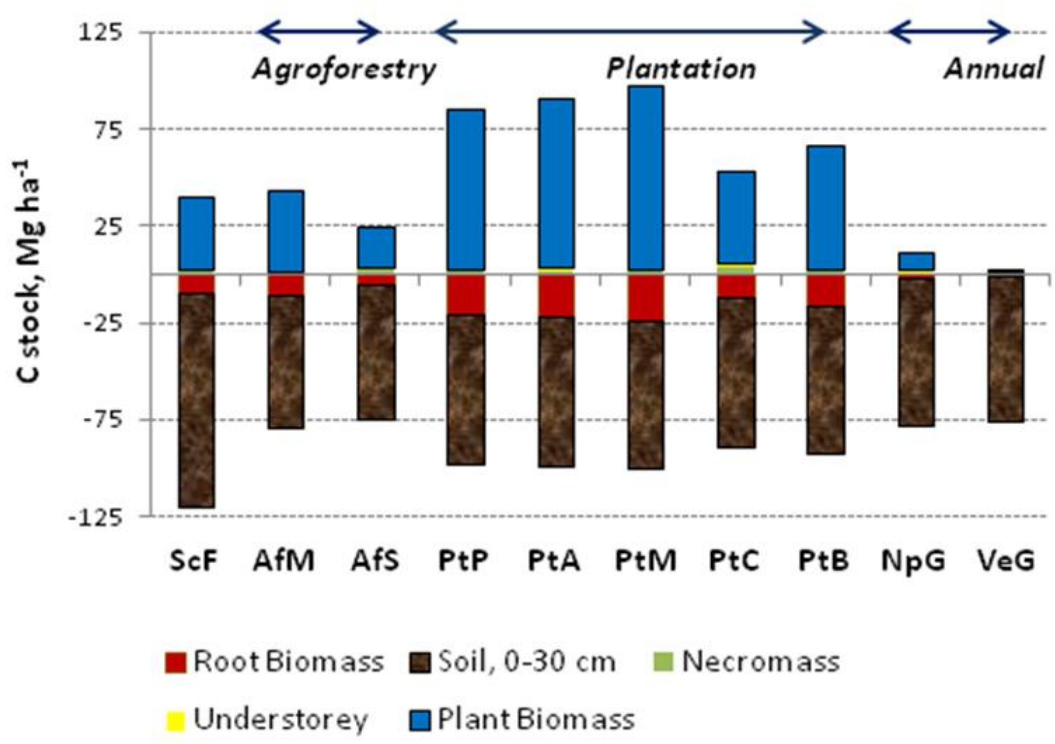

Figure 2. Total C stock of different C componens of various land use tipes (ScF= secondary forest, AfM_Mult= Multistrata coffee-based Agroforestry; AfS= simple coffee agroforestry, PtP = plantation pinus, PtA= plantation Agathis, PtM = plantation mahogany, PtC= plantation clove and PtB= plantation bamboo), NpG= napier grass and VeG=annual crops mainly vegetable

For tree plantations system (pinus, mahogany, and damar mostly aged 25-40 years) the C stock was ranging from 159 to 198 Mg C ha^{-1} (Table 2). In coffee agroforestry system in west

Lampung, shade trees contributed about 40% of total C stock [3]. This contribution can be higher by increasing tree diversity and its population density [10].

The time-averaged C stock was calculated to reflect the dynamics of C that is present in a certain land use systems over its life span, it is depends on rate of C accumulation, the minimum and maximum of C stored by the systems, and the time required to reach the maximum value and the rotation time. The time averaged C stock of tree plantations (pinus, mahogany, and damar mostly aged 25-40 years) was calculated based on equation developed in Figure 3. In plantation system the time averaged C stock was estimated to be 139 Mg C ha^{-1} (Table 1), agroforestry was to be 111 Mg ha^{-1}, while annual crops was only 1.5 Mg ha^{-1}. The soil in Kalikonto (mostly Andisol and Inceptisol) contribute C stock about 40 – 70 % of total C stock of each land use, which is higher than earlier C stock soil data of from Ultisol (Sumatra) around 10-20% only.

