EFFECT OF FOREST LOGGING PRACTICES ON CARBON STOCK RECOVERY IN KIBALE FOREST NATIONAL PARK, KANYAWARA, UGANDA

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Abstract

Reducing carbon emissions from deforestation and degradation (REDD+) as a mitigation strategy in developing countries is of central importance if humanity is to combat climate change. Understanding the effect of different logging practices on carbon stock recovery is therefore important if credible REDD+ investments are to be made in such forests. This preliminary study sought to find out differences in carbon stocks between differently logged forests in comparison to pristine forests after 43 years of regeneration in the Kanyawara area of Kibale National Park, Uganda. The study was done in 9 plots in three differently managed compartments: K15 (Heavily logged), K14 (Lightly logged), and K30 (Pristine forest). Diameter at Breast Height (DBH) measures of individual trees in the plots were used to calculate Above Ground Biomass (AGB) using allometric equations, which was then converted to carbon estimates. Carbon stock was found to be the highest in pristine forest, followed by lightly logged forest and heavily logged forest respectively; however, there was no significant difference in the carbon stocks of the different compartments. The results indicate that previously logged regenerated forests have considerable carbon stocks that should also be considered in the REDD+ financial incentive schemes for developing countries. Further implications to the pertinent question of climate change is that previously logged forests have a role to play as reservoirs of carbon stocks and should be considered for any climate change mitigation strategies as would pristine forests.

Keywords: Forests, developing countries, climate change, REDD+, carbon stock, carbon emissions.

Introduction and Literature Review

Climate change is one of the greatest challenges of humanity in the 21st century. In an attempt to reverse the effects of climate change, different mitigation strategies have been proposed including reducing greenhouse gas emissions a major cause of anthropogenic climate change (Saatchi et al., 2011).

One of the notable strategy is REDD+, which is a set of steps designed to use market and financial incentives to reduce the emissions of greenhouse gases from deforestation and forest degradation in developing countries (Myers, 2007). The strategy was developed from a proposal in 2005 by a group of countries calling themselves the Coalition for Rainforest Nations (Myers, 2007). The proposal received support because estimates for deforestation and forest degradation were shown to account for approximately 20% of greenhouse gas emissions, higher than the transportation sector (Myers, 2007). These observations made countries realize that mitigation of global warming would not be achieved without the inclusion of forests in an international regime. Therefore, in 2007 during the Bali UNFCCC meeting (COP-13), an agreement was reached on "the urgent need to take further meaningful action to reduce emissions from deforestation and forest degradation" (Richards, 2009).

In 2009, at COP-15 in Copenhagen, the Copenhagen Accord of 18th December, 2009 was reached, noting in section 6 the recognition of the crucial role of REDD and REDD-plus and the need to provide positive incentives for such actions by enabling the mobilization of financial resources from developed countries (UNFCC, 2009). The basic concept is simple: governments, companies or forest owners in developing nations should be rewarded for keeping their forests instead of cutting them down.

As the world grapples with the numerous challenges of REDD+ implementation, understanding where these incentives will yield maximum sustainable results is important if humanity is to collectively combat climate change.

The Global Forestry Resource Assessment (2010), estimates that the world's forests store 289 giga tonnes (Gt) of carbon in their biomass alone. While sustainable management, planting and rehabilitation of forests can conserve or even increase forest carbon stocks, deforestation, degradation and poor forest management reduce them. For the world as a whole, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the global forest area (GFRA, 2010).

Kibale National Park is rich in biodiversity, home to at least 372 bird species, 4 species of wild cats and 351 tree species. The Park also supports 13 species of primates, 67% of the country's total species, and is home to one of the largest chimpanzee populations in the world (Carbon Clear, 2009).

The forest contributes to climate change mitigation by sequestering greenhouse gases in existing forest sinks, and increasing natural tree cover through the planting of indigenous trees species, and assisted natural regeneration of existing forest. According to a carbon verification organization-Carbon Clear, the forest is expected to sequester 4,450,862 of the CO_2 during the 60 year crediting period earmarked in 2009 (Carbon Clear, 2009).

