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Carbon stocks in semi-arid pastoral ecosystems of northern Kenya

Bulle Hallo Dabasso^{1*}, Zerihun Taddese² and Dana Hoag³

Abstract

Data on carbon stocks in pastoral ecosystems is important for assessing their contribution for offsetting emissions of greenhouse gases through carbon storage. Such data also provides baseline information to determine if pastoral grazing management can be engaged for carbon credit trading. Real and accurate carbon data is scarce. Much of the available data is often based on limited assessment of carbon stocks in a specified range unit, which fails to capture the spatial and temporal heterogeneity that characterizes pastoral ecosystems. In this study, we considered heterogeneity of semi-arid pastoral ecosystems of northern Kenya by aggregating sample results taken during wet and dry seasons and from various landscape types. We found average carbon stocks of 93.01 ± 15.72 tonnes ha⁻¹ across landscape types and seasons. The measured amount of stored carbon is sufficient to have an important contribution in controlling the atmospheric concentration of greenhouse gases; it also indicates a potential to improve pastoralist livelihoods through carbon credit trading. However, more research would be required in order to qualify pastoralists for carbon credits since the data collected in this study is not sufficient to determine the change in carbon storage by grazing practices. In addition, uncertainty in the value of carbon credits needs to be considered to avoid relying on a risky prospect.

Keywords: Carbon stocks; Green house gases; Landscape types; Northern Kenya; Pastoral ecosystems

Background

Carbon dioxide (CO₂) is considered one of the greenhouse gases (GHGs) that has been associated with global climate change. Since pre-industrial times, global CO₂ has increased by 40% (IPCC 2013). Although empirical evidence on the contribution of GHGs in causing atmospheric warming is not certain (see Kobash et al. 2011; Mangini et al. 2005), land uses that offset atmospheric CO₂ emissions through carbon storage in plants and soils are commonly considered environmentally friendly (e.g. Lal 2001). The potential of rangelands to store carbon in soils and vegetation has been acknowledged in many studies (e.g. IPCC 2007) and lies within the natural state of rangelands or rangelands moderately disturbed by grazing (Perez-Quezada et al. 2011). Nevertheless, in pastoral ecosystems^a characterized by communal grazing, carbon storage potential is poorly understood. Continuous grazing in pastoral ecosystems is often thought to reduce primary productivity or species composition; therefore,

no substantial carbon stocks are assumed (Piñeiro et al. 2010). This assumption is not supported by accurately collected carbon data, as the results of this study will show. Carbon stocks are often measured in a single assessment of a certain range environment. However, pastoral ecosystems are heterogeneous, both in spatial and temporal dimensions (Qi et al. 2000). The spatial heterogeneity results from the variations in micro-climate, physical landforms and precipitation, and creates a skewed distribution of soil moisture and nutrients that influence carbon storage (Aguiar and Sala 1999). Temporal heterogeneity arises from seasonal difference in net primary productivity influenced by rainfall patterns and the variation in the grazing condition (Nori 2006). More often than not, attempts to estimate carbon stocks in pastoral ecosystems seldom consider the challenges emanating from rangeland heterogeneity and therefore assume uniformity. As Kratli and Schareika (2010) observed, an average of measurements taken from different sampling points to represent rather heterogeneous environments is misleading since asymmetric distribution of carbon that characterizes pastoral ecosystems

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is not captured. Studies that use this methodological approach are therefore misleading and result in incomplete accounting of carbon stock estimates in rangelands.

Environmental dynamics in pastoral ecosystems has already led to the development of at least two contrasting ecological models, with different implications for its capacity to store carbon in eastern Africa. (Coppock 1994), for example, describes the pastoral ecosystem in southern Ethiopia as being an equilibrium state where the major determinants for vegetation change is grazing. Illius and O'Connor (1999) made similar descriptions of the arid and semi-arid grazing systems. These views, however, contrast with those of other authors who describe systems in eastern Africa as non-equilibrium (Behnke et al. 1993; Ellis and Swift 1988; Oba et al. 2003; Scoones and Graham 1994), where change in vegetation is driven by non-density-dependent factors such as rainfall. However, there is a possibility that the two models are relevant in what is described as a continuum between equilibrium and non-equilibrium (Derry and Boone 2010; Vetter 2005).

