DOI: 10.21276/sajb.2016.4.9.4

Scholars Academic Journal of Biosciences (SAJB)
Sch. Acad. J. Biosci., 2016; 4(9):716-721
ISSN 2321-6883 (Online)
ISSN 2347-9515 (Print)

(An International Publisher for Academic and Scientific Resources)
www.saspublisher.com

Original Research Article

The Potential of Selective Harvesting in Mitigating Biomass and Carbon Loss in Forest Co-management Block in Liwonde Forest Reserve, Malawi

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Abstract: Carbon reduction strategies in "forests remaining as forests" are currently limited to forest plantations and harvesting "avoidance" activities. However, emerging modalities such as selective harvesting are gaining increased recognition. This study was conducted to determine the potential of selective harvesting in mitigating biomass and carbon loss in forest co-managment block in Liwonde forest reserve, Malawi. The results showed that there were no significant (P>0.05) differences on forest living biomass and carbon stock between non-harvested area and harvested area after four years of harvest. The total living biomass and carbon stock for non-harvested area were 140.34 tha^{-1} and 70.17 $tCha^{-1}$, respectively; while for harvested area were 122.12 tha^{-1} and 61.06 $tCha^{-1}$, respectively. The rate of carbon sequestration in the non-harvested area was 0.72 $tCha^{-1}y^{-1}$, while for the harvested area was 5.40 $tCha^{-1}y^{-1}$. The carbon stock estimation prediction models established indicate that beyond 6 years after harvest, the carbon stock would be equal in both harvested and non-harvested areas. The uncertainties for the estimated living biomass and carbon stock were within those recommended for REDD+ mechanism (<15%). Therefore, selective harvesting has the potential to mitigate biomass and carbon loss. Hence, it is possible to register carbon projects in Malawi through selective harvesting with Chindenga forest co-management block in Liwonde forest reserve as one of the site.
Keywords: Carbon sequestration, carbon project, prediction model, biomass, carbon stock, mitigation.

INTRODUCTION

Forests play a vital role in the global carbon cycle through the storage and sequestration of carbon in living forest biomass [1]. This has been recognized with the international climate change mitigation initiative to reduce emissions from deforestation and forest degradation (REDD+) coupled with the enrichment of forest carbon stocks through forest restoration, sustainable forest management and forest conservation in developing tropical countries [2, 3]. Mitigating initiatives such as REDD+ can potentially offer economic, environmental and social benefits with the intersection of carbon markets, climate and environmental protection and, if implemented appropriately, could provide wider social and economic opportunities for indigenous people in developing tropical countries [1].

Carbon reduction strategies in "forests remaining as forests" are currently limited to forest plantations and harvesting "avoidance" activities [4, 5]. However, emerging modalities such as selective harvesting are gaining increased recognition [4]. Modification of forest harvesting operations could play an important role in climate change mitigation by adopting sound harvesting technique such as selective harvesting [6]. Afforestation or reforestation is arguably the most widely embraced carbon sequestration technique because of its low cost, benign nature and many co-benefits. However, its capacity is limited by the availability of land and the carbon sink diminished as the forest matures [7]. On the other hand, selective harvesting has an advantage of creating a continuous stream of carbon sink. Therefore, mitigation through selective harvesting is now viewed as a low cost approach with relatively modest total mitigation potential [7, 8].

Malawi lost about 60% of its forest cover from 1975 to 2010 and the rate of deforestation between 1975 and 1990 was 3.5%, while between 1990 and 2010 was 0.4% [9 -11]. The major causes of deforestation have been fires, encroaching in the forest reserves by farmers to sustain livelihoods, an ever-increasing demand for fuelwood [11]. In its effort to alleviate this problem the government of Malawi through the Department of

Forestry recognized the need of participatory forest management (PFM). PFM is stipulated in the National Forest Policy of 1996 [12] and operationalized by the National Forest Act of 1997 [13]. The law recognizes two main types PFM, namely: Co-management and Community Based Forest Management (CBFM). Co-management and CBFM in Malawi are well explained by other researchers [9].

Malawi is in initial stages of REDD+ activities and the silvicultural system introduced in both co-management and CBFM is selective harvesting. However, there is no information on the impact of selective harvesting on the forest living biomass and carbon stock in Malawi forest reserves. Therefore, the main objective of this study was to determine the potential of selective harvesting in mitigating biomass and carbon loss in forest co-management block in Liwonde forest reserve, Malawi. Specifically, the study aimed to compare (1) estimates of forest living biomass in harvested and non-harvested areas, (2) estimates of total (above and below ground) carbon stocks in harvested and non-harvested forest areas after four years of harvest, and (3) the rate of carbon sequestration in harvested and non-harvested areas.