Kibale Forest was subjected to different intensities of logging in the late 1960s that created a mosaic of conditions from heavily logged, lightly logged and unlogged sites. Compartment K15 was heavily logged with a basal area reduction of >50%, whereas compartment K14 was lightly logged with a basal area reduction of 25-27.4%.These activities were both carried out in 1969. Compartment K30, which we used as a benchmark in our study, has not experienced any commercial, mechanized or large scale logging (Struhsaker, 1997; Skorupa, 1988).

Logging involves the cutting down of trees in the forest for different purposes, i.e. timber, cultivation, firewood and many other uses. There remains much uncertainty on the effects of logging on forest biomass and carbon storage, especially in tropical forests (Chazdon, 2003). Generally, the intensity of the logging is thought to be an important factor in determining the speed and specific pathway of forest succession following disturbance (Pickett et al., 1987; Chazdon, 2003). The ecological make-up of the forest in question plays an important role in its response to logging intensity and effects on carbon stocks in the forest (Pickett et al., 1987; Chazdon, 2003).

Long-term vegetation plots have been employed as an effective tool for monitoring tree population dynamics, allowing researchers to test succession theories and estimate recovery times of forests (Condit, 1995; Sheil et al., 2000). A review of previously published studies, where long-term vegetation plots were used to compare forest recovery from past logging in East Africa have shown that the recovery rates of these forests are uncertain (Plumptre, 1996). Studies have estimated that a minimum of 60 years is required for recovery to pre-logging conditions (Fashing et al., 2004).

The objective of the study was to determine the amount of carbon stocks in the differently logged compartment and hence compare carbon stocks in the differently logged forest compartments with the benchmark pristine forest compartments .The prediction was that there would be no significant difference in carbon stocks between the highly logged, lightly logged and pristine compartments.

The purpose of the study was to create a case for previously logged forests as important carbon stock reservoirs and hence their relatively important role in any proposal for climate change mitigation such as the proposed REDD+ strategy.

Methods

Study Site

Kibale National Park with an area of 795 km^2 is located in western Uganda and is largely composed of moist-evergreen forest (0°13'–0°41' N and 30°19'–30°32' E) that receives approximately 1698 mm (1990–2008) of rain annually (Chapman et al., 2010). Almost 60 percent of the park is characterized by tall forest with the canopy generally being approximately 25–30 m high, and the remainder is comprised of a mosaic of wetland, grassland, pine plantations, thicket, and colonizing forest (Chapman & Lambert, 2000).

Our study focussed on a subsection of the park – Kanyawara, (classified as a *Parinari forest* by foresters). We compared three areas within the Kanyawara forest, which have been subjected to different logging histories as earlier mentioned: K15, K14 and K30.

Sampling Design

The treatments of interest, pristine forest (K30), lightly logged (K14) and heavily logged forest (K15) in the Kanyawara area were divided into square grids of 20*20m (0.04ha), 3 plots in each area of interest were randomly selected.

The diameter at breast height (dbh) was determined by use of a dbh tape for all the individual trees in the selected plots with a circumference of ≥ 15 cm.The dbh data collected here was the "D" to be later used in the adopted equation by Chave, (2005) that was used to derive the Above Ground Biomass (AGB) and subsequent carbon stocks estimates as explained in the analysis. Other data collected include the names of tree species and the general description of the state of the forest plots i.e. forest structure, forest gaps and herbivore activities.

Data Analysis

Carbon Estimation in Trees

Carbon pool focus in our study was the Above Ground Biomass (AGB) which has high importance (4 in the scale of 1-4), inexpensive cost of (2 in the scale of 1-4) respectively. AGB also accounts for 70-90% of tropical forest biomass carbon. Carbon stored in the roots (Below Ground Biomass) was also inferred from the default values for the shoot/root ratio (SR-ratio) of 4:1 for humid tropical forest on normal upland soils (Saatchi et al., 2011).This combination of AGB and BGB gave the approximate carbon pool of each tree sampled.