Limited understanding about the amount of carbon stocks in pastoral ecosystems thus results from a failure to consider spatial and temporal environmental dynamics. This poses challenges for policy development to promote, manage or protect pastoralism to safeguard the atmospheric environment from GHG emissions, in addition to providing local pastoralists with a reasonable livelihood. Consequently, there has been a general development of replacing pastoralism with other land uses without looking at associated environmental implications (Behnke and Kerven 2013).

This study seeks to assess carbon stocks in semi-arid pastoral ecosystems, commonly perceived to have been degraded by grazing. We purposively selected a site in northern Kenya with adequate heterogeneity in spatial characteristics, and we sampled across wet and dry seasons to capture temporal variability. The site was classified into landscape types depending on vegetation life form^b and systematically assessed for carbon stocks. We proposed the following two research questions:

- What is the amount of carbon stocks in semi-arid pastoral ecosystems of northern Kenya?
- How does the spatial and temporal heterogeneity of the environment influence the amount of carbon stocks in pastoral ecosystems?

It is also important to determine the potential that these lands hold for selling carbon credits, which potentially provide a much needed income stream to local pastoralists. While we did not have the appropriate data

to address this question, we took the first steps by quantifying how much carbon is stored on a continuously grazed system. More research would be required to determine the impact of grazing on storage and the viability of carbon markets to provide reliable income.

Study area

This study was conducted in Marsabit Central grazing land, located along the topographical gradient of Marsabit Mountain of northern Kenya. The topographical gradient stretches from the upper side of Marsabit Mountain forest through the transitional zone to the foot slopes (Figure 1). Diverse vegetation that consists of grassland, shrubland and woodland are found along the topographical gradient. Vegetation dominated with grasses and dense shrubs are found on the upper side of the slope, while scattered trees intercepted with some scrub vegetation are found on the foot slope. Like the vegetation, soil types are also diverse, ranging from deep and well-weathered soils with clay-like texture found on the upper slope to sandy loam type of soils with moderate weathering on the lower slope.

The area is semi-arid with annual rainfall ranging from 400 to 750 mm, distributed bio-modally between

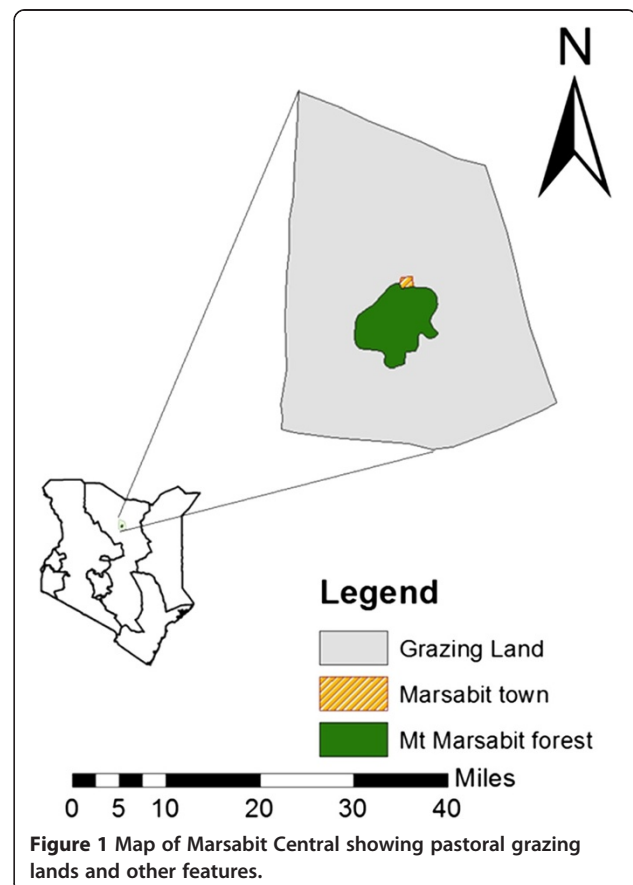


Figure 1 Map of Marsabit Central showing pastoral grazing lands and other features.

long rainy and short rainy seasons. The prevailing livelihood option is pastoralism where cattle, sheep, goats and camels are kept in communal grazing lands. Livestock form key individual or family assets for food and income, and also for defining social and cultural identity. A semi-sedentary system of livestock production is the common practice where small herds are left at home for milking and for other domestic needs while the remaining herds are kept in strategic movements between landscapes, to opportunistically use available resources.