MATERIALS AND METHODS

Study site

The study was conducted in Liwonde forest reserve in Chindenga forest co-management block in Machinga district, Malawi. Liwonde forest reserve is located at latitude $15^{0}21'$S and longitude $35^{0}21'$E. The altitude of the area ranges from 800 m to 2080 m above the sea level. The mean annual rainfall is 840 – 960 mm with a mean annual temperature range between 18^{o}C – 25^{o}C. The area experiences a 5-6 month dry season from May to October. The reserve is dominated by ferrallitic latosols soils with an average pH of 5.2 [14]. The natural vegetation of the area is miombo woodland dominated by Brachystegia and Uapaca species. Chindenga forest co-management block covers approximately 901 ha and it is situated about 326 km south east of Lilongwe the capital [15].

Experimental design, sample plots and data collection

The experimental design constituted two treatments of harvested and non-harvested areas. The required number of sample plots and grid interval were determined using the procedure outlined by other researchers [16]. A total of 24 sample plots (twelve for each treatment) at an interval of 100 m in each treatment were used for the inventory. Two concentric circular plots of radius, 12 m (medium) and 20 m (large) were established at each sampling point and diameter at breast height (dbh) for each tree in the plots were measured and recorded. Trees were measured using the following standard: medium plot (5 cm ≤ dbh ≤ 15 cm); and large plot (dbh >15 cm). The dbh was measured using diameter tapes. The name of each tree measured was also identified and recorded. Data was collected in October 2010 and July 2014 while the harvesting was done in August/September 2010 for timber and energy use. Selective harvesting involved removing of old-growth trees; leaving the retained trees more or less evenly spaced out and about 30% of the growing stock's canopy was removed. Harvesting was done using chain saws and an area of about 5 ha was harvested.

Biomass, carbon and uncertainty estimation

Above ground biomass (AGB) and below ground biomass (BGB) of a tree were estimated using the following site specific equations developed by other researchers [17]:

$$AGB = 0.103685 \text{ x } (dbh)^{1.921719} \text{ x } ht^{0.844561}$$

$$BGB = 0.284615 \text{ x } (dbh)^{1.992658}$$

Where: AGB and BGB are above ground biomass and below ground biomass (kg dry matter per tree), respectively; dbh is a diameter at breast height (1.3 m above the ground level) (cm); and ht is the total tree height (m). Tree height was estimated using the following site specific height-diameter model developed by other researchers [17]:

$$ht = 1.3 + \exp(3.787685 - 6.62809*dbh^{-0.455222})$$

Total living biomass of a tree (TLB) was calculated as the sum of AGB and BGB, while carbon stock (C) was calculated using the following formula:

$$C = TLB \text{ x } CF$$

Where: CF is the carbon factor and varies from 0.45 to 0.50 [18]. In this study a default value of 0.5 was used. Monte Carlo procedure (well explained by other researchers [19]) was used to estimate uncertainty of the parameters studied at 95% confidence interval.

Statistical analysis

Data obtained on living biomass and carbon stock were tested for normality and homogeneity with Kolmogorov-Smirnov D [20]. After the two criteria were met the data were subjected to student t-test. The characteristics of the data set are presented in Table 1. Student t-test was performed in order to determine whether there were significant differences on forest living biomass and carbon stock between harvested and non-harvested areas at 0.05 level.

Table-1: Characteristics of the data set

Category	Plot	Mean	Minimum	Maximum	SD
Non-harvested area	Diameter at breast height (dbh) (cm)				
	Medium	8.9	5	15	2.6
	Large	24.8	15.1	52.4	6.7
	Density (stems ha^{-1})				
	Medium	876	595	984	110.4
	Large	154	119	183	20.7
Harvested area	Diameter at breast height (dbh) (cm)				
	Medium	13.1	5	15	1.8
	Large	25.3	15.1	36.3	5.1
	Density (stems ha^{-1})				
	Medium	835	722	992	79.1
	Large	30	8	56	15.1