The dbh was converted to AGB using allometric equations as per the dry forest stands (Chave et al., 2005). The dry regression equations were used over the moist regression equations although the Kanyawara area is in a borderline between the two. Dry regression equations were preferred because upon evaluation with remote sensed carbon estimations by Saatchi, moist empirical equations seemed to overestimate the carbon. The adopted dry forest regression equation was as follows:

$$AGB= \rho*\exp(-0.667+1.784*\ln(D) +0.207(\ln(D))^2-0.0281(\ln(D))^3)$$

Where:

ρ = wood specific gravity = oven–dry wood over green volume (g/cm³). The mean ρ for tropical forests Africa is estimated to be 0.5 g/cm³.

D = tree diameter at breast height (1.3 m) or dbh data collected from individual trees in the plots.

The AGB was then converted into carbon estimates by multiplying by 0.5 on the assumption that on average the dry carbon mass is 50% of dry wood mass. To get the AGB + BGB, AGB carbon was multiplied by 1.25 on the assumption of a shoot: root ratio of 4:1 to yield the approximate carbon content for each tree in kilograms (Chave et al*.,* 2005).With knowledge of the area sampled the carbon content in kilograms was converted into the standard carbon measure of tonnes per hectare.

Carbon Stock Recovery Analysis

The difference in carbon stocks between 3 compartments was analyzed by using a one-way ANOVA in Minitab statistical software (Release 13.32). Because of our low number of replicates the normal distribution was judged from residual plots and hence parametric statistics used to analyze the data.

Table1
Species and their numbers in differently logged forest compatments

Highly Logged	No.	Lightly Logged	No.	Pristine Forest	No.
Aningeria altissima	1	*Albizia grandibracteata*	1	*Albizia grandibracteata*	4
Antiaria toxicaria	1	*Aningeria altissima*	1	*Antiaria toxicaria*	5
Celtis Africana	12	*Aphania senegalensis*	2	*Aphania senegalensis*	4
Celtis durandii	11	*Apodytes dimidiata*	1	*Bosqueia phoberos*	31
Chaetacme aristata	3	*Blighia unijugata*	2	*Cassipourea ruwensorensis*	3
Clausena anisata	4	*Bosqueia phoberos*	15	*Celtis africana*	3
Diospyros abyssinica	18	*Cassipourea ruwensorensis*	1	*Celtis durandii*	2
Dovyalis macrocalyx	1	*Celtis africana*	7	*Chaetacme aristata*	3
Euadenia eminens	1	*Celtis durandii*	9	*Chrysophylum albidium*	5
Fagaropsis angolensis	2	*Chaetacme aristata*	3	*Conopharyngia sp.*	1
Funtumia elastica	7	*Clausena anisata*	3	*Cordia melnii*	1
Kigelia mossa	8	*Coffea eugenoides*	7	*Diospyros abyssinica*	16
Linocera johnsonii	7	*Diospyros abyssinica*	16	*Dombeya mukole*	4
Llex mitis	1	*Dombeya mukole*	1	*Euadenia eminens*	1
Markhamia platycalyx	3	*Fagaropsis angolensis*	2	*Fagaropsis angolensis*	3
Millettia dura	1	*Funtumia elastic*	6	*Ficus exasperate*	4
Myrianthus arboreus	1	*Leptonychia mildbraedii*	3	*Funtumia elastic*	6
Newtonia buchananii	4	*Markhamia platycalyx*	19	*Llex mitis*	2
Olea welwitschii	5	*Millettia dura*	1	*Lovoa swynnertonii*	3
Parina excelsa	3	*Myrianthus arboreus*	2	*Mimusops bagshawei*	5
Teclea nobilis	13	*Newtonia buchananii*	3	*Monodora myrisica*	1
Uvaryopsis congensis	4	*Oxyanthus speciosus*	1	*Newtonia buchananii*	15
Vangueria apiculata	1	*Scolopia rhamniphylla*	1	*Oxyanthus speciosus*	2
		Strombosia scheffleri	3	*Pancovia turbinata*	14
		Strychnos mitis	4	*Parina excelsa*	2
		Symphonia globuliera	2	*Psedospondias myclocrpa*	4
		Teclea nobilis	12	*Rothmannia urceliformis*	2
		Uvaryopsis congensis	7	*Scolopia rhamniphylla*	4
				Strombosia scheffleri	6
				Strychnos mitis	1
				Symphonia globuliera	1
				Teclea nobilis	3
				Uvaryopsis congensis	4

The three significant tree species that had significant carbon content were *Mimusops bagshawei, Olea welwitschi* and *Parinari excelsa as shown in* (Figure 1, Appendix codes: 32,36 and 39).