Livestock production is faced with numerous challenges including continuous loss of grazing lands and frequent feed shortages especially during drought conditions. Like most parts of northern Kenya, herd mobility faces continuous deprivation of access rights resulting from land privatization by individuals and other land users (Lengaiboni et al. 2010). The continuous loss of land, coupled with frequent drought occurrences, had made a large number of pastoralists to adopt a sedentary lifestyle (Little 1985). Nonetheless, recent recognition of communal land tenure rights by the Kenyan constitution might reverse the trend of land loss to private investors (Odote 2013). Land is communally owned by a variety of ethnic groups, not limited to Borana, Rendille and Gabra. A large proportion of each ethnic group can be rated as poor - earning less than \$2 a day (Hogg 1986). Poverty is directly linked to limited government commitment in promoting pastoralism as a viable and sustainable land use (Hesse and MacGregor 2006). As observed by Haro et al. (2004), both colonial and even early post-Independence governments thought that northern Kenya pastoralists accumulate more herds beyond optimal carrying capacity from an environmental perspective and therefore encouraged destocking. Herd accumulation was assumed to result in overgrazing and cause the problem of land degradation (Lamprey 1983).

Environmental destruction by pastoralism as a land use option is rarely substantiated (Roba and Oba 2008; Ward et al. 1998). The perception of pastoralism as an environmentally destructive livelihood may mask carbon storage potential in pastoral ecosystems. This is despite positive implications of grazing already found due to soil carbon storage related to nutrient cycling and plant photosynthesis. For example, comparative soil carbon evaluation between grazed and non-grazed pastures in the semi-arid rangelands of America showed positive implications of grazing in soil organic matter formation and accumulation (Reeder and Schuman 2001).

Methods

A survey of the study site was conducted during which samples of grassland, woodland and shrubland vegetation were identified and selected.^c Each major vegetation type was considered a landscape type in the study. The

landscape types were replicated three times ($n = 3$). Within each landscape type was a permanent plot of 400 m × 400 m, established using a Global Positioning System (GPS) and its borders marked with paint for future reference. From the centre of permanent plots, transects of 200 m in east, west, north and south directions were laid out. At intervals of 30 m, nested sub-plots (of 10 × 10 m for trees, 4 × 4 m for shrub and 1 × 1 m for herbaceous) were established. Woody carbon ($n = 72$), herbaceous carbon ($n = 72$) and soil carbon ($n = 72$) were assessed for each landscape type within its nested sub-plots. The assessments were done for two consecutive seasons of wet and dry in 2013.

Woody carbon assessment

Using a flexible tape, the diameter at chest height (DCH) (1.3 m above the ground) of all the trees within 10 × 10 m plots and basal diameters (BD) of all shrubs within the 4 × 4 m plots were taken. Both DCH and BD were recorded in prepared data sheets, and carbon estimates within each plant were done using allometric equations as described by (Henry et al. 2011). The following allometric equation was applied:

$$\text{Trees : } Y = 0.1975x\text{DCH}1.1859,$$

$$\text{Shrubs : } Y = 0.1936 (x1.1654)$$

where

$$Y = \text{Fresh weight of trees/Shrub biomass (kg).}$$

$$x = \text{DCH / BD (cm).}$$

The results of allometric equation only provide fresh biomass estimates. In order to measure dry biomass, the results are multiplied by 60% and the carbon content taken as 50% of the dry biomass weight (Brown et al. 1999). Root carbon estimates were 20% of above-ground carbon (Cairns et al. 1997). Both above-ground and below-ground carbon estimates within nested plots were converted to carbon in tonnes per hectare (1 tonne = 1,000 kg, 1 ha = 10,000 m²).

Herbaceous carbon assessment

A prepared quadrant of 1 m² was placed in each of 0.5 × 0.5 m sub-plot. Herbaceous materials within 1 m² were then clipped at 1-cm stubble height. Clipped materials, together with litters, were put in sample paper bags and their fresh weights recorded. Herbaceous root materials were also excavated and fresh weight recorded. Care was taken to collect and separate fine roots from soils. Both the above-ground and root materials of herbaceous plants were oven-dried at 80°C for 48 h. Herbaceous carbon contents were calculated as 50% of oven-dried herbaceous biomass. The results were recorded in a prepared data sheet. Sample results were then converted into carbon tonnes per hectare (1 tonne = 1,000,000 g).