Note: SD=standard deviation; ha=hectare

RESULTS AND DISCUSSION

Biomass and carbon stock estimation

Living biomass and carbon estimated in harvested and non-harvested areas in forest co-management block in Liwonde forest reserve are presented in Table 2. The estimates include above ground living biomass, above ground carbon stock, below ground biomass and below ground carbon stock in roots. The results indicate that there were not statistically significant (P>0.05) differences on total living biomass and carbon stock between harvested and non-harvested areas after four years of harvest, even though the total carbon stock and biomass for non-harvested area was slightly higher than the harvested area. The total carbon stock for non-harvested area and harvested area for the year 2014 were 70.17 $tCha^{-1}$ and 61.06 $tCha^{-1}$, respectively; while for the year 2010 were 67.28 $tCha^{-1}$ and 39.45 $tCha^{-1}$, respectively. This means that the rate of carbon sequestration in the non-harvested area was 0.72 $tCha^{-1}y^{-1}$, while for the harvested area was 5.40 $tCha^{-1}y^{-1}$ (Figure 1). This is in agreement with other researchers [7] who reported that selective harvesting creates a continuous stream of carbon sink, while in non-harvested areas carbon sink diminishes as the forest matures.

The results have revealed that in the year 2010, there were significant (P<0.05) differences on below ground biomass between harvested and non-harvested areas. However, in the year 2014 no significant (P>0.05) differences were observed on below ground biomass between harvested and non-harvested areas. This suggest that in the harvested area, the miombo trees first establish themselves below the ground, in order to provide anchorage to the above ground biomass, before they fully establish above the ground. This is in agreement with the reports in literature [17].

Figure 1 shows the prediction models for carbon stock in a harvested area and non-harvested area after four years of harvesting. The findings indicate that beyond 6 years after harvesting, the carbon stock would almost equal in both harvested and non-harvested areas. This is an indication that selective harvesting has the potential to mitigate the biomass and carbon loss. Therefore, it is possible to register carbon projects through selective harvesting. The present results are in line with those in literature [1,4,6,7,21].

Table-2:Biomass and Carbon Stock Estimates for Chindenga Forest Co-management Block

Parameter	**Density (tha^{-1}) in different Categorical Years**			
	2014		**2010**	
	NHA	**HA**	**NHA**	**HA**
Above Ground Biomass	91.11 ± 6.36^a	75.97 ± 1.91^b	80.46 ± 3.12^a	52.48 ± 2.37^b
Below Ground Biomass	49.23 ± 2.49^a	46.15 ± 0.92^a	54.10 ± 2.19^a	26.42 ± 1.09^b
Total Living Biomass	140.34 ± 8.81^a	122.12 ± 2.77^a	134.56 ± 5.36^a	78.90 ± 3.42^b
Above Ground Carbon Stock	45.55 ± 3.18^a	37.99 ± 0.95^b	40.23 ± 1.56^a	26.24 ± 1.18^b
Below Ground Carbon Stock	24.62 ± 1.25^a	23.08 ± 0.92^a	27.05 ± 1.09^a	13.21 ± 0.54^b
Total Carbon Stock	70.17 ± 4.40^a	61.06 ± 1.38^a	67.28 ± 2.68^a	39.45 ± 1.71^b

Note: Density followed by different letter within the same categorical year in a row significantly differ (P<0.05); NHA=non-harvested area; HA=harvested area