Appendix of Tree Species Code in Figure 1

*Tree species	Code
Albizia grandibracteata	1
Aningeria altissima	2
Antiaria toxicaria	3
Aphania senegalensis	4
Apodytes dimidiate	5
Bosqueia phoberos	6
Blighia unijugata	7
Cassipourea ruwensorensis	8
Casearia sp.	9
Celtis africana	10
Celtis durandii	11
Chaetacme aristata	12
Chrysophylum albidium	13
Clausena anisata	14
Coffea eugenoides	15
Conopharyngia sp.	16
Cordia melinii	17
Diospyros abyssinica	18
Dombeya mukole	19
Dovyalis macrocalyx	20
Euadenia eminens	21
Fagaropsis angolensis	22
Ficus exasperate	23
Funtumia elastic	24
Kigelia mossa	25
Leptonychia mildbraedii	26
Llex mitis	27
Linocera johnsonii	28
Lovoa swynnertonii	29
Markhamia platycalyx	30
Millettia dura	31
Mimusops bagshawei	32
Monodora myrisica	33
Myrianthus arboreus	34
Newtonia buchananii	35
Olea welwitschii	36
Oxyanthus speciosus	37
Pancovia turbinata	38
Parinari excelsa	39
Rothmannia urceliformis	40
Pseudospondias myclocarpa	41
Scolopia rhamniphylla	42
Strychnos mitis	43
Strombosia scheffleri	44
Symphonia globulifera	45
Teclea nobilis	46
Uvaryopsis congensis	47
Vangueria apiculata	48