Assessment of soil carbon

Soil sampling was done in each 0.5 × 0.5 m sub-plot at a 30-cm depth using a soil auger whose volume head had been pre-determined using the formula below:

$$V = \pi r^2 h$$

where

V = volume head
 π = 3.14 cm
 r = head radius (cm)
 h = head height (cm)

Soil samples were labeled and oven-dried at 80°C for 48 h. The oven-dried samples were then sieved by passing through 2-mm sieve. Bulk density of each soil sample was then calculated using the following formula;

$$BD_{\text{sample}} = ODW_{\text{sample}} / VAD$$

where

BD_{sample} is the bulk density of soil sample (g cm^{-3})
 ODW_{sample} is the weight of oven-dried sample (g)
 VAD is the volume of soil auger head (cm^3)

The results were recorded in a prepared data sheet. An estimated 10-g sample of sieved soil was taken for carbon content analysis. Soil carbon (C) was determined through oxidation as described by Anderson and Ingram (1993). The carbon concentrations were read on the spectrophotometer at 600 nm. The concentrations (%) obtained from the laboratory were used to calculate carbon mass per unit area. Carbon contents in the samples were calculated using the indicated formula below:

$$C (\text{g cm}^{-3}) = (BD_{\text{sample}} \times C\%)$$

where

BD_{sample} is the bulk density of soil sample (g cm^{-3})
 $C\%$ is the percentage carbon concentration of the sample

Sample carbon content was multiplied by soil sampling depth (30 cm) to carbon content per unit surface area using the formula:

$$CSA (\text{g cm}^{-2}) = C (\text{g cm}^{-3}) \times SD (\text{cm})$$

where

CSA = carbon per unit of surface area (g cm^{-2})
 C = carbon content in the sample (g cm^{-3})
 SD = soil sampling depth (cm), taken as 30 cm

The results were converted into carbon tonnes per hectare using the ratio of hectare to cm^{-2} (1:1,000,000).

Data analysis

Aggregations of carbon from various carbon pools (above-ground herbaceous, below-ground herbaceous, above-ground woody, below-ground woody, soil carbon) were done and averages calculated for each landscape type. The least significant difference (LSD) was used to separate the means. To evaluate the effect of landscape type and season on the carbon level of various carbon pools, a general linear model (GLM) was used and significant difference accepted at 5% level of probability error. The GLM analysis procedure is as follows (SAS 1999, version 8):

$$\text{Model : } y_{ijk} = \mu + \rho_i + \alpha_j + \varepsilon_{ijk},$$

where

y_{ijk} is the observation from the ij combination of factors, landscape type and season
 μ is the overall mean of carbon content
 ρ_i is the effect of i factor of landscape type on carbon content
 α_j is the effect of j factor of season on carbon content
 ε_{ijk} is the error term

Results and discussion

Carbon stocks in the grazed landscapes of Marsabit Central

Results of carbon stocks in various landscape types are presented in Table 1. The results are averages from wet and dry season carbon storage and disaggregated into

Table 1 Carbon stocks in the grazed landscapes of Marsabit Central

Landscape type	Carbon level (tonnes ha^{-1})					
	Above-ground herbaceous carbon	Below-ground herbaceous carbon	Above-ground woody carbon	Below-ground woody carbon	Soil carbon (at 0- to 30-cm depth)	Total carbon
Grassland ($n = 3$)	0.28 ± 0.04	0.44 ± 0.03	2.21 ± 0.825	0.44 ± 0.16	92.86 ± 14.62	96.23 ± 14.78
Shrubland ($n = 3$)	0.53 ± 0.04	0.17 ± 0.03	6.48 ± 0.83	1.3 ± 0.16	107.22 ± 14.84	115.7 ± 15.00
Woodland ($n = 3$)	0.32 ± 0.04	0.17 ± 0.03	4.63 ± 0.83	0.93 ± 0.16	78.93 ± 15.63	85.15 ± 15.28

landscape carbon pools. In Table 1, summation of carbon in every carbon pool was also presented as total carbon for each landscape type. Calculations of the total carbon stocks across all landscape types showed an average carbon level of 93.01 ± 15.72 tonnes ha^{-1} . The result is consistent with carbon stocks for grazing areas of sub-Saharan Africa (see Matieu 2010). The measured amount of stored carbon exists under communal grazing management in the study area's semi-arid pastoral ecosystems. Pastoral grazing management through herd mobility across landscape types might have helped the maintenance of stored carbon. The conversion of measured carbon stocks in Marsabit Central grazing lands is equivalent to 341.35 tonnes ha^{-1} of carbon dioxide, which is considered as one of the greenhouse gases.^d This therefore depicts the importance of pastoral ecosystems in preventing the release of carbon dioxide that could have an influence on climate.