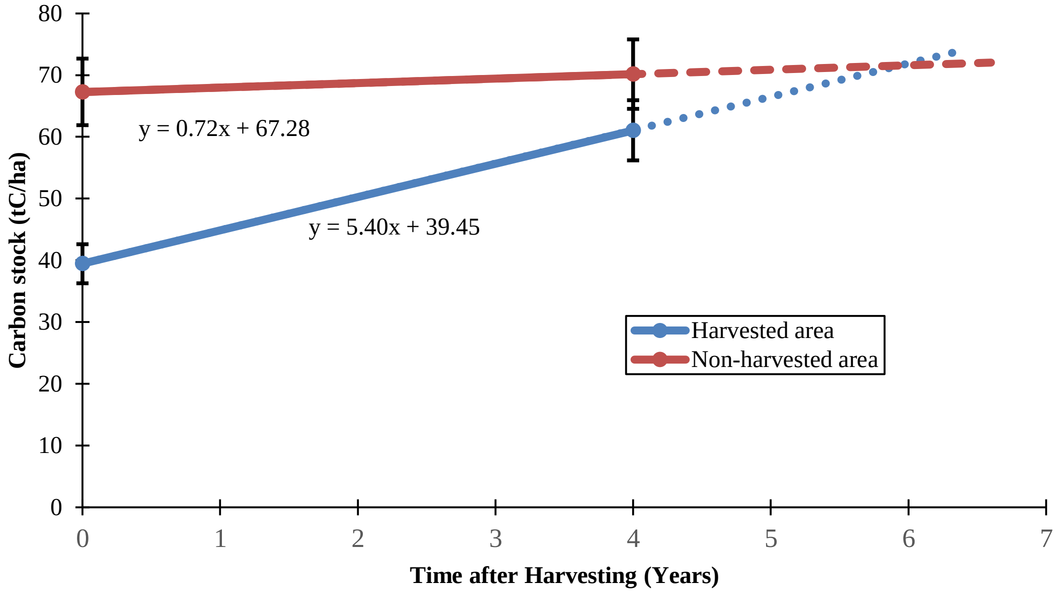

Fig-1: Prediction models for carbon stock in harvested and non-harvested areas in Chindenga forest co-management block in Liwonde forest reserve, Malawi

Uncertainty analysis

Forest biomass and carbon stock estimation are always associated with uncertainties and it is essential to minimize them [22]. Sources of error in estimation of forest biomass and carbon stock includes: field measurements, distribution of sample plots and use of allometric equations [22-24]. The uncertainty estimates for forest living biomass and carbon stock for non-harvested and harvested areas are presented in Table 3. The results indicate that the uncertainties were low (<15%). This shows that the estimated forest biomass and carbon stock in the present study were significantly minimized. Field measurements error was minimized by measuring a large number of trees. A total of 1558 trees and 1309 trees were both measured in non-harvested and harvested areas, respectively. Measuring large amounts of trees leads to measurements errors which are normally distributed and have minimal effect on the final biomass determination [25]. Sample plots were uniformly distributed in both non-harvested areas and this minimized the distribution of sample plots error.

The use of site specific allometric equations in the present study also helped to minimize the uncertainties. The site specific allometric models significantly (P>0.05) differed from default allometric model used by other researchers [10] in the same site. The default allometric model underestimated the below ground biomass (>54%) and the uncertainties were high (>29%). The recommended uncertainties for REDD+ mechanism is less than 15% at 95% confidence interval [26]. The use of site specific allometry could also help Malawi to achieve Tier 3 level of accuracy for REDD+ framework. Therefore, the present study has shown that selective harvesting has the potential to mitigate the biomass and carbon loss. Hence, it is possible to register carbon projects through selective harvesting with Chindenga forest co-management block in Liwonde forest reserve as one of the site.

Table-3: Biomass and Carbon Stock Uncertainty at 95% Confidence Level for Chindenga Forest Co-management Block in Liwonde Forest Reserve, Malawi

Parameter	Uncertainty (%) in different Categorical Years			
	2014		2010	
	NHA	HA	NHA	HA
Above Ground Biomass	13.68	4.92	7.60	8.85
Below Ground Biomass	9.93	3.89	7.93	8.09
Total Living Biomass	12.30	4.44	7.81	8.50
Above Ground Carbon Stock	13.68	4.92	7.60	8.85
Below Ground Carbon Stock	9.93	3.89	7.93	8.09
Total Carbon Stock	12.30	4.44	7.81	8.50

Note: NHA=non-harvested area; HA=harvested area

CONCLUSION

The present study has shown that there is potential for selective harvesting to mitigate biomass and carbon loss. There were no significant differences on total forest living biomass and total carbon stock for non-harvested and harvested areas after four years of harvest, even though the total carbon stock and biomass for non-harvested area was slightly higher than the harvested area. The rate of carbon sequestration in the non-harvested area was 0.72 $tCha^{-1}y^{-1}$, and 5.40 $tCha^{-1}y^{-1}$ for the harvested area. The carbon stock estimation prediction models established indicate that beyond 6 years after harvest, the carbon stock would be almost equal in both harvested and non-harvested areas. The uncertainties for the estimated living biomass and carbon stock were low. Therefore, it is possible to register carbon projects in Malawi through selective harvesting with Chindenga forest co-management block in Liwonde forest reserve as one of the site.

ACKNOWLEDGEMENTS

The authors are grateful to the staff at Machinga District Forestry Office for allowing the study to be conducted at Chindenga forest co-management block and also for the assistance provided during data collection.

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