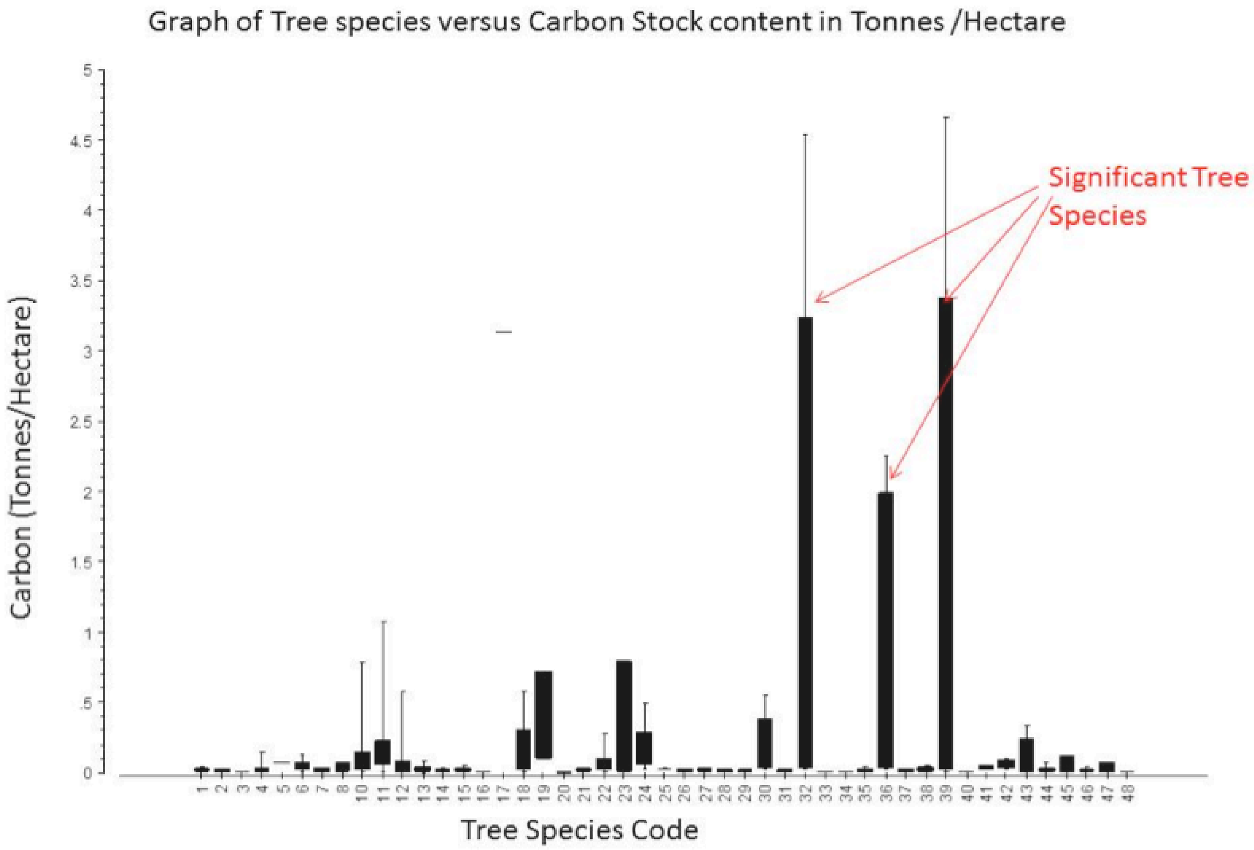

Figure 1

Graph of tree species versus carbon stock content in t/ha.

Carbon stocks in the different compartments

The average carbon stock after 43 years of regeneration was found to be 158.50 ± 85.84 t/ha for the heavily logged compartment (K15), 210.48 ± 56.91 t/ha for lightly logged (K14) and 249.54 ± 23.85 t/ha for the pristine forest (K30). (Figure 2)

Differences in carbon stock in the compartments

There was no significant difference in the carbon stocks of the differently logged forest compartments in comparison with each other and with the benchmark pristine forest.
(One way ANOVA, $F_{2, 6}$=1.68, P=0.263) (Figure 3)

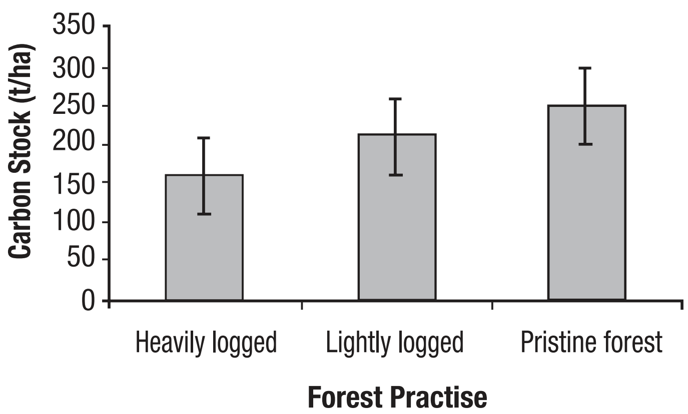

Figure 2
Range of Carbon stocks in differently managed compartments

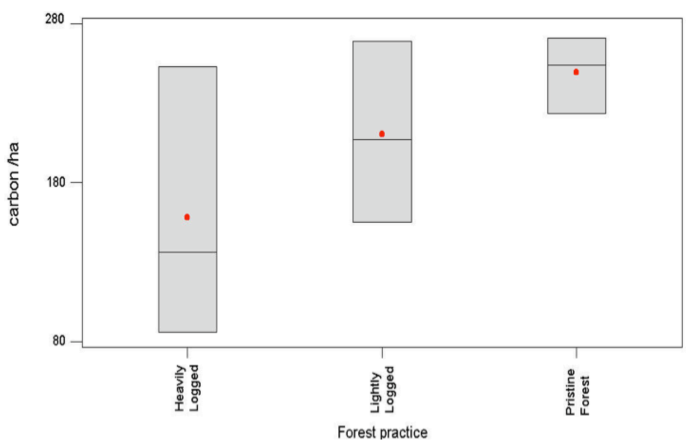

Figure 3
Median box plot of carbon in t/ha in plots in the differently logged compartment

Discussion

Carbon stocks in the different compartments

Carbon stocks were the highest in pristine forest, followed by lightly logged and heavily logged compartments. This was probably because of a number of reasons that may include different tree species, large gaps and other disturbances.