Disaggregation of the above amount of carbon stocks into carbon levels for various carbon pools indicate that 98.39% of the carbon is stored in the soils, 1.2% in the above-ground woody vegetation, 0.2% in woody roots, 0.12% in above-ground herbaceous and 0.07% in herbaceous roots. Any anthropogenic activities that might have adverse effects on soils will therefore have significant implications in reducing carbon stocks in the grazing lands. Cultivation of grazing lands is already found to reduce soil carbon stocks due to disturbance of the soil surface (Jiao et al. 2009). A study by Wang et al. (2008) in Inner Mongolia, observed a 22% reduction in soil carbon stocks when grazing land was converted into cultivated land. It is therefore important to guard grazing lands from degradation that will eventually interfere with soil condition.

The contribution of pastoral grazing systems is very significant when the vastness of the global pastoral ecosystems is considered. Pastoral ecosystems cover 40.5% of the terrestrial ecosystem, equivalent to 5,250 M ha (White et al. 2000). The contribution of pastoral ecosystems in offsetting atmospheric greenhouse gases through carbon storage is however seldom appreciated. Instead, livestock production in the rangelands has been accused of emitting greenhouse gases through enteric fermentation (see Gerber et al. 2013; Steinfeld et al. 2006). The contribution of livestock production in rangelands to provide ecosystem services by maintaining an important amount of carbon stocks in the soils and vegetation should be considered in order to balance the associated potentially adverse effects of greenhouse gas emissions (see also Herrero et al. 2009).

Effect of landscape types on the carbon stocks of Marsabit Central grazing lands

Effects of landscape types were significant on carbon stocks for all carbon pools of the landscapes (all $P < 0.05$) - see

Table 2. The effects are also significant on average carbon stocks at the landscape level ($P < 0.05$). Shrubland had more total carbon stocks than both grassland and woodland landscape types (Table 1 above). Woodland had the least carbon stocks. Woodland possibly had less herbaceous vegetation cover, which does not facilitate an adequate rate of plant material decomposition into the soils for soil carbon formation (see also Kurgat 2011). Landscape types with more herbaceous cover are often thought to have a relatively higher rate of organic matter decomposition compared to woody types of vegetation (Rice 2005). These effects of landscape types on rangeland carbon stocks are also a likely demonstration of rangeland ecological variability in terms of differences in the spatial distribution of plant communities. Rangelands are generally considered mosaics of diverse ecological conditions created by spatial variation in soils, topography and micro-climate (Scoones 1999). The ecological variations result in asymmetric distribution of carbon stocks. Assessment of carbon content or biomass productivity should therefore consider the heterogeneous nature of the environment to avoid errors arising from asymmetric resource distribution (Kratli and Schareika 2010).

Effects of seasons on the carbon stocks of Marsabit Central grazing lands

Unlike the landscape types above, seasonal effects on the carbon stocks are not significant for most carbon pools (all $P > 0.05$). Season only influenced the above-ground herbaceous carbon pool (Table 3 below). The seasonal difference in carbon stocks is a proxy for assessing the implications of grazing intensity on rangeland carbon. The wet season is commonly viewed as a period of less grazing pressure because of an abundance of grazing resources initiated by enhanced soil moisture. On the other hand, the dry season is seen as a period of resource scarcity arising from a lack of or limited soil moisture. Evaluation of seasonal differences in the carbon stocks of rangelands will thus help in understanding implications of temporal variability of rangeland carbon. In this study, lack of significance implies that livestock

Table 2 Effects of landscape types on carbon stocks of Marsabit Central grazing lands

Carbon pool	Degree of freedom (df)	P value	R ²
Above-ground herbaceous carbon	2	0.0001	0.050251
Below-ground herbaceous carbon	2	0.0001	0.213012
Above-ground woody carbon	2	0.0001	0.062989
Below-ground woody carbon	2	0.0048	0.025326
Soil carbon (at 0 to 30 cm)	2	0.0001	0.241363
Total carbon	2	0.0001	0.170183