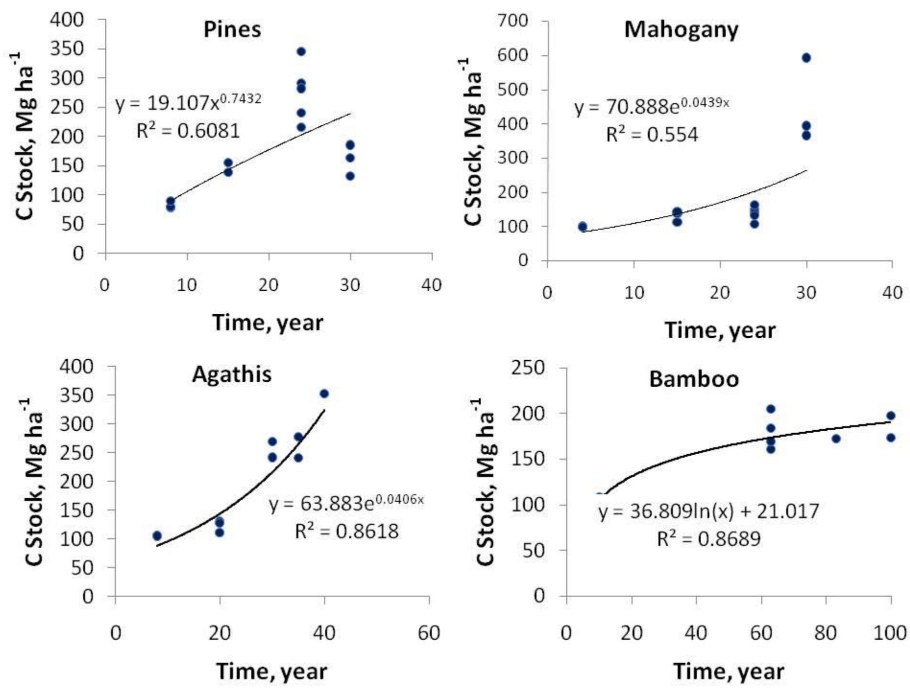

Figure 3. Relationship between total C stock and age of trees in monoculture system, the time averaged C stock of each species was estimated using its equation

Estimation the changes of C stock at landscape level

The geographic distribution of forest conversion and thus C stock reduction was mainly occurred in the area of high forest conversion in up-north of Pujon district covering 5 villages i.e. Pandesari, Wiyurejo, Madiredo, Tawangsari and Ngabab village (Figure 4). While in the southern part includes 3 vilages from Pujon district i.e. Pujon, Sukomulyo, and Bendosari, and 3 villages in Ngantang District i.e. Purworejo, Sidodadi, and Banjarejo.

Table 2. Carbon stock of various components of different land use types in Kalikonto sub-watershed

Land cover	LUS	Plant density per ha	Above ground	Estima-ted Root	Under-storey	Necro-mass	Soil, 0-30 cm	Total C stock	Max. Age,	Time Avg. C Stock,
			Mg ha^{-1}						year	Mg ha^{-1}
Forest	Degraded Forest	2248	38.4	9.60	0.15	2.15	111	161	50	161
Agrofo-restry	AF_Multi-strata	3970	42.1	10.5	0.14	1.29	69	123	30	111
	AF_Simple	4018	21.4	5.3	0.91	2.33	69	99	30	
Plantati-on	Pinus, 24yr	795	82.6	20.7	1.22	1.59	77	183	30	144
	Agathis		87.5	21.9	2.67	1.34	77	190	40	146
	Mahogany	963	95.2	23.8	0.69	1.54	77	198	50	212
	Clove		47.3	11.8	1.53	4.15	77	142	35	70
	Bamboo	3188	63.9	16.0	0.40	2.20	77	159	15	121
Grass-land	Napier grass, 4 months	-	15.0	3.7	4.41	1.02	76	100	0.25	11
	Napier grass, 1 month	-	0.9	0.2	0.21	0.53	76	78		
Annual crop	Vegetables	-	1.8	0.4	0.68	0.55	76	79	0.25	1.5

*Napier grass = Pennisetum purpureum (*Ind: Rumput Gajah*)*

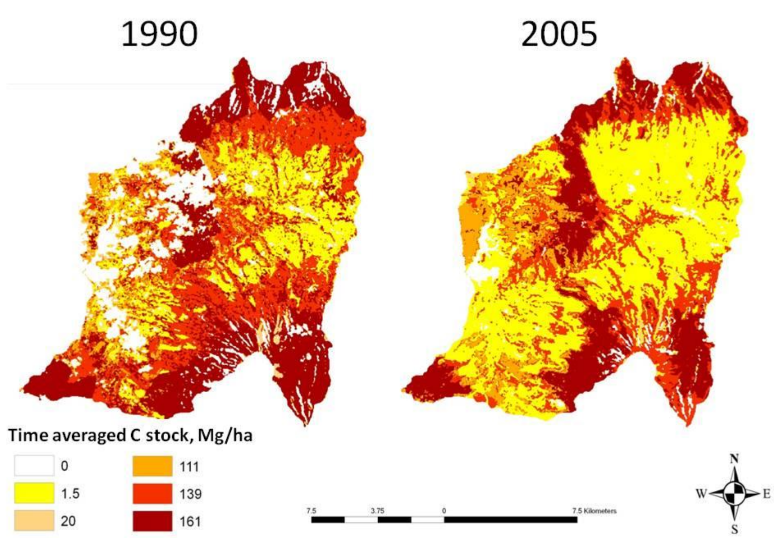

Figure 4. Distribution of carbon density in Kalikonto sub-watershed in 1990 and 2005

Extrapolation of C stock at plot level to watershed level was done by multiplying the area of each land cover with its time-averaged aboveground C stock (see Table 2). Within 15 years, C lost for the whole watershed (23810 ha) was estimated to be 25,924 Mg yr^{-1} or equivalent to a yearly C loss of 1.48 Mg ha^{-1}. Carbon lost from natural forest was about 1.09 Mg ha^{-1} yr^{-1}, tree plantations lost 0.25 Mg ha^{-1} yr^{-1}. Carbon lost from coffee-based agroforestry systems was relatively small, about 0.05 Mg ha^{-1} yr^{-1}. Increasing the area of annual crops in 2005 lead to a small gaining of C stock in the landscape was about 0.03 Mg ha^{-1} yr^{-1} but the C lost from the landscape exceeded this gain. Planting more trees (damar, pinus, mahogany) in the landscape through the Reforestation Program of the Forest Estate (PERHUTANI) in the 1990-2005 period was not able to reduce the C lost from the landscape, planting more trees in the landscape through agroforestry and plantation may compensate the loss of C through forest conversion.

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