Some trees species were found to be fast growing compared to others and attained different sizes at maturity e.g. *Ficus exasperate*. A few tree species were found in certain compartments and they were missing in the other compartments, for example pristine forest had greater number of tree species with largest dbh and most of these were not found in heavily logged and lightly logged forests. The species included; *Parinari excelsa*, *Mimusops bagshwei, Cordia melinii, Dombeya mukole, Ficus exasperate and Olea welwitschii*. These species were probably the ultimate winners of the vicious succession competition that has occurred over the years for the pristine forest to attain its rather "stable" state.

According to Struhsaker (1997), tree species diversity is greatly reduced by heavy and moderate logging even when measured many years after logging. Large gaps created during heavy logging lead to increased mortality of seedlings and saplings due to the competition of fast growing shrubs and herbs. This was observed in compartment K15 (heavily logged) and in some parts of K14 (lightly logged). Large gap sizes in the canopy lead to arrested succession and may affect the carbon stocks in the regenerated forests. This phenomenon may be explained by the role of *Acanthus pubescens* in supressing tree seedling growth and survival as observed in an experiment conducted in the Kibale Forest (Babaasa et al., 2004; Paul et al., 2004).

Furthermore, the presence and population density of elephants in the region reinforced the maintenance of these gaps, possibly enlarging them, as elephants are found to favour open gaps with herbaceous material as food sites (Struhsaker et al*.*, 1996; Babaasa, 2000). Elephant presence in these gaps further increased seedling mortality, as well as the mortality of other younger trees in the surrounding area (Babaasa et al., 2004; Paul et al*.*, 2004; Lawes & Chapman, 2006). In Kibale National Park, Uganda, an unfavourable succession pathway seems to slow down or arrest forest succession (Babaasa et al., 2004; Chapman & Chapman, 2004), possibly requiring longer to recover. Evidence of elephant presence in Kanyawara spans almost 50 years when they were most dominant according to a survey carried out between October 1962 to 1965 (Wing & Buss, 1970). The local effect of their presence on succession has been further demonstrated by elephant damaged saplings and poles in 11 plots surveyed in logged area between 1978-1979 (Kasenene, 1980).

On the other hand, carbon stocks in the different forest compartments seemed to be an overestimate in reference with previously remote sensed data that estimates carbon stock within the Kibale area to be between 100-150 t/ha (Saatchi et al*.*, 2011). This would probably be due to generalization of the allometric equations by (Chave et al., 2005) and also the generalization of all the tree wood densities to be 0.5 g/cm^{3}, which is the mean for Africa. The estimates would have been more accurate if tree wood densities were considered to be different for the different tree species.

Differences in carbon stock in the compartments

Despite pristine forest having higher carbon stocks as earlier discussed there was no significant difference in the overall comparison of carbon stock in the three investigated treatments. This is probably because of the remarkable recovery rate and undisturbed regeneration, facilitated by the presence of the Kibale Forest Research Project and later Makerere University Biological Field Station (MUBFS) established by Dr. Thomas Struhsaker in 1970 which has maintained minimum disturbance since its inception.

Further, there has been a tremendous recovery rate in the last 43 years as comparative data from Struhsaker (1997) show a huge disparity of 30-90% of dbh in the heavily and lightly logged compartments in studies carried out 25 years ago. The heavily logged compartment seems to have overcome pressures that seemed to arrest regeneration, such as elephant interferences as mentioned earlier (Struhsaker et al*.*, 1996; Babaasa, 2000) and emerged as an important carbon stocks. However, caution should be exercised when considering these for carbon investments since most of their carbon is derived from smaller dbh classes i.e. 15-30 cm which are much more susceptible to mortality as compared to pristine carbon stocks (Byamukama, Pers.comm).

In regards to the REDD+ debate, if indeed there is no difference in the carbon stocks of lightly logged, heavily logged regenerating forests and the pristine forests as this preliminary report suggests, then there is a credible case of regenerating forests as equal recipients of the REDD+ investments in tandem with pristine forests as a strategy of mitigating climate change at suggested by Article 6 of COP-15 in the Copenhagen accord (UNFCC, 2009).

From this preliminary study further investigation is suggested by establishment of at least 14 plots per compartment as derived from estimations from data herein using sample size determining equations proposed by Pearson (2005). This will give room for more conclusive and reliable results, and indeed bring forth a better case for regenerating forests as important carbon stocks.

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