Table 3 Seasonal variations of carbon stocks of Marsabit Central grazing lands

Landscape carbon pool	Seasonal variation		P value
	Wet	Dry	
Above-ground herbaceous carbon	0.49 ± 0.02	0.39 ± 0.02	0.0027
Below-ground herbaceous carbon	0.27 ± 0.01	0.24 ± 0.01	0.1208
Above-ground woody carbon	4.43 ± 0.47	4.4 ± 0.47	0.9833
Below-ground woody carbon	0.88 ± 0.0957	0.89 ± 0.0957	0.9844
Soil carbon	93.32 ± 9.06	87.5 ± 9.06	0.0926
Total carbon	99.39 ± 9.1576	93.42 ± 9.1576	0.0942

grazing and soil moisture variation did not impact the carbon stocks of the rangelands. These findings are consistent with other studies (e.g. Schuman et al. 2002; Reeder and Schuman 2002). However, it is crucial to note that the impact of grazing and soil moisture gradient can be complex, depending on the type of ecosystem in question. As suggested by Piñeiro et al. (2010), soil carbon can decrease, increase or not change depending on the ecological condition. These findings should be understood in the context of semi-arid ecosystems with annual precipitation of 400 to 750 mm. A more elaborate carbon measurement repeated over series of years covering periods of dry and wet seasons is necessary to better understand the effects of seasons on rangeland carbon stocks.

Conclusions and recommendations

In this study, we have measured carbon stocks in a case study of semi-arid pastoral ecosystems under communal and mobile grazing management, considering the spatial and temporal heterogeneity of range environments. The variation of carbon stocks with landscape types affirms the need to consider asymmetric distribution of range resources in the assessment of rangeland carbon content. In our aggregation of sample results from varying landscape types and seasons, we found 93.01 ± 15.72 tonnes of carbon ha^{-1} stored in Marsabit Central grazing lands of northern Kenya. Conversion of the measured level of carbon into carbon dioxide equivalent depicted the importance of these kinds of pastoral ecosystems in offsetting atmospheric greenhouse gases that could influence the global climate. Carbon stocks have been possibly maintained by pastoralists' grazing practices, which are characterized by herd mobility over diverse grazing landscapes to utilize the patchiness of range resources. Upholding these grazing practices will reinforce the contribution of pastoral ecosystems in protecting the atmospheric environment. Furthermore, the largest proportions of carbon stocks were found in the soils, meaning that any alternative land use to pastoralism that exposes soil carbon would have substantial adverse environmental effects.

Carbon credit trading could be an important source of income to improve the livelihoods of pastoralists whose grazing practices maintained substantial amount of carbon stocks in extensive rangelands. But carbon markets require proof of additional storage to existing carbon stocks, which has not been shown in this study. Further research should therefore focus on assessing grazing practices that facilitate additional carbon storage so that pastoralists can qualify for carbon credits; research is also needed to understand whether such improvement in their incomes can make pastoralism more sustainable in the future. Uncertainty in the value of carbon credits needs to be considered as well, to avoid relying on a risky prospect. This study has established a baseline in a case study of northern Kenya, of carbon stocks stored in soils and vegetation. In future, this case study area can be monitored, if grazing practices that encourage additional carbon storage and carbon credit trade are established and adopted.

Endnotes

^aThe term 'pastoral ecosystem' is widely used in this study to depict the role pastoralism has played in shaping the environment. It is interchangeably used with the word 'rangeland' or 'grazing land'.

^bThe vegetation life form assessed included grassland, shrubland and woodland.

^cClassification of vegetation types was according to the method used by Pratt and Gwynne (1977). Grassland is taken as an area dominated by grasses and herbs with woody canopy cover of less than 2%; woodland is an area dominated by woody plants that grow up to 18 m in height with not less than 20% canopy cover. Shrubland is an area dominated by woody plants of not more than 6 m in height with canopy cover of not less than 20%.

^dA tonne of carbon is equivalent to 3.67 tonnes of carbon dioxide (see Niles et al. 2010; Tennigkeit and Wilkes 2008).

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

BHD developed the concept, carried out the field data collection and data analysis, and drafted the manuscript. TZ and DH made comments on the manuscript. All authors read and approved the final manuscript